Evaluation of Energy Yield Ratio (EYR), Energy Payback Period (EPBP) and GHG-emission Mitigation of Solar Home Lighting PV-systems of 37Wp Modules in India

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Abstract - An attempt has been made to find the energetic feasibility of solar photovoltaic home lighting systems (SPVHLS) for some locations in India. In this perspective modules of 37Wp of different technologies have been adopted. The study has been divided in three parts viz. (1) a general discussion on replacing PV-systems with frequently used conventional fuel devices. (2) Comparison of PV-systems with diesel generator and (3) Evaluation of GHG-emission mitigation for some conventionally fuel devices. The process analysis method has been adopted to evaluate total embodied energy. Output energy/energy saved was calculated by the comparison of these systems with conventionally used devices and with diesel generator. For feasibility analysis of these systems, energy yield ratio (EYR) and energy payback period (EPBP) have been evaluated. The EYR value of 2y and EPBP value of 11y have been found approximately in case of wick lamp. However, with diesel generator, EPBP value has been found approximately 4y. GHG-emission mitigation (tCO_2) of 934 was found in case of kerosene lantern and 41551, 76350 for diesel oil and kerosene oil operated Generator respectively.

Keywords: Energetic feasibility; energy yield ratio; energy payback period; process analysis method; GHG-emission mitigation.

1. Introduction

India has second largest population in the world after China and with the increasing population of the country the demand of energy is increasing in different sectors. The conventional fuels has limited source in the country and has several limitations to provide electricity for rural areas. Due to greenhouse gases emission as a result of fossil fuel burning and impact of conventional energy resources on climate change, several countries are now shifting towards non-conventional energy sources. [1-2]. Solar photovoltaic home lighting systems, SPVHLS(s) has been deployed in India to provide electricity and power generation in areas which are far from the grids and playing important role in CO_2 emission mitigation. According to the report of International energy agency (IEA), solar photovoltaic system technology has 100Giga tons potential of CO_2 emissions mitigation in the period of 2008-2050 [3].

Renewable energy systems are expected to consume large amount of energy in the form of materials required in manufacturing, their transportation and distribution. Though during operation of SPVHLS(s), there is not any requirement of conventional fuels. However, substantial amount of energy is needed in manufacturing and periodic replacement of its components during its lifetime. In addition, to make the SPVHLS (s) compatible for use anywhere they are required energy storage component like batteries. This causes considerable increase in the amount of energy embodied in the systems. This prompted researchers to analyze the energy embodied in the system as compared to the energy provided by them. Such analysis and evaluation is critically important for SPVHLS(s) in selected locations. This ensures the societal decisions to invest energy in the manufacture, installation, operation and maintenance of these systems results in net energy gain.

Over the past decade a significant studies has been carried out on economic and feasibility analysis of PV systems [4-7] but limited work has been carried out on energy requirement with and without balance of systems. Gregory et al. [8] evaluated the total energy investment, including material production, distribution and manufacturing, for the United Solar UPM-880 standard module. They include specific energy requirements for material production, distribution and manufacturing. But their results do not account for manufacturing facility overhead and process material energy. Frankl et al. [9] evaluated the energy requirement for manufacturing PV system with support structure for both open fields mounted and rooftop. In his consideration same life time of PV system and battery were taken. Alsema et al. [10] calculated the energy requirement for manufacturing of PV system, energy payback time (EPBT) and CO_2 emissions without consideration of support structure, replacement of battery during lifetime of system and efficiency of balance of system. They used the same efficiency of the system throughout the lifetime of the system. Krauter et al. [11] evaluated the energy requirement for manufacturing the PV system and CO_2 emissions without considering the above-mentioned parameters. Carl et al. [12] worked on the technical performance and energy requirements for production and transportation of a stand-alone photovoltaic (PV)-battery system at different operating conditions with batteries of eight technologies. Nawaz and Tiwari [13] have evaluated the energy payback time of a single crystalline silicon PV system for open field and rooftop conditions with balance of systems. Khagendra et al. [14] presented a systematic review and a meta-analysis of the embedded energy, energy payback time (EPBT), and energy return on energy invested (EROI) metrics for the crystalline Si and thin film PV technologies.

