Solar Water Heating: The Case of Mauritius

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Abstract

A small-island developing state with a fragile eco-system, dependent largely on tourism and vulnerable to climate change, Mauritius is in search of a sustainable future. In spite of an average daily insolation of 7 kWh/m2 per day with at least 11 hours of sunlight throughout the year, Mauritius remains depend at 80% on imported coal and oil for its needs. Liquid Petroleum Gas (LPG) is subsidized and as much as 50 000 tonnes are used annually for domestic water-heating purposes. Electricity derived from fossil fuel is also used for the latter purpose.

The Government has launched a programme to promote solar-water heaters instead, providing a subsidy of USD 300 per household to some 40 000 beneficiaries. This paper analyses the Energy, Engineering, Economic, Environmental and Ethical (E5) dimensions of this initiative from a multidisciplinary perspective.

The potential to reach 160 000 remaining households is also assessed. The compliance of the programme in terms of sustainability criteria as well as Life-Cycle Analysis studies are conducted to encompass its holistic impacts and outcomes.

The feasibility of replicating the programme in other small-island economies is also analysed. Comparison is also made with similar projects elsewhere. Finally, an Energy Management programme is proposed to ensure the long term sustainability of the initiative taking into account its constraints, limitations and specific strengths. The scope of this programme in terms of North-South and South-South cooperation in the post-Kyoto era is also considered.

Keywords: Solar, Water-heaters, Mauritius, Renewable, Energy, Environment.

Background

Figure 1 shows schematically the operation of a typical solar-water heating system.

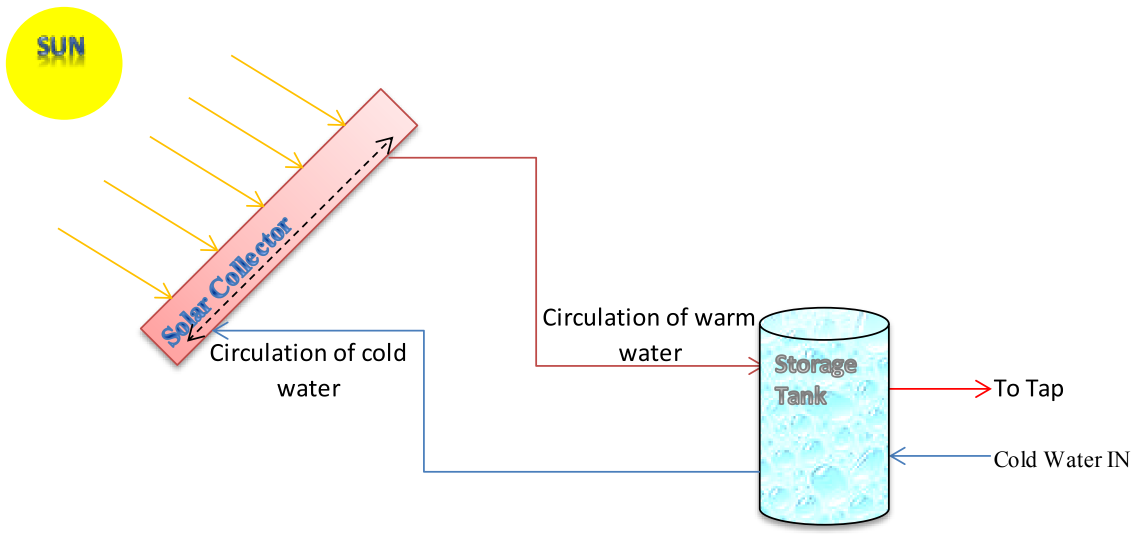

Figure 1: Solar water heater system

The characteristics of a solar water heater are determined by the thermal performance, transmittance, absorption and conduction of solar energy and the conductivity of the working fluid (Jaisankar et al., 2009a; Jaisankar et al., 2009b). The performance of a solar water heater is influenced by the product configuration and the local meteorological conditions as fully discussed by Budihardjo and Morrison, 2009. Solar water heaters can operate as a solar pre-heater in series with a boost tank or instantaneous gas heater or as a single-tank system with a boost element incorporated in the solar tank. The collector is usually mounted at a standard roof inclination, but can also be adjusted to optimise the performance during winter months when the hot water demand is the highest (Budihardjo and Morrison, 2009; Budihardjo et al., 2007).

Engineering

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. A comprehensive list is shown in Table 1.

