

**Assessment of carbon dioxide reduction potential and energy
payback period of solar home systems in developing countries: Case
of Bangladesh**

**Assignment No. 3
Energy and Environment**

Submitted by
Md. Anisuzzaman

Submitted on
21 January 2004

**Student no. 12000016
School of Construction Management and Engineering
The University of Reading**

Contents

Abbreviations	iii
Summary	iv
1.0 Introduction	1
2.0 Baseline information	1
3.0 Base case energy estimation: households	2
3.1. Kerosene	2
3.2. Automotive battery charging	2
4.0 Base case energy estimation: shops	3
5.0 Emission: base case	3
5.1. Household	3
5.2. Shops	3
6.0 Emission: PV system	3
6.1. Energy requirement for PV system	3
6.2. Emission	6
7.0 Energy payback	6
8.0 Emission reduction	7
9.0 Discussions	7
10.0 Conclusions	8
11.0 References	8
Appendix A	10
Appendix B	11

Abbreviations

Ah	Ampere-hour
BOS	Balance of system
B/W	Black and White
DOD	Depth of discharge
GI	Galvanized iron
kWh	Kilowatt-hour
kWh _{th}	Kilowatt-hour (thermal)
kWh _e	Kilowatt-hour (electrical)
kWp	Kilowatt-peak
MJ _{prim}	Mega joule (primary energy)
MC	Multi crystalline
MU	Micro utility
PV	Photovoltaic
SC	Single crystalline
SHS	Solar home systems
TK.	Taka
Wp	Watt-peak

Summary

In this report, the CO₂ reduction potential and energy payback period for solar home systems in Bangladesh have been calculated. The base case fuel in this context was identified as kerosene for lighting and lead-acid battery for powering television. Small shops in the rural markets use diesel generator powered fluorescent lamps. For simplicity of analysis, 50Wp system of both single and multi crystalline modules for two applications (household and market place) have been considered. 50Wp system when installed in a household reduces CO₂ about 300 gm CO₂ per kWh per Wp. The values are similar for both single and multi crystalline modules. However, the potential decreases slightly when installed on a GI pole, which requires more material than the simple mounting structures. The same system when installed in market place, reduces 131 to 144 gm CO₂ per kWh per Wp depending on the type of mounting it uses. Energy requirement for a 50 Wp system over lifetime (20 years) including manufacturing and replacements was found 5,188 MJ for using single crystalline and 4,593 MJ for using multi crystalline module when installed on the roof with simple mounting structure. This values increase by about 3% when installed on bamboo, which require a heavier structure, and by about 16% when installed on GI pole. Energy payback periods were found to be 7.43 and 6.58 years for systems using single crystalline and multi crystalline modules respectively when installed with simple roof mounting structure. Again this values increase by 3% and 17% when installed on bamboo and GI pole respectively. The study concludes that solar home systems in Bangladesh has good potential for mitigation of CO₂ and offset the upstream reduction in very short period and pays back the energy in less than half of the lifetime. This fact would be true for most of the developing countries, particularly places with similar socio-economic and geographical conditions.

1.0 Introduction

One of the main driving issue of photovoltaic systems is that it reduces greenhouse gas emission and thus termed as environment friendly technology. Several studies have been carried out to calculate the possible CO₂ reduction by solar home systems. As the SHSs are mainly used in the rural areas of developing countries, it is worth calculating the potential of CO₂ reduction in that context. The rural households who are the main users of solar home systems in Bangladesh (as well as in all other developing countries) use kerosene as their lighting fuel and automotive battery to power their Black and White television. Therefore, installation of a SHS in such a house will replace both kerosene and the energy required to charge the battery.

Another key issue that is receiving a great deal of public attention is the energy payback capability of SHSs. Until recently, it was believed that SHSs use energy during their manufacturing almost as much as they produce in their whole life. Recent studies have changed this view to some extent. However, it is also worth calculating the energy payback period for those systems installed in Bangladesh. It is to be noted that energy payback period is also location dependent as the energy production varies with irradiation.