The present study focused on “energy analysis” of 37Wp modules of three technologies viz. Single-crystalline (si-c-silicon), multi-crystalline (m-c-silicon) and amorphous (a-silicon) of PVHLS(s). The feasibility of PVHLS(s), has been carried out by the prominent deciding terms: energy yield ratio (EYR) and energy payback period (EPBP). In this perspective comparison has been made with the conventionally used devices and with diesel generator. The study is also emphasized on the evaluation of GHG-emission mitigation in case of frequently used fuel devices.

2. Measurements

2.1. Energy Input

To observe the effect of detailed changes in the consumption pattern on the energy requirement of SPVHLS (s), process analysis method is used [15]. In this method complete process of manufacturing a renewable energy device is studied and analyzed. Thus entire requirement of materials, their processing to manufacture the finished good, operation and maintenance aspect are taken into account.

Energy embodied in the material used in a renewable energy system E_{mate} can be expressed as:

$$E_{mate} = \sum_{i=1}^{n} e_i m_i \tag{1}$$

If direct energy consumed in the process of manufacturing be E_{dir}, then total energy embodied of the finished renewable energy systems, $E_{finished}$ can be expressed as:

$$E_{finished} = E_{mat} + E_{dir} \tag{2}$$

Energy embodied in periodic replacement and maintenance, E_{om} of a renewable energy system can be estimated as:

$$E_{om} = \sum_{i=1}^{n} \left[\frac{EUL_{res}}{FRE_i} - 1 \right]^{+} \left(e_i m_i \right) \tag{3}$$

Where the ‘+’ sign indicates that for the quantity inside the bracket, the next higher whole number is taken.

The life cycle embodied energy, E_{emb} in the renewable energy systems can therefore be obtained by adding equations (1), (2), (3) and (4) and can be expressed as:

$$E_{emb} = E_{direct} + E_{mate} + E_{om}$$

In other words,

$$E_{emb} = E_{direct} + \sum_{i=1}^{n} e_i m_i + \sum_{i=1}^{n} \left[\frac{EUL_{res}}{FRE_i} - 1 \right]^{+} \left(e_i m_i \right) \tag{4}$$

Where, e_i represents the energy intensity (MJ per unit mass or MJ per unit volume as applicable) of the material of the i^{th} component, m_i, the mass/volume of the i^{th} component in the energy device system (kg or Wp as applicable), EUL_{res}, expected useful life of the renewable energy system (years), and FRE_i, frequency of replacement of the i^{th} component of the system.

2.2. Energy output

The estimation of energy output of any device depends upon the end use of the device. If the device is merely an energy-producing device like a power plant then the actual power generated by the plant can be taken as its energy output value. However, in a device where energy generated by one of its component is being used by the other component, energy output value can be taken as the primary energy consumed by any such device during equivalent hours of operation, which is being replaced by the solar home lighting system. Thus the energy output can be shown as:

$$Q = \sum_{j=1}^{U_L} \left(\sum_{i=1}^{365} n_{ij} \right) (Fs)(CV_f) \tag{5}$$

Where CV_{f} , represents primary energy equivalent of fuel saved (MJ), n_{ij}, number of hours in a year of useful life time of the system(s) and F_{s}, fuel saved/hour.

2.3. Energy yield ratio:

Energy yield ratio is defined as the ratio of life cycle primary energy output E_{out} delivered by the systems to the life cycle primary energy embodied E_{emb} in manufacture, operation and maintenance of the systems i.e.

$$EYR = \frac{E_{out}}{E_{emb}} \tag{6}$$

For any energetically feasible system, the EYR should be greater than one. This ratio indicates the effectiveness of applying energy sources (both direct and indirect) to a given technology in order to gain more useful energy for application elsewhere. Higher the ratio, greater will be the amount of energy of available to maintain the rest of the economy and to facilitate growth, per unit of energy invested.

2.4. Energy payback period:

EPBP of a renewable energy system is the time elapsed in recovering the energy investment made in manufacturing the systems (E_{input})

$$EPBP = \frac{E_{input}}{E_{annualoutput}} \tag{7}$$

Where, $E_{annuloutput}$ represents energy produced /saved by the renewable energy system in one year (MJ).