Motion of fluid	**Collector type**	**Absorber type**	**Concentration ratio**	**Indicative temperature range (^{0}C)**	**Available in Mauritius**
Stationary	Flat plate collector (FPC)	Flat	1	30-80	yes
	Evacuated tube collector (ETC)	Flat	1	50-200	yes
	Compound parabolic collector (CPC)	Tubular	1-5	60-240	yes
Single-axis tracking					
	Linear Fresnel reflector (LFR)	Tubular	10-40	60-250	no
	Parabolic trough collector (PTC)	Tubular	15-45	60-300	no
	Cylindrical trough collector (CTC)	Tubular	10-50	60-300	no
Two-axes tracking	Parabolic dish reflector (PDR)	Point	100-1000	100-500	no
	Heliostat field collector (HFC)	Point	100-1500	150-2000	no

[adapted from Kalogirou, 2004; Kalogirou, 2009]

Table 1: Types of solar thermal collectors

A high-efficiency collector will be best suited in climates with relatively low solar radiation with low ambient temperatures or where large volumes of water at temperatures in excess of 60°C (140°F) are required whereas a low-efficiency collector may be used in high-irradiation climates, milder ambient temperatures or for low-temperature applications.

A high-performance collector stays reasonably efficient even at large temperature differences between the collector and the ambient whereas a low-performance collector loses heat rapidly at high temperature differences. The overall thermal performance of solar collector depends on its efficiency and loss factor.

Survey

This section describes the analysis of the survey carried out in Mauritius in November and December 2012 among a random sample of 100 respondents defined as households from the local population. The sample size is stratified as follows (Table 2):

Districts	Number of households*	Estimated size	Percentage (%)	Required sample size
Port-Louis	32723	33000	9.82	10
Pamplemousses	36150	37000	11.01	11
Rivière du Rempart	29373	30000	8.93	9
Flacq	36625	37000	11.01	11
Grand-Port	30360	31000	9.23	9
Savanne	18992	19000	5.65	6
Plaines Wilhems	103921	104000	30.95	31
Moka	22122	23000	6.85	7
Black River	21025	22000	6.55	6
Total	331291	336000	100.00	100

Table 2: Population sampling

* Official value from Central Statistics Office (CSO, 2011)

The stratified random sampling technique is a probability sampling technique that uses a two-step process to partition the population into subsequent subpopulations, or strata. Elements are selected from each stratum by a random procedure.

Moreover a pilot testing was carried out after the questionnaire was designed whereby five respondents selected. Response was received from the pilot respondents, hence further changes had to be brought forward. Some questions had to be rephrased and simplified and the sequence of some questions was changed. Some questions had to be eliminated as well some technical jargons were clarified to enhance participant's comprehension. Questions structures were adjusted by increasing options and more elaboration was needed in order to facilitate the respondent in answering the questions. This has helped in making the study realistic and meaningful.

As shown in Figure 2, 60% of the respondents have at least one water heater at home, 22% have two water heaters, and 9% have three water heaters. Only 9% have no water heater.

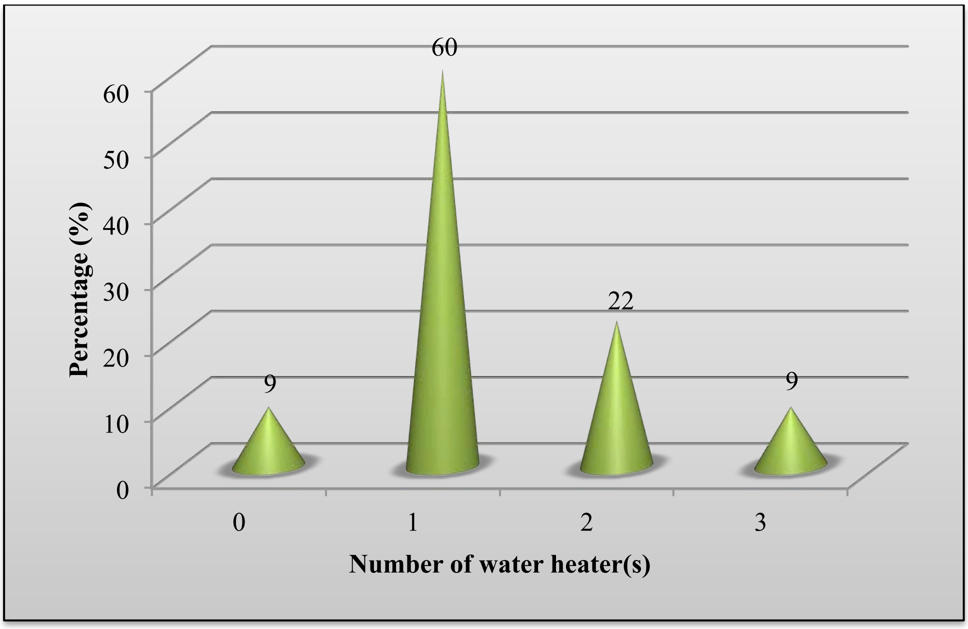

Figure 2: Number of water heater per household

45% of the respondents have solar water heater compared to 31% having electric water heater. Gas water heater represents 15% and 9% of respondents have no water heater. This shows a significant bias compared to data provided from Central Statistics Office (CSO, 2011). This factor is taken into account later in the further analysis. Focusing on solar-water heaters, the following findings were made:

- 49% have a tank capacity of 200 L, 18% for 150 L and 33% in total for 100 L, 250 L and 300 L as given in Figure 3.

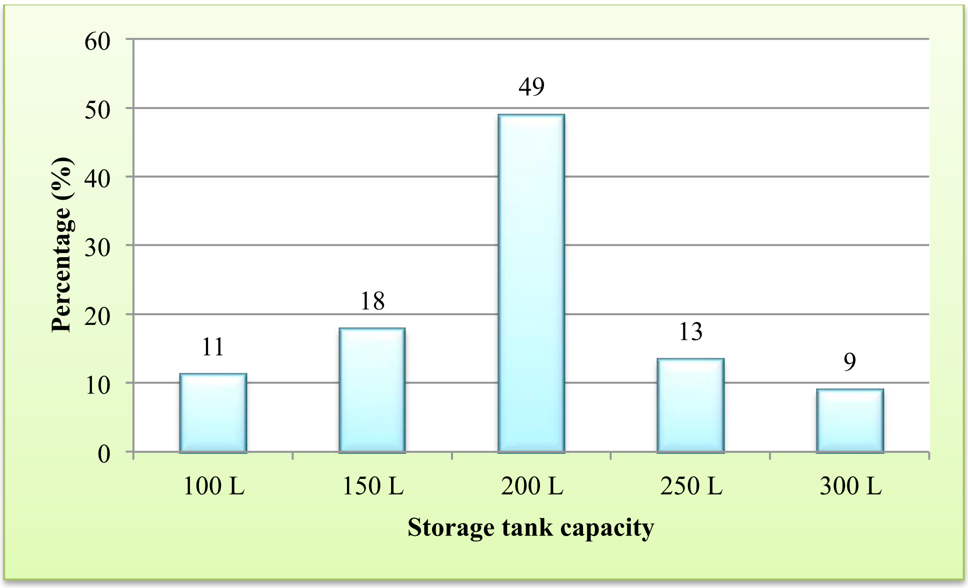

Figure 3: Storage tank capacity

- 87% of those who have solar water heater use evacuated tube solar collector compared to flat plate collector (13%) as shown in Figure 4.

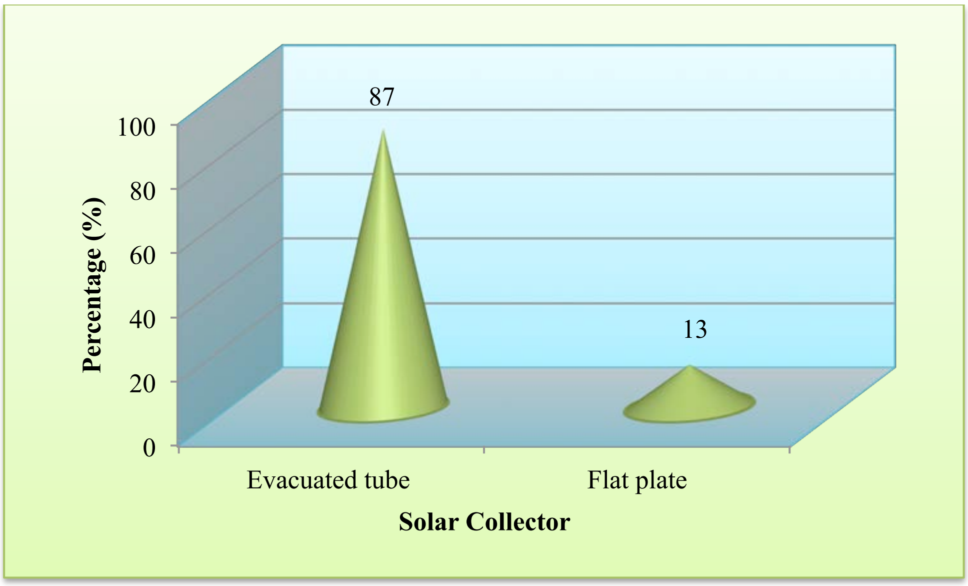

Figure 4: Solar collector

It was noted that:

- 80% of those having solar water heater have low-pressure solar water heater and 20% have high-pressure solar water heater (11% coil type and 9% heat pipe). No respondent has split unit water heater.
- 84% of solar water heater users stated its quality is excellent with only 7% moderate and 9% poor.
- On average, the cost of a low-pressure solar water heater is Rs 15,000 (USD 500) and for high-pressure solar water heater is Rs 25,000 (USD 830) irrespective of the tank capacity. The prices vary depending on the suppliers and from where it is imported and/or manufactured.
- 78% of solar water heater users did not encounter any problems with their solar water heater whereas 22% states they encountered problems.
- Problems frequently encountered on solar water heater are overflow, poor water heating in warm conditions and algae deposition.
- Majority of the respondents stated that they perform their own maintenance such as cleaning the glazing or vacuum tube with detergent to remove fungus deposition.
- 83% of the solar water heater respondents have bought their solar water heater from the Government-sponsored Development Bank of Mauritius (DBM) scheme only and 13% from their own means only. Only 4% have bought both from their money and the DBM scheme.
- 96% of the respondents agree that the DBM project on solar water heater is a success as they say it helps the reduction of emission of pollutant gases emitted to the atmosphere, provides awareness to most people about the importance of having solar water heater, and helps people to reduce electricity consumption which leads to lower monthly expenses.
- 4% of the respondents stated that it requires further improvements such as providing standard and quality solar water heaters, trained personnel, and implementing solar water heater in apartments, industries, commercials and hotels.

- 98% of the interviewees stated that the Central Electricity Board (CEB) bill has decreased after they have installed solar water heater. Of the 98%, 71% have "seen'' their CEB bill decrease less than Rs 500, 13% in the range Rs 500 – Rs 1,000, 11% in the range Rs 1,000 – Rs 1,500, and 2% greater than Rs 1,500. Some 2% who did not notice a reduction in their CEB bill stated that the presence of gas water heater had kept their CEB bill stagnant. This is shown in Figure 5. It is to be noted that there is no indication or record as to whether electricity was the only source of energy for heating before the purchase of a solar-water heater. The estimate on savings is based on the respondents' perception.

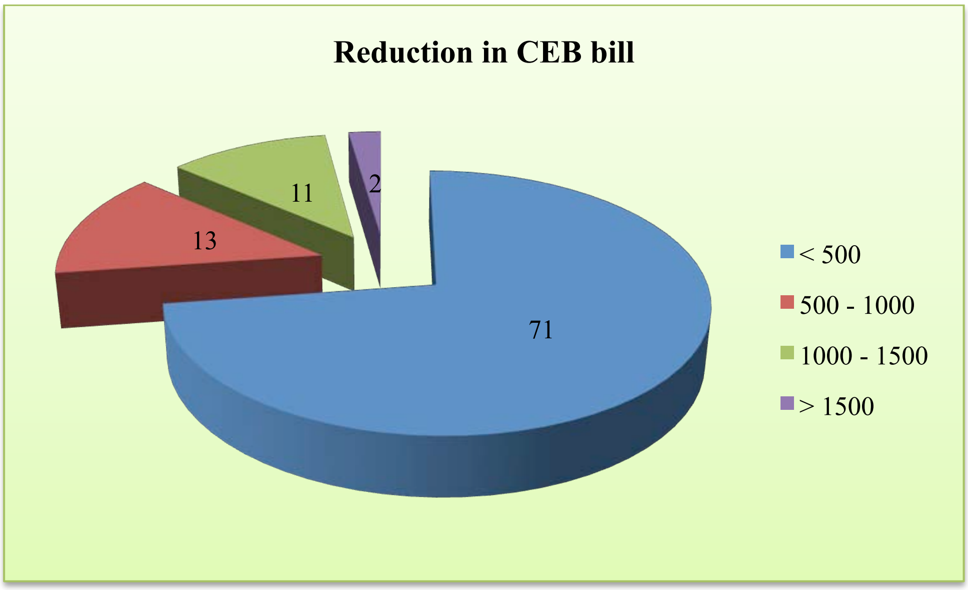

Figure 5: Reduction in CEB bill

- 65% of all the respondents use hot water for bathing, 22% for washing, 10% for cooking and 3% for cleaning (Figure 6). This shows that solar water heater is almost a necessity for bathing during warm condition.