This report aims to work out the CO₂ reduction potential and energy payback period of solar home systems. The assessment will be done based on the cases of Bangladesh (located between 20.34⁰ to 26.38⁰ N and 88.01⁰ to 92.41⁰ E). For simplicity, one particular size of system (mostly used) will be assessed for two different types of application. One is in household where the system is used to power both lights and Black and White television. Another is in shops where one system is installed in a suitable location and the connections are given to the nearby shops who use one light for 4 hours in the evening. This approach is known as micro utility (MU).

The calculation will be carried out in the following steps:

- a) Energy requirement in base cases for both the applications will be identified;
- b) Emission from those energy uses will be estimated based on the literature reviews;
- c) Energy requirement for PV system manufacturing (including the replacement components) will be calculated and the emission from that energy will be worked out;
- d) Energy production of the system in lifetime will be calculated; and
- e) Finally, the emission saving and energy payback will calculated.

2.0 Baseline information

The following information will be used during the assessment:

1. Selection of system size: Distribution of SHSs installed in Bangladesh shows that the most installed system size is 50Wp. Such a system when installed in a household contains a 50Wp module of either SC or MC, a 71 Ah battery @ 12V, a 10A charge controller, a socket to power a 14" B/W TV of 14W, 3 units of 6W lights, cables and fixtures. The same system when installed in a market (in the form of MU) contains a 50Wp module of either SC or MC, a 71 Ah battery @ 12V, a 10A charge controller, 5units of 6W lights, cables and fixtures.

2. Solar irradiation: Islam (2002) notes the solar irradiation for different places of Bangladesh recorded during 1988 to 1998 (Table A1 in Appendix A). Although, all the measurements have been taken in cities/towns, irradiation for Jessore (kWh/m²/day) has been selected as there are many systems installed around this location.
3. Energy demand: As 50Wp system has been selected for calculation, energy demand of the households, which can afford or need such a system has been estimated. Observations reveal that such households usually use 3 hurricanes for lighting and an automotive battery to power a 14" B/W TV of 14W. Each small shop operates a 20W fluorescent light for 4 hours a day powered by diesel generator.

3.0 Base case energy estimation: households

3.1. Kerosene

Kerosene is the main fuel for lighting in rural areas, which is used in "Hurricane" or "Cuppi". Various sources have been consulted to get an estimate of the fuel used per household per month. It has been noticed that fuel consumption varies with the economic health of the household/family.

An early study made by Cabraal (1996) shows that kerosene consumption of a household using wick lamps in Sri Lanka was 0.5 to 1 litre per day i.e. 15 to 30 litres per month. LUTW (2004) notes from studies made in Nepal, Sri Lanka and India that the average kerosene consumption per wick lamp is 0.04 to 0.06 litres per hour. Assuming an operating hour of 4 hours, which is the usual for PV system, the consumption becomes 4.8 to 7.2 litres per day per lamp. A household, which desires for a 50 Wp system uses at least 3 such lamps and therefore, the consumption is 14.4 to 21.6 litres per month.

A survey made in Bangladesh in 1997 to identify the potential of commercialization of PV systems for rural electrification shows that household desires to use 35Wp PV system spends about TK¹. 300 per month (Khan and Huque, 1998). The cost of kerosene was about Tk. 18 per litre in 1997, which gives the consumption of about 17 litre per month. Since a 35wp system provide 2 lights with an option for a B/W TV, the consumption for 50Wp equivalent system (powering 3 lamps and a B/W TV) would be in the range of 20 to 22 litre per month. Based on the above studies, the displacement of kerosene by a 50Wp system can be taken as 22 litres per month.

3.2. Automotive battery charging

The households that wish to buy a 50Wp system, use automotive battery of 70 to 100 Ah to power a B/W TV, which needs 4 to 5 charges per month. This is usually done by the nearest stand-alone diesel operated generator services. To charge an automotive battery of 100 Ah (which is usually drained to more than 40% DOD) needs about 500Wh energy to get fully charged by a generator. This gives 2.5 kWh energy requirement per month @ 5 charges per month.