To be an energetically feasible system, the EPBP should be less than its useful lifetime. Lower the value of EPBP earlier will be the energy recovery period. To evaluate the energy payback period for different locations, comparison of solar home lighting systems has been made with a diesel generator which converts primary energy (or fuel) into electricity at an average efficiency of 25%. EPBP has been taken as the ratio of production energy requirement to the power rating or efficiency of generator multiplied by insolation at particular location. The equivalent primary energy requirement, is the amount of primary energy (or fuel) necessary to produce the components. So all electrical energy input is converted into primary energy requirement with an assumed conversion efficiency of 35%. For the present aspect 1MJ of primary energy equivalent to 0.097 KWh of electrical energy was taken [16].

3. Methodology

The total energy embodied in SPVHLS have been evaluated by dividing it into five parts viz. (i) PV module (ii) battery (iii) CFL and electronics components (iv) Outer casing and (v) charge controller. To save embodied energy, module mounting hardware is not considered in the total embodied energy for the system as the modules can be directly mounted on the rooftop. PV modules of different technologies viz. single-crystalline module (si-c-silicon module), multi-crystalline module (m-c-silicon module) and amorphous module (a-silicon module) are adopted for detail analysis. The expected life of the si-c-silicon module and m-c-silicon modules is taken 20y and for a-silicon module the expected life is taken 10y. However, the life times of these modules prolong more than their expected values. Usually the useful life of the SPVHLS(s) is taken as that of the SPV-modules in case of si-c-silicon module and m-c-silicon module. However, replacement of a-silicon module once is to be taken into account due to its short period of life. During this useful life of the SPVHLS(s), the other prominent components have also been replaced due to their short period of life. In the present study lead-acid battery has been used and is the most widely used secondary battery in most PV systems [17]. In case of battery it has been assumed that it contains 70% lead, 20% electrolyte and 10 % case. The CFL consist glass, silicon, iron and copper. The outer casing of CFL and charge controller is made of plastic. The lifetime of the battery, CFL and outer casing has been assumed 3, 7 and 10y respectively. The characteristic property of PV-modules has been taken in terms of power output and of other components in mass. The energy intensity values have been concerned from literature due to unavailability of these values at local conditions [16, 18-21]. As mentioned above the process analysis method has been used for estimation of embodied energy in the PV-systems in which only the first two levels of regression viz. the direct energy inputs and the energy embodied in the materials has been considered [19]. The values of ambient temperature for different selected locations have been taken from the RET-Screen online weather database according to the latitude and longitude of the locations. GHG-emission mitigation (tCO_2) potential of different considered SPVHLS have also been evaluated with RET-Screen software [22].

4. Results and Discussion

Different components of SPVHLS(s), their useful life, primary material used and their characteristic property, total energy embodied in different component during installation and the total energy embodied in replicable components during useful life of 20 y is summarized in Table 1. Table 1 also depicts the energy intensity value across different components and number of times of their replacement for its useful life time. The energy intensity values have been taken from the available literature and are mentioned in the Table 1. The replacement of battery, CFL, its outer casing and charge controller has been taken 6, 2, 1 and 1 times respectively due to their short life time. During installation of SPVHLS the values of mass of battery, CFL & electronic, CFL outer casing and charge controller has been estimated approximately to be 372.87, 14.1, 37.57 and 14.83kg respectively.

The estimated values of total energy embodied in SPVHLS(s) having different technologies modules for their useful life time are given in Table 2. The evaluation was carried out by using equation (4) and with the help of data given in Table 1.

It has been found to be 7621.64MJ for single crystalline, 7362.64MJ for multi- crystalline and 7362.64MJ for amorphous type modules. Primary energy output provided by the SPVHLS(s) for the purpose of energy analysis depends

Table 1 Components of SPVHLS, energy embodied in them and total energy inputs of replacing the components for its useful lifetime.