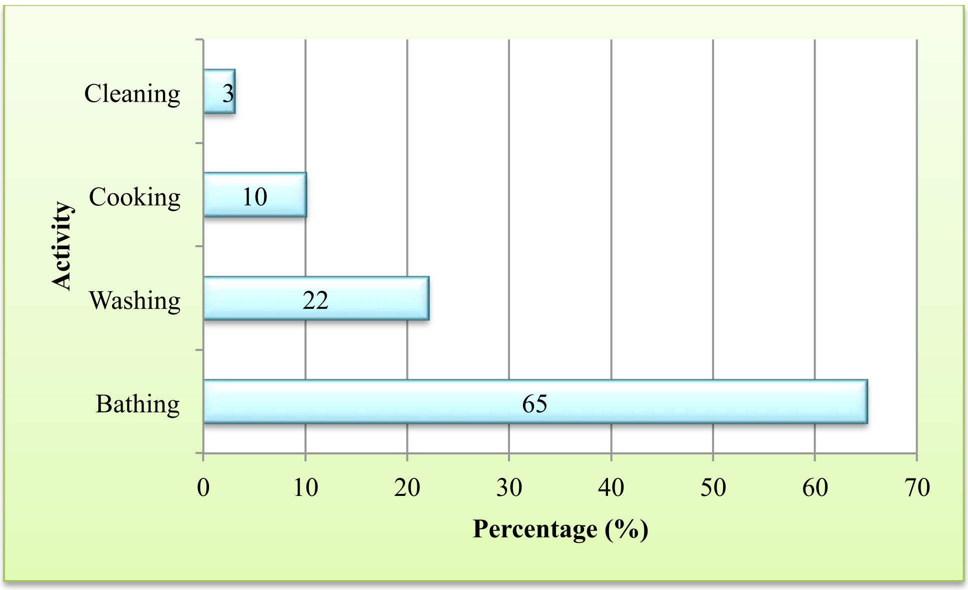

Figure 6: Hot water activity

Life-Cycle Analysis

According to ISO 14040 and ISO 14044, Life Cycle Cost (LCC) is usually carried out in four steps:

1. Define a goal, scope and functional unit
2. Inventory costs
3. Aggregate costs by cost categories
4. Interpret results

STEP 1: Define a goal, scope and functional unit

The goal of the life cycle cost was to compare, for solar, electric, and gas water heater, the LCC results of the three versions. In LCC, the geographical coverage was Mauritius. In terms of time-related coverage, only cost data in year 2012 were used. The LCCs were calculated for the whole assuming a length of Life Cycle Cost (LCC) of 19 years for all the three water heaters (solar, electric and gas) with no income tax applicable which served as the functional unit for the three versions.

STEP 2: Inventory costs

The relevant cost elements considered for the LCC of the three water heaters were:

i. Cost of solar, electric and gas water heater (including installation)
ii. Electricity consumption
iii. Maintenance cost
iv. Replacement cost for electric and gas water heater
v. Total Net Present Value

An inflation rate of 4% as from December 2012 and a discount rate of 10% were taken for all three water heaters.

STEP 3: Aggregate costs by cost categories

Table 3 gives the assumption taken into consideration when calculating the LCC.

	Units	
Number of family sizes	-	4
Litres of hot water per person per day	L	30.00
Total litres of hot water needed per day	L	120.00
Estimated family electricity used for water heating	kWh/yr	2239.92
Inflation rate	%	4
Discount rate	%	10
Residential electricity utility rate (including fuel adjustment)	Rs/ for 1st 25 kWh	3.16
Residential non-utility ("bottled") gas/propane cost	Rs/12 kg	330.00

Table 3: Assumptions taken into consideration when calculating LCC of water heaters

Figure 7 gives the results of the LCC of the three water heaters in Mauritius.