¹ 1 USD = Tk. ~60 (January 2004)

4.0 Base case energy estimation: shops

Energy estimation (base case) of shops is rather straightforward and can be obtained as the product of number of lights (5 lights), watt of each light (20W) and operating hours per day (4 hours). This gives 400 Wh per day or 146 kWh/year.

5.0 Emission: base case

5.1. Household

Kerosene

IPCC (1996) gives a guideline to calculate CO₂ emission from different fossil fuel. It calculates carbon content of kerosene is about 87% by weight. Taking the density of kerosene to be 0.8 kg/litre, and multiplying by the factor 44/12 (to convert from C to CO₂) yields the emission factor roughly 2.5 kg/litre. Therefore, the emission from a 50 Wp equivalent system is 55 kg per month or 660 kg per year.

Diesel for automotive battery charging

The emission factor for diesel based generator has been sourced from Kaufman (1999), which notes that the figure varies among various sources. However, the average can be taken as 2.5 kg/kWh. Based on this value, the total emission for battery charging is 6.25 kg per month i.e. 75 kg per year.

Total emission

Neglecting the emission due to transportation of diesel and kerosene to the site, which is very negligible compared to the above emissions, the total emission from the base case fuel use for a 50Wp system equivalent household is 735 kg per year.

5.2. Shops

It has been noticed earlier that emission from diesel generator is 2.5 kg/kWh. This gives yearly emission of 365 kg from a 50Wp displaceable system.

6.0 Emission: PV system

There has been various studies toward estimating the emission from the PV systems. This is mainly from the manufacturing process of PV modules but also includes BOS components as well. However, to calculate the emission, the energy requirement throughout the whole process including module manufacturing, BOS manufacturing transportation and installation is to be worked out.

6.1. Energy requirement for PV system

Module

Alsema (1998) presents a very clear calculation of energy requirement for various components of PV systems. Table 1 shows the energy requirement for different types module manufacturing. This estimation included silicon production, silicon purification, crystallization process 1 and 2, wafering, cell processing and module assembly. High and low variants present different approaches with respect to silicon feedstock production. The low value assumes that the primary crystallization step (which is about 4300 MJ/kg) is not involved, which is usually the case for module manufacturing. Therefore, our calculation has been based on the low value.

Table 1: Energy requirement for frameless module manufacturing

Module type	Energy requirement (MJ/Wp)	
	Low	High
Single crystalline	47	109
Multi crystalline	35	96

Source: Alsema (1998)

Aluminium frame

As the PV systems in our case will use framed modules, energy requirement for aluminium frame has been calculated. Alsema (1998) estimates that 1 m² of PV module requires 2.5 kg aluminium frame, which requires 500MJ of thermal energy. To find out the size of a 50Wp single crystalline module, BP solar product databases has been consulted (BP, 2002) and (BP 2003), which give the area of 50Wp module is 0.44 m² for single crystalline (BP250) and 0.45 m² for multi crystalline (BP350). Based on this value, the energy requirement for aluminium frame is 220 and 225 MJ for SC and MC modules respectively.

Balance of System

Battery

Batteries constitute a critical part of stand-alone PV systems. Alsema (1998) suggests that the energy requirement range for lead-acid batteries is 25 to 50 MJ/kg. This value assumes 30 to 50% of lead recycling. The energy density of battery is typically 40Wh/kg, which gives 0.94 MJ/Wh. As the 50Wp PV system uses a 71Ah battery @ 12V (852Wh), the energy requirement becomes 800 MJ per battery.

Charge controller

Energy requirements for charge controller was very difficult to find. As most of the sources mention about the energy requirement for grid connected PV systems, which do not use any charge controller (rather use inverters), this particular information was not available. Twedell (1999) suggests that the energy requirement for a 3 kW inverter is 2,105 MJ. The energy requirement in our calculation was worked out from this figure based on the weight comparison². BP (2003a) gives the weight of a 1 kW inverter is 18.5 kg and Morningstar (2000) gives the weight of a 10 ampere charge controller is 0.23 kg. Based on the linear algebra the energy requirement for 10 amps charge controller was calculated to be 9 MJ.