S.No.	Component	Useful Life (Years)	Primary Material & characteristic property	Value /unit	Energy Intensity (MJ/Unit)	Energy Embodied in the Component (MJ)	Energy Embodied in the SPVHLS (MJ)	Number of times it will be replaced in 20 Years	Total Energy inputs of Replaceable components during 20 years	Reference(s) for Energy Intensity
1	Solar PV module	20	Single Crystal Silicon Solar Cell (power output)	37Wp	41	1517	2479.47	...	.....	Alsema (1998)
		20	Multi Crystal Silicon Solar Cell (power output)	37Wp	34	1258	2220.47	---	.....	
		10	Amorphous Silicon Solar Cell	37Wp	21	777	1739.47	1	777	
2	Battery (20Ah)	3	70% Lead (active material, plates & connectors) (Mass)	16.1kg	41	660.1		6	4982.8	Linden (1984) & Sullivan et al. (1995)
			20% electrolyte (aqueous solution of H2SO4) (Mass)	4.6 kg	----	.....				
			10% Case (propylene) (Mass)	2.3kg	74	170.2				
			Total			830.3				
3	CFL & Electronic Compo.(11W)	7	Glass, Silicon, Iron, Copper (Mass)	0.12kg	235	28.2		2	56.4	Mathur and Bansal (1999)
4	CFL Outer casing	10	Plastics (Mass)	0.76kg	98.87	75.14		1	75.14	Boustead & Hancock (1979)
5	Charge Controller	10	Outer Casing of Plastics (Mass)	0.15kg	98.87	14.83		1	28.83	Sullivan et al.(1995)

upon the amount of conventional fuel saved by it. Obviously the type and amount of fuel saved would depend upon the existing domestic lighting devices used by the household and annual hours of lighting provided by the SPVHLS(s).

Table 2 Life cycle embodied energy in SPVHLS having different technologies modules.

Module Capacity (Wp)	Module technology type	Life Cycle energy input for 20 years (MJ)
37	si-c-silicon module	7621.64
	m-c-silicon module	7362.64
	a-c-silicon module	7658.64

The primary energy output of the SPVHLS(s), in this study, has therefore been considered to be equivalent to the primary energy content of the fuel saving accrued due to the use of the home lighting system. As a base value it is assumed that a standard SPVHLS(s) would provide illumination for 1200hours (4 hours daily for 300 sunny days) in a year. The fuel consumption rates for each of the conventional lighting devices used in the households of the state have been taken from the literature [23]. The total primary energy saved by the SPVHLS(s) in twenty year has been estimated and the results are summarized in Table 3 and calculated by using equation (5). The evaluation has been made for two units because the 37Wp module SPVHLS facilitates of using two bulbs. In this analysis, the quality of the light output has not been taken into account because generally the user does not increase the number of devices to increases the light output of the device. From Table 3 one can also depicts the values of EYR in comparison of SPVHLS to different conventional fuel devices. The EYR values were calculated by using the equation (6). The highest EYR value of 19.05 in case petromax for multi-crystalline silicon module and lowest value of 1.35 in case of incandescent bulb for amorphous silicon module has been noticed.

Table 3 Characteristics of commonly used domestics lighting systems and EYR for SPVHLS on replacement with commonly used domestics lighting systems.

S. No.	Devices	Fuel type	Fuel consumption rate	Primary energy consumed/saved during 20 years (1200 hours per year operation), (MJ)	EYR		
					Module technologies type		
					si-c-silicon	m-c-silicon	a-silicon
1	Wick Lamp	Kerosene	0.008 L/h	14027.52	1.84	1.91	1.83
2	Hurricane	Kerosene	0.05 L/h	87672.00	11.50	11.91	11.45
3	Petromax	Kerosene	0.08 L/h	140275.20	18.40	19.05	18.32
4	LPG based	LPG	30 g/h	72000.00	9.45	9.78	9.40
5	Incandescent bulb	Electricity	60 W	10368.00	1.36	1.41	1.35

The values of energy payback period of SPVHLS(s) with the replacement of these systems with conventional fuels used devices have been mentioned in the Table 4 and evaluated by equation (7). It is clear from the table that in case of wick lamp and incandescent bulb the value of EPBP is approximately 10 and 13.50y respectively for all technologies types' modules. It is because of low fuel consumption rate of these devices. However, in case of hurricane lantern, petromax and LPG lamp, the energy payback period is less than 2 y.

Table 4 EPBP of SPVHLS on replacement of these systems with commonly used domestics lighting systems.