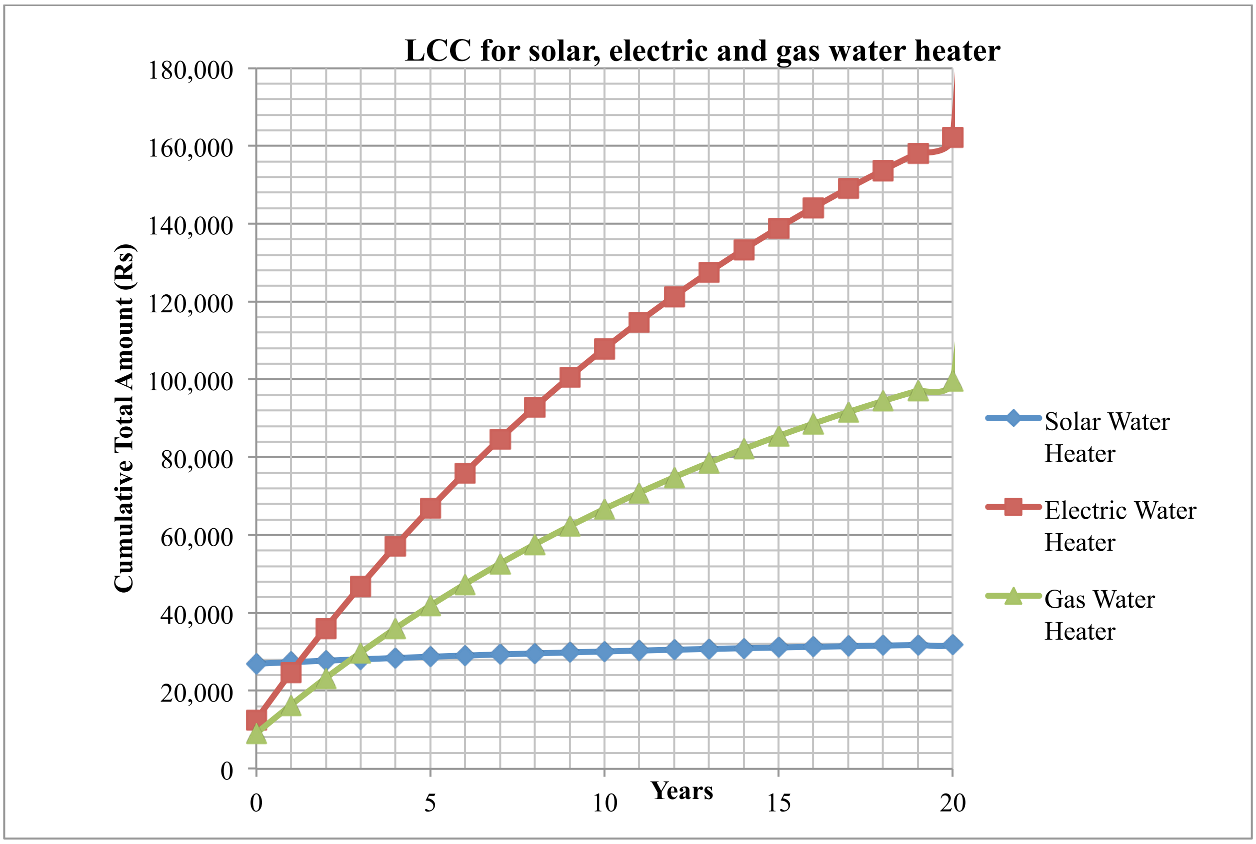

Figure 7: LCC for solar, electric and gas water heater without replacement cost

STEP 4: Interpretation

The economic analysis above based on marginal costs and current financial parameters shows the obvious benefit of solar-water heaters. Furthermore, the electricity rate is assumed at a minimal value in the analysis. The LCC for the latter is likely to be much more than the calculated value. Environmental and social costs are also not quantified in the above analysis. It is proposed that other dimensions are also included to the Energy, Engineering and Economic aspects already addressed above. A holistic analysis must also include the following non-quantitative benefits and costs.

Environmental and ethical (or social) aspects

Appendix I show a detailed analysis of the CO_2 emission related to use of electricity and LPG instead of solar energy for heating. About 250 000 tonnes/year of CO_2 are thus to be avoided if solar water heating substitutes the former, including about 150 000 tonnes/year related to LPG alone. The latter is subsidized for domestic use to the tune of about 40%.

Some 60% of the total households in Mauritius use LPG as the principal source of fuel to heat water for bathing (CSO, 2011). However, most of the residents are not “fully” aware of the dangers that may cause by LPG cylinder. Gas water heater requires the availability of butane LPG cylinders, which is heavy to carry by elderly or handicap people and provides risks of explosion if no proper care is taken into consideration. The transport costs to and from the households, alone, may effectively increase the cost of LPG by at least 10%.

In the past, people have died due to accumulation of carbon monoxide (CO) in poorly ventilated areas in private dwelling such as bathroom. High concentration of CO may kill a person within few minutes as it is absorbed more readily into the blood stream than oxygen (O_2). When haemoglobin, or red blood cells become saturated with CO, no oxygen can be absorbed which will result in blood poisoning.

In almost all cases, proper inspections by registered engineers were not performed after a gas water heater had been installed to check whether the installation had been done accordingly to standards such as BS 5482-1:2005. Depending on the frequency of usage of gas water heater, a person has to spend between Rs 300 to Rs 700 monthly to buy LPG cylinder(s), which is considered as an additional cost compare to solar water heater.