Lamps, cables and fixtures

The energy requirements for lamps, cables and fixtures required for a solar home system would be very small compared to those for other components because the size of production (in bulk) is very high compared to that a system uses. Although, there would be values higher than zero, due to lack of available information and simplicity this values have been neglected.

Mounting structure

PV systems in rural areas of Bangladesh are usually mounted in two different ways. Firstly, mounting on the roof of the house. Most of the households in the rural area

² The relation is not linear but this would not have a large effect on the whole energy calculation as the energy for controller would be very small compared to the others

have tin shed roof. Therefore, to fix the module a very simple and light weight steel frame is used, which is screwed between the module and the roof. The weight of this structure is about 2 kg per system. Wheldon et.al (2000) notes the energy requirement for galvanized steel is 50 MJ/kg, which gives 100 MJ per system.

Another approach of mounting is using bamboo or GI pole (where there is no option for putting the module on the roof). For bamboo mounting, the structure becomes a bit heavier and weighs about 3.5 kg consumes 175 MJ. In case of pole, the average size is used of 5 meter long and 6 cm diameter, which weighs roughly 12 kg. This gives energy need of 600 MJ.

Either the bamboo or the GI pole is inserted into the earth, tightened heavily and fastened with the surrounded support (i.e. with nearby pillars, etc.). As it is very difficult to source any concrete structure easily in the rural area as well as they are expensive too, use of this is usually avoided.



Figure 2: PV module installed on the roof with simple mounting support



Figure 3: PV module installed on the bamboo with no concrete support

Lifetime

- Module: 20 years (confirmed by most of the manufacturers)
- Battery: Communication with Grameen Shakti (the major SHS implementers of Bangladesh) revealed that the deep cycle battery the use has life time of more than 6 years. Some batteries have already crossed 5 years and are still in running conditions.
- Charge controller: It uses very little amount of electronics, which have lifetime of 10-15 years. On average we consider 10 years.
- Mounting structure: Galvanized steel usually have very long life of about 10 years.

Installation

During this type of system installation no energy intensive equipment is used and therefore the energy requirement is neglected.

Transportation

Since the components of solar home systems are transported in bulk size at the site, the energy requirement in transportation for individual system is very small compared to the other energy needs and is neglected.

Total

Table 2 gives the total primary energy requirement for a 50Wp system including initial (i.e. manufacturing) and replacements. The detailed calculation is given in Appendix B.

Table 2: Energy requirement for 50Wp PV system in different option

Items	Mounting options	Energy requirement (MJ)	
		SC	MC
Initial energy requirement (MJ _{prim})	Roof mounting	3479	2884
	Bamboo mounting	3554	2959
	GI pole mounting	3979	3384
Replacement energy requirement (MJ _{prim})	Roof mounting	1709	1709
	Bamboo mounting	1784	1784
	GI pole mounting	2209	2209
Total energy requirement in 20 years (MJ _{prim})	Roof mounting	5188	4593
	Bamboo mounting	5338	4743
	GI pole mounting	6188	5593

6.2. Emission

As the all energy used in manufacturing and replacement of PV system is in the form of electricity, the total emission can be obtained very easily. Alsema (1998) notes that the emission from electricity generation is 0.055 kg CO₂/MJ. This gives emission over 20 years from a 50Wp system using single crystalline module is 285 kg for roof mounting, 294 kg for bamboo mounting and 340 kg for GI pole mounting. The figures are 253 kg, 261 kg and 308 kg respectively for multi crystalline module. Therefore, the emission reduction in 20 years is about 14 tonnes.

7.0 Energy payback

Energy output from PV system

Energy output of a 50Wp system can be calculated by the following relation:

$$\text{Energy output per year (kWh)} = \text{kWp rating of PV module} \times \text{Irradiation (kWh/m}^2\text{/year)} \times \text{PR}$$

For irradiation of 4.85 kWh/m²/day and performance ratio 55%, the yearly energy output is 48.5 kWh_e for both types of modules. This gives equivalent primary energy of 194 kWh_{th} based on a 25% conversion efficiency³, i.e. 698 MJ.