S. No.	Devices	EPBP		
		Module technologies type		
		si-c-silicon	m-c-silicon	a-silicon
1	Wick Lamp	10.87	10.50	10.92
2	Hurricane lamp	1.74	1.68	1.75
3	Petromax	1.09	1.05	1.09
4	LPG based lamp	2.12	2.05	2.13
5	Incandescent bulb	14.70	14.20	14.77

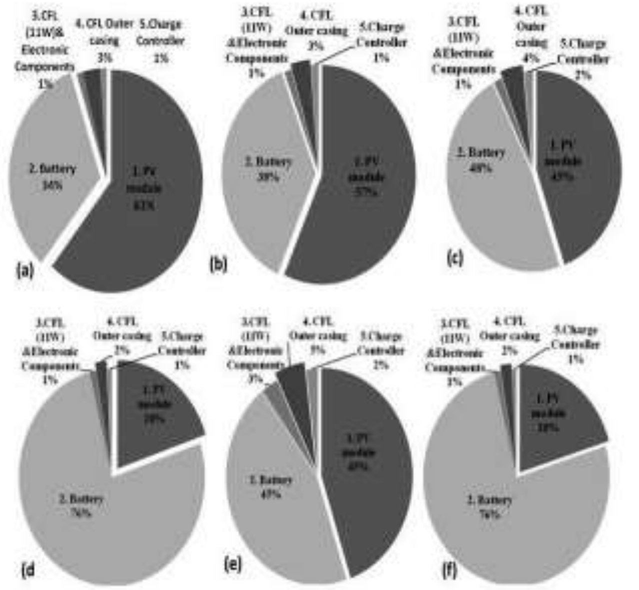

Fig 1.(a, b, c) Energy embodied in different components of SPVHLS during manufacturing and (d, e, f) Energy embodied in different components during its useful lifetime by using 37Wp of si-c-module, m-c-module and a-silicon modules respectively.

Figs.1 (a, b, c) represent energy embodied in different components of SPVHLS(s) during manufacturing/installation and Figs. 1(d, e, f) energy embodied in different components during its useful lifetime by using 37Wp of si-c-module, m-c-module and a-silicon module respectively. From Figure 1, one can observe that during installation, the PV-modules are the most energy consumable part followed by battery. PV-modules shares 63%, 57% and 45% energy for single, multi-crystalline and amorphous modules respectively of the total energy embodied in SPVHLS(s) whereas, the energy embodied on battery has been found 31%, 35% and 45%. However, later on the battery becomes the most energy intensive part of the system. It contributes value of 75%, 78% and 74% for single, multi-crystalline and amorphous type modules systems. The variations of temperature in different months for different locations have been shown in fig 2.

The EPBP of SPVHLS(s) having different technology modules for different locations with the replacement of these systems with diesel generator have been shown in the Table 5.

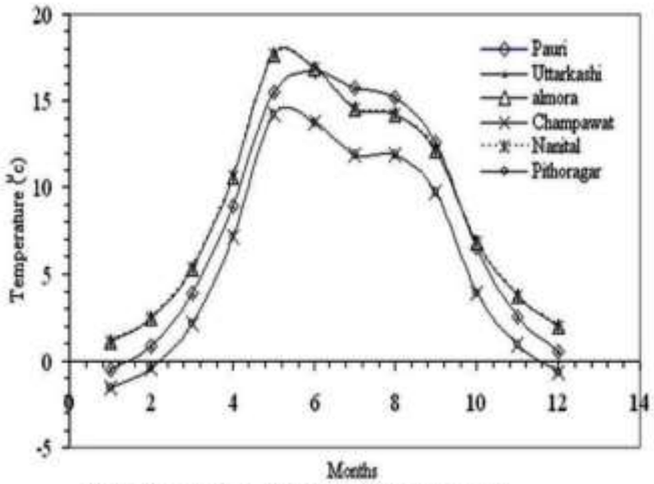

Fig.2. Variation trend of temperatures across months for different locations

From Table 5 it is clear that energy payback period is less than and up to 4y for three selected technologies type modules at different locations. The availability of solar insolation at different locations has been also mentioned in the Table 5. The area of 37Wp modules was measured and found 0.42m^2. The energy payback period in case of multi-crystalline silicon cell module has been found less in comparison to single crystalline and amorphous type modules.