The main hazards associated with gas water heater are:

i. impact from the blast of a gas cylinder explosion or rapid release of compressed gas;
ii. impact from parts of gas cylinders or valves that fail, or any flying debris;
iii. impact from falling cylinders;
iv. contact with the released gas or fluid (such as chlorine);
v. manual handling injuries;
vi. fire resulting from the escape of flammable gases or fluids (such as LPG);

When carrying LPG, the cylinders must be stowed and secured upright, with the valves uppermost. Open back vehicles are considered when transporting LPG cylinders, however small LPG quantity may be transported in closed vans. But currently the legislation in the country does not allow for the latter. In spite of this, most people do it.

Electric water heater provides the risk of electrical shock when exposed to water or high humidity. Also, users might not be able to use electric water heater during midday due to frequent cut of main water supply as pressure is needed to trigger the heater.

The power input of the electric water heater is around 1.5 kW, which makes it one of the highest rated electrical appliances for the home. With the need to reduce the peak power consumption to lighten the need to install further power stations, the use of electric heaters can be a source of problem for the CEB as most people normally take shower around the same time in the morning and evening, contributing to considerable peak power on the grid. This leads to the need of urgent investment in extra generation capacity at a high economic, social and environmental cost.

From the survey carried out in December 2012, most respondents stated that their existing electric water heater contribute an increase in the CEB bill. They would take the opportunity to buy a solar water heater in the future.

Solar water heaters are much safer in operation, with no risk of gas leakage and electric shock. Furthermore, with the thermal storage it has, there is better availability of hot water, even at night and the likelihood of not having hot water is less than for electric and gas water heaters, which are based on instantaneous heating as opposed to heating over a whole day for the solar water heater. Despite its initial high cost, solar water heater has proved to be a budget saving compared to electric and gas water heater as solar energy is free and abundant to use. Solar water heater has proved to be beneficial for washing purposes as well as providing warm water in winter.

Since the introduction of Solar Water Heater Scheme by the Government in July 2008, there has been an increase in the number of suppliers and wide range of solar water heaters being imported with different prices and standard. This in turn has created a number of job opportunities for new and existing applicants. As at December 2012, there are about 31 registered solar water heaters suppliers. Together with other suppliers not registered with DBM, they provide a job opportunity for 200 to 300 people. The workers would be given an estimated salary of about Rs 10,000 to Rs 20,000 depending on their jobs they perform.

Conclusion

Mauritian population is becoming aware of the importance and advantage of installing a solar water heater as it can be seen that the demand for a solar water heater is increasing. Solar water heater has the advantage over electric and gas water heater as it does not make use of LPG cylinder or electricity and hot water may be available on a sunny day, thereby saving energy from the usage of electricity and gas water heater. The intervention of the Government in subsidizing its introduction has created an increase in job opportunities for sales executives, maintenance manager and technicians. More importantly, a new mindset has emerged such that the solar-water heater is becoming part of our lifestyle.

Future work related to replicating and adapting the programme in other small-island developing states will be reported in a later version of this paper to be uploaded on the website of the Conference. Comparison with the cases of Reunion, Malta, Israel and other countries will be pertinent. Besides, the Third Solar-Water Heater Scheme sponsored by the Government has to be integrated in the analysis. The latter scheme is now in its early phase of implementation. Consequently the final version of this paper, to be uploaded and published in September 2013 after the Conference, will include recommendations and findings related to a holistic Energy Management programme for solar-water heaters in Mauritius. The sister-islands of Rodrigues and Agalega can also be included. Discussions during the Conference as well as references to other papers presented during the event will hopefully identify avenues of North-South and South-South cooperation in the context of mitigating climate change in the post-Kyoto era. This will serve promote sustainability.

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APPENDIX I

Energy Impact of Solar, Electric and Gas water heater per household

To restrict the possibility of the growth of Legionella bacteria, a minimum storage temperature of 60 °C should be attained, with a minimum secondary return (if provided) temperature of 50 °C [1].

Assumption:

- Number of family size = 4
- Number of litres of water a person uses per day = 30 L
- Total liters of water needed per day = 120 L
- Average temperature for bathing = (60 – 20) = 40 °C
- Maintenance cost (assume to be the same for all three water heaters) = Rs 400
- Cost of a 12 kg LPG bottle = Rs 330
- Length of Life Cycle Cost = 19 years (2012-2030)
- Operating cost of solar = Rs 0
- 1 kWh = 3.6 MJ
- Energy factor of gas water heater = 0.50 – 0.70 [2]
- Energy factor of electric water heater = 0.75 – 0.95 [2]

Calculation:

Energy required to heat water = $m\ c\ \Delta T = 120 * 4200 * 40 = 20.16$ MJ

Where m = mass of water (kg)

c = Specific heat capacity of water (J/kgK)

ΔT = Average temperature for bathing (°C)

The energy required to heat water is the same for solar, electric and gas water heater.