Payback time

Energy payback can be calculated by the following equation:

³ Alsema (1998) states that grid supply in remote rural area has a conversion efficiency similar to diesel generator i.e. 25%

$$\text{Energy payback time (years)} = \frac{\text{Energy required for PV system in life time (20 years)}}{\text{Energy output of PV system per year}}$$

Based on the obtained values, the energy payback times for using SC modules have been calculated to be 7.43 and 6.58 years for systems using single crystalline and multi crystalline modules respectively when installed with simple roof mounting structure. This values increase by 3% and 17% when installed on bamboo and GI pole respectively.

8.0 Emission reduction

Emission reduction is the total emission by the base case system less the emission by the PV system (both initial and replacements). This gives the emission reduction by PV system about 297 kg for systems installed in households and 131 to 144 kg for systems when installed in shops depending on type of mounting the system uses. Table 3 gives a summary of the results while the detailed calculation is attached in Appendix B.

Table 3: Summary of results

Energy production (kWh _e /year from 50Wp)		48.5	48.5
Energy payback time (years)	With roof mounting	7.43	6.58
	With bamboo mounting	7.64	6.79
	With GI pole mounting	8.86	8.01
Emission from a 50Wp system in 20 years (kg CO ₂)	With roof mounting	285	253
	With bamboo mounting	294	261
	With GI pole mounting	340	308
Emission reduction (g CO ₂ / kWh _e /Wp) – household	With roof mounting	297	298
	With bamboo mounting	297	298
	With GI pole mounting	296	297
Emission reduction (g CO ₂ / kWh _e /Wp) - shops	With roof mounting	130	131
	With bamboo mounting	144	144
	With GI pole mounting	144	144

9.0 Discussions

Results show that the emission reduction by PV system has great potential. Systems when installed in households give a reduction of about 300 gm per kWh per Wp and when installed in shops the reduction is between 130 to 144 gm per kWh per Wp. This results compare with Alsema (1998), which gives the emission reduction of stand-alone PV systems is about 280 gm per kWh per Wp. The difference between shops and households comes from the different base case fuel use, which proofs that kerosene emits more CO₂ than diesel. The variation between SC and MC is negligible.

The energy payback for this particular size of system has been obtained as little above 7 years for SC and 6 years for MC. This difference is due to higher energy consumption in the process of production of SC modules due to high level of silicon purification. However, when installed with GI pole mounting, the energy payback

period increases by 1 more year, as the energy required for GI pole is higher (due to its more weight) than the simple mounting structures. These results also compare with the values mentioned in Alsema (1998), which calculates the energy payback period for solar home system installed in Indonesia is more than 7 years.

In our calculation we have not included the Cuppi and dry cell batteries as we assume that the household will still be using even after having PV system (as they are related to outdoor application). This should not affect our calculation as we have calculated emission per kWh.

10.0 Conclusions

Solar home systems have good potential in mitigating CO₂. The systems directly displaces the hydrocarbon fuels and provides a clean environment. Emission from manufacturing of the system components is offset in very short time, as the emission from base case fuel is very high. Although, the production of PV module and its accessories is energy intensive, the system pays back the energy in less than their half life. Calculations show that in terms of emission reduction, use of SHS in household application has much better result than using them in shops. This is because the shops are using diesel operated generator service which emits less CO₂ than kerosene.

11.0 References

Alsema E. A (1998), Energy requirement and CO₂ mitigation potential of PV systems, PV and the Environment 1998, BNL/NREL Workshop, Keystone, CO, USA, 23-24 July 1998

BP (2002a), BP solar, Solar product database, module BP 250, <http://www.bpsolar.com/ContentDocuments/123/bp2.pdf>, 2002, consulted 18 January, 2004.