Table 5 EPBP of SPVHLS on replacement of these systems with diesel generator.

Location	Latitude/ Longitude/Altitude	Insolation (KWh/m^2/year)	EPBP (in year)		
			Module technologies type		
			si-c-silicon	m-c-silicon	a-silicon
Almora	29.37°N/79.40°E/1646m	1823	3.86	3.73	3.88
Champawat	29.20°N/80.60°E/1615m	1826	3.86	3.72	3.87
Nanital	29.23°N/79.27°E/1938m	1844	3.82	3.69	3.84
Pauri	30.90°N/78.47°E/1814m	1791	3.93	3.80	3.95
Pithrougarh	29.35°N/80.13°E/1645m	1824	3.86	3.73	3.88
Uttrakashi	30.44°N/78.27°E/1158m	1755	4.01	4.03	3.88

In general practice, an amorphous type module need replacement during 20y and hence is less attractive. GHG-emission mitigation in 20y due to installation of SPVHLS of modules of different technologies have been also made and shown in Table 6. Table 6 represents that the total installation capacity of SPVHLS is approximately 55250 by making assumption that on the average fifty families are in one village. Different parameters have been used to calculate the energy output and GHG emission mitigation and are given also in Table 6. The value of specific fuel consumption has been taken 0.026 liter/y for kerosene in case of lantern and 0.40liter/kWh for diesel oil and 0.80liter/kWh for kerosene in case of generator. GHG-emissions factors for electricity produced by different fuels and provided by grid extension using the values of fuel mix and transmission losses of 100% and 8% respectively have been used and given also in table. Table 6 also indicates that if the consumption time of fuels is more than the adoption level (four hours) than the SPVHLS(s) will contribute significantly in mitigation of GHG-emission.

5. Conclusions

The energy payback period has been found less than the useful lifetime of the SPVHLS(s) with the replacement of conventional fuel devices. The EPBP has been found less than 4y of the replacement of SPVHLS with diesel generator. The installation of SPVHLS of amorphous type module takes no advantages in comparison to other considered technology type modules due to its lower value of lifetime. Environmental freshness aspects due to installation of these devices can be achieved. Increasing trend of modules efficiency and improvement in battery technology would further improvement in the energetic viability of the systems.

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Table 6 Estimated values of GHG-emission reduction (tCO_2).

No of un-electrified villages	Average families in each villages	Total installation capacity of homelighting systems	Module rating (Wp)	Energy Output for 20 Years (MWh)	GHG emission reduction (tCO_2)= Base case GHG-emission factor(tCO2/MWh x End use energy delivered for 20 Years (MWh) + Proposed case GHG-emission factor(tCO_2/MWh)								
					Base case home lighting system (Fuel type)								
					Lantern	Genset		Grid extension					Non-rechargeable batteries
					Kerosene	Diesel oil	Kerosene	Coal	Natural gas	Diesel	Biomass	Propane	
					Base case GHG Emission factor (tCO_2/MWh)								
					0.026	**1.157**	**2.126**	**1.069**	**0.491**	**0.975**	**0.03**	**0.552**	**0.269**
1105	50	55250	37	35913	934	41551	76350	38391	17633	35015	1077	19824	9661

References

[1] M.S.Adaramola, “Techno-economic analysis of a 2.1 kW rooftop photovoltaic-grid-tied system base on actual performance,” Energy Convers. Manag, Vol. 101, pp. 85–93, 2015.

[2] M.S.Adaramola, E.E.T. Vagnes, “Preliminary assessment of a small-scale rooftop PV-grid tied in Norwegian climatic conditions,” Energy Convers Manag; Vol. 90, pp. 458–65, 2015.

[3] Ministry of Power, Government of India, Central Electricity Authority. http://www.cea.nic.in/reports/monthly/xecutive_rep/Nov14.pdf

[4] S. Kirmani, M. Jamil and Iram Akhtar, “Effective low cost Grid-Connected Solar Photovoltaic System to Electrify the Small Scale industry/Commercial Building,” International Journal Of Renewable Energy Research, Vol 7(2), pp. 797-806, 2017.