ELECTRIC WATER HEATER

Assume an energy factor for an electric water heater = 0.9

$$\text{Energy for electric heater} = \frac{\text{Energy required to heat water}}{\text{Energy factor for an electric heater}} = \frac{20.16}{0.9}$$

$$= 22.4 \text{ MJ}$$

= 6.222 kWh/day

= 186.66 kWh/month

= 2239.92 kWh/year

Cost of monthly electricity bill for 186.66 kWh => CEB BILL TARIFF 110

	CEB Tariff (Rs)	Cost (Rs)
1st 25 kWh	3.16	79.00
Next 25 kWh	4.38	109.50
Next 25 kWh	4.74	118.50
Next 25 kWh	5.45	136.25
Next 86.66 kWh	6.15	532.96
Total cost (Rs) / month		976.21
Total cost (Rs) / year		11,714.51

GAS WATER HEATER

Assume an energy factor for a gas water heater = 0.66

$$\text{Energy for gas heater} = \frac{\text{Energy required to heat water}}{\text{Energy factor for a gas water heater}} = \frac{20.16}{0.66}$$

= 30.5 MJ

Calorific value of LPG = 45.6 MJ/kg (from Total, Mauritius) [3]

Mass of gas needed per day = (30.5/45.6) = 0.669 kg/day

Mass of gas needed per year = 244.13 kg

Number of LPG bottles = (244.13/12) = 20.34

Number of LPG bottles = approximately 21

Annual Energy Cost = (330 * 21) = Rs 6930

SCENARIO 1: Consider the situation where all households in Mauritius have an electric water heater

Average unit used by a household consist of 4 people = 2,239.92 kWh/year

Number of households in Mauritius = 331,291 (CSO, 2011)

From CEB: CO_2 emission = 1 tonne/MWh

1 MWh = 1000 kg

1 kWh = 1 kg of CO_2 emitted

Number of kg of CO_2 emitted = (Average unit used by a household * Number of households in Mauritius * 1)

= (2,239.92 * 331,291 * 1)

= 742, 065.34 tonnes

SCENARIO 2: Consider the situation where all households in Mauritius have a gas water heater

The combustion equation for LPG is: $2C_4H_{10} + 13O_2 \longrightarrow 8CO_2 + 10H_2O$

$2C_4H_{10} \longrightarrow 8CO_2$

58 g $\longrightarrow$ 176 g

1 g $\longrightarrow$ 3.03g

For each gram (g) of gas burnt, 3.03 g of CO_2 is emitted. Therefore, the ratio is 1:3.03.

Average mass of gas needed per year for a household consist of 4 people = 244.13 kg

For each household, the amount of CO_2 emitted per year is = 244.13 * 3.03 = 739.71 kg

331,291 households, the amount of CO_2 emitted per year is = 331,291 * 739.71

= 245,060.56 tonnes

SCENARIO 3: Carbon dioxide emission of electric and gas water heater according to CSO 2011

According to CSO 2011, the number of households that uses principal fuel for heating water for bathing is:

Principal fuel	No. of household	%
LPG	200,723.00	60.59
Electricity	40,925.00	12.35
Solar	40,973.00	12.37
Other	6,586.00	1.99
None	41,538.00	12.54
Not stated	546.00	0.16
Total	331,291.00	100

- *Electric water heater:*

Average unit used by a household consist of 4 people = 2,239.92 kWh/year

Number of households in Mauritius that have electric water heater = 40,925 (CSO, 2011)

From CEB: CO_2 emission = 1 tonne/MWh

1 MWh = 1000 kg

1 kWh = 1 kg of CO_2 emitted

Number of kg of CO_2 emitted = (Average unit used by a household * Number of households in Mauritius * 1)

= (2,239.92 * 40,925 * 1)

= 91,668.73 tonnes

- *Gas water heater:*

For each gram (g) of gas burnt, 3.03 g of CO_2 is emitted. Therefore, the ratio is 1:3.03.

Average mass of gas needed per year for a household consist of 4 people = 244.13 kg

For each household, the amount of CO_2 emitted per year is = 244.13 * 3.03 = 739.71 kg

200,723 households, the amount of CO_2 emitted per year is = 200,723 * 739.71

= 148,476.81 tonnes

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