BP (2002b), BP solar, Solar product database, Inverter GCI 2000, <http://www.bpsolar.com/pdf/BP31.pdf>, 2002, consulted 18 January 2004

BP (2003), BP solar, Solar product database, Module BP 350, http://www.bpsolar.com/ContentDocuments/84/350U_4022_2_Aug_03.pdf, 2003, consulted 18 January, 2004.

Cabraal A, Cosgrove-Davies M, and Loretta SL (1996), Best practices for photovoltaic household electrification programs: Lessons from experiences in selected countries. World Bank Technical Paper 324, World Bank: Washington, DC, 1996

Foley G (1995), Photovoltaic applications in rural areas of the developing world, World Bank Technical paper no. 304, Washington DC, World Bank, 1995, pp-25

IPCC (1996), Intergovernmental Panel for Climate Change, IPCC guidelines for national greenhouse gas inventories, Reference Manual (Volume 3), 1994 and revised 1996

Islam M (2002), Assessment of Renewable Energy Resources of Bangladesh, Version 1, May 2002, <http://shakti.hypermart.net/publications/ebook1.pdf>, consulted 18 January 2004

Kaufman SL (1999), Calculating, Monitoring, and Evaluating Greenhouse Gas Benefits from Solar Home Systems in Developing Countries, Renewable Energy Policy Project, April 1999, <http://solstice.crest.org/repp/index.html>, consulted on 18 January 2004.

Khan HJ and Huque AJ (1998), Solar photovoltaic in rural electrification: Market assessment survey in Bangladesh, Village Power '98, Washington DC, 1998

LUTW (2004), Light up the World Foundation, Environment, Fuel-based lighting, <http://www.lightuptheworld.org/index.html>, date of page not found, consulted on 18 January 2004

Morningstar (2000), Morningstar Corporation, Products, Sunsaver SS-10, <http://www.morningstarcorp.com/products/SunSaver/info/Morningstar-Product-Datasheet.pdf>, 2000, consulted 18 January 2004

Talukdar QA (2003), Personal communication, Accounts and Purchase Officer, Grameen Shakti, Dhaka, Bangladesh, December 2003

Twedell T (1999), Analysis of the photovoltaic roof on the engineering building at The University of Reading, M.Sc thesis, University of Reading (1999), pp-42

Wheldon AE, Bently RW, Whitfield GR, Tweddel T and Weatherby CK (2000), Payback times for energy and carbon dioxide: comparison of concentrating and non-concentrating PV systems, Proceedings of the 16th European Photovoltaic Solar energy Conference, Glasgow, May 2000.

Appendix A

Table A1: Solar irradiation at different locations of Bangladesh (kWh/m²/day - 1988 to 1998)

Month	Dhaka	Rajshahi	Sylhet	Bogra	Barishal	Jessor
January	4.03	3.96	4.00	4.01	4.17	4.25
February	4.78	4.47	4.63	4.69	4.81	4.85
March	5.33	5.88	5.20	5.68	5.30	4.50
April	5.71	6.24	5.24	5.87	5.94	6.23
May	5.71	6.17	5.37	6.02	5.75	6.09
June	4.80	5.25	4.53	5.26	4.39	5.12
July	4.41	4.79	4.14	4.34	4.20	4.81
August	4.82	5.16	4.56	4.84	4.42	4.93
September	4.41	4.96	4.07	4.67	4.48	4.57
October	4.61	4.88	4.61	4.65	4.71	4.68
November	4.27	4.42	4.32	4.35	4.35	4.24
December	3.92	3.82	3.85	3.87	3.95	3.97
Average	4.75	5.00	4.54	4.85	4.71	4.85

Source : Islam (2002)

Appendix B

1.0 Energy and emission: base case

1.1 For household

Fuel/energy requirement

Household can afford 50Wp system uses 22 litre kerosene per month	264	L/year
Charging 100Ah (@40% DOD) @ 500Wh per charge @ 5 charges per month	30	kWh/year

Emission

Emission factors

From kerosene for lighting	2.5	kg/litre
From diesel generator for charging automotive battery	2.5	kg/kWh