[5] H. S. Das, A. Dey, T. C. Wei and A. H. M. Yatim, “Feasibility Analysis of Standalone PV/Wind/Battery Hybrid Energy System for Rural Bangladesh,” International Journal Of Renewable Energy Research, Vol 6(2), pp. 402-412, 2016.

[6] R. Srivastava and V. K. Giri, “Techno-Economical Analysis of Grid Connected PV System For A University In India,” International Journal Of Renewable Energy Research, Vol 6(2), pp. 535-540, 2016.

[7] A. Q. Al-Shetwi, M. Z. Sujod, A. Al Tarabsheh and I. A. Altawil, “Design and Economic Evaluation of Electrification of Small Villages in Rural Area in Yemen Using Stand-Alone PV System,” International Journal Of Renewable Energy Research, Vol 6(1), pp. 289-298, 2016.

[8] A.Gregory, Keoleian and McD Geoffrey, “Application of Life-Cycle Energy Analysis to Photovoltaic Module Design, Progress in Photovoltaics,” Research and Applications, Vol. 5, pp. 287-300, 1997.

[9] P. Frankl, A. Masini, M. Gamberale, D. Toccaceli, “Simplified life cycle analysis of PV system in buildings present situations and future trends," Progress in Photovoltaic: Research Applications, Vol. 6 (2), pp. 137–146, 1998.

[10] E.A .Alsema, E. Niluwlaar, “Energy viability of photovoltaic systems,” Energy Policy, Vol. 28, pp. 999–1010, 2000.

[11] S. Krauter, R. Ruther, “Considerations for the calculations of greenhouse gas reduction by photovoltaic solar energy,” Renewable Energy, Vol. 29, pp. 345–355, 2004.

[12] C.Johan Rydh, B jo¨rn A. Sande´n, “Energy analysis of batteries in photovoltaic systems. Part I: Performance and energy requirements,” Energy Conversion and Management, Vol.46, pp. 1957–1979, 2005.

[13] I. Nawaz and G.N. Tiwari, “Embodied energy analysis of photovoltaic (PV) system based on macro and micro-level,” Energy Policy, Vol. 34, pp. 3144–3152, 2006.

[14] K. P. Bhandari, J.M. Collier, R. J. Ellingson, D. S. Apul, “Energy payback time (EPBT) and energy return on energy invested (EROI) of solar photovoltaic systems: A systematic review and meta-analysis,” Renewable and Sustainable Energy Reviews, Vol. 47, pp. 133–141, 2015.

[15] I. Boustead, and G.F. Hankok, Handbook of industrial energy analysis, Ellis Har,wood Limited, Market Cross House, Chichester West Sussex, England, 1979.
[16] E.A. Alsema, "Energy Requirement and CO_2 Mitigation of PV System". In PV and the environment 1998 Workshop. BNL/NREL, Keystone, USA, July 1998.
[17] W.G.A. Baldsing, J.A. Hamilton, A.F. Holenkamp, R.H. Newham, and D.A. Rand, “Performance of lead-acid batteries in remote-area power supply applications,” J. Power Sources, Vol. 35, pp. 385, 1991.
[18] J. Mathur, and N.K. Bansal, “Energy analysis of solar water heating systems in India,” Int. J. Life Cycle Analysis, V0l.4, pp. 113, 1999.
[19] D. Linden, Handbook of Batteries and Fuel Cells. McGraw-Hill, New-York, USA, 1984.
[20] J.L. Sullivan, and J. Hu, “Life Cycle Energy Analysis for Automobiles,” Technical Paper 951829, SAE International, 1995.
[21] T. Tsoutsos, N. Frantzeskaki, and V. Gekas, “Environmental impact from the solar energy technologies,” Energy Policy, Vol. 33, pp. 289-296, 2005.
[22] RET-Screen Software, Government of Canada, Natural Resources Canda’s CANMET Energy Diversification Research Laboratory (CEDRL), 2000. Available at http://rescreen.gc.ca.
[23] S. Rubab, and T.C. Kandpal, “Energetics of household biogas plant in India,” Int. J. Ambient Energy, Vol. 16, pp. 49, 1995.