Emission per year

From kerosene	660	kg CO ₂
From diesel generator	75	kg CO ₂
Total emission per year	735	kg CO ₂
Total emission over 20 years life	14,700	kg CO ₂

1.2 For shops/markets

Fuel/energy requirement

Energy from diesel generator (5 units of 20W lights @ 4 hours per day)	146	kWh/year
--	-----	----------

Emission

Emission factors	2.5	kg CO ₂ /kWh
Emission per year	365	kg CO ₂
Total emission over 20 years life	7,300	kg CO ₂

2.0 Energy and emission: PV system

2.1 Energy requirement - initial (for 50Wp system)

System components	Description	Energy needs (MJ)	
		SC	MC
Module	47 & 35 MJ/Wp for single & multi resp.	2,350	1,750
Aluminium frame	500 MJ/m ² (single-0.44 m ² , multi-0.45m ²)	220	225
Battery	0.94 MJ/Wh (for 12@71Ah battery)	800	800
Charge controller	For 0.23 kg @ 39 MJ/kg	9	9
Lamps, cables, fixtures	Neglected	-	-
Mounting structures	Roof mounting (for 2 kg @ 50 MJ/kg)	100	100
	Bamboo mounting (for 3.5 kg @ 50 MJ/kg)	175	175
	GI pole mounting (for 12 kg @ 50 MJ/kg)	600	600
Installation	Neglected	-	-

Appendix B ... Contd

Transportation	Neglected	-	-
Initial energy requirement (MJ_{prim})	With roof mounting	3,479	2,884
	With bamboo mounting	3,554	2,959
	With GI pole mounting	3,979	3,384

2.2 Energy requirement - replacements (system life 20 years)

Module	No replacement (@ 20 years life)	-	-
Battery	2 replacements (@ 6 years life each)	1,600	1,600
Charge controller	1 replacement (@ 10 year life each)	9	9
Mounting structures	Roof mounting-1 replacement (@ 10 yrs life each)	100	100
	Roof mounting-1 replacement (@ 10 yrs life each)	175	175
	Roof mounting-1 replacement (@ 15 yrs life each)	600	600
Replacement energy requirement (MJ_{prim})	With roof mounting	1,709	1,709
	With bamboo mounting	1,784	1,784
	With GI pole mounting	2,209	2,209

2.3 Energy requirement - total (in 20 years)

Total energy requirement (MJ) in 20 year life (2.1+2.2)	With roof mounting	5,188	4,593
	With bamboo mounting	5,338	4,743
	With GI pole mounting	6,188	5,593

3.0 Energy payback (independent of household or shops)

Energy production (kWh _e /Wp/year @ irradiation 4.85 kWh/m ² /day, 55% PR)	0.97	0.97	
Energy production (kWh _e /year from 50Wp)	48.5	48.5	
Equivalent thermal energy (kWh _{th} /year) required to produce this electricity from an electricity plant (@ conversion efficiency 25%)	194	194	
Energy requirement in MJ/year	698	698	
Energy payback time (years)	With roof mounting	7.43	6.58
	With bamboo mounting	7.64	6.79
	With GI pole mounting	8.86	8.01

4.0 Emission (independent of household or shops)

Emission factor for generating electricity is **0.055 kg/MJ_{prim}**

Emission from a 50Wp system in 20 years (kg CO₂)	With roof mounting	285	253
	With bamboo mounting	294	261
	With GI pole mounting	340	308

5.0 Emission reduction**5.1 For household**

Total emission by base case in 20 years (kg CO₂) 14700

Energy production by 50Wp system in 20 years (kWh_e) 970 970

Emission reduction (g CO₂/ kWh_e/Wp)	With roof mounting	297	298
	With bamboo mounting	297	298
	With GI pole mounting	296	297

5.1 For shops

Total emission by base case in 20 years (kg CO₂) 7300

Energy production by 50Wp system in 20 years (kWh_e) 970 970

Emission reduction (g CO₂/ kWh_e/Wp)	With roof mounting	130	131
	With bamboo mounting	144	144
	With GI pole mounting	144	144