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Economic and environmental analysis of solar water heater utilisation in Gauteng Province, South Africa

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Abstract

This paper focuses on the energy economics and environmental impacts of solar water heaters (SWH) in the Gauteng Province and compares the results with other technology options for residential water heating with regard to the different income groups. The critical energy situation in South Africa and the highly coal dependent energy generation demonstrates the need to shift to a more sustainable way of living. The residential sector proves to be an optimal starting point to implement new technologies, especially for water heating.

The residential hot water demand calculation shows that the annual demand in Gauteng is about 188 million cubic meters. In order to satisfy this demand, different technologies are investigated in this paper, where SWHs lie in focus.

Due to the vast income inequality in Gauteng, and also in South Africa, it is obvious that there cannot be one single optimal solution suitable to all households. Therefore, this paper focuses on the differentiation of the residential sector into income groups to show the divergence in warm water demand and the applicability of alternative technologies. In order to analyse appropriate solutions for all income groups, low-cost alternatives are also analysed. The economic analysis shows that although SWHs have higher investment costs than conventional technologies, the payback periods are relatively short (between 3 and 4 years) for high and mid income groups. The payback periods will be even shorter when the planned electricity price tariff increase comes into effect. Furthermore, SWH utilisation has the additional effect of reducing the overall electricity demand up to 70% and greenhouse gas emissions significantly. In addition, SWHs are the most cost-effective water heating technology to reduce greenhouse gas emissions for mid and high income groups with negative abatement costs.

It is concluded that the SWHs are the most suitable option to decrease fossil energy consumption and reduce the household's expenditure for energy services, especially for mid and high income groups. For lower income groups the utilisation of solar energy can increase the access to energy services and living quality and, therewith, lessen the financial burden to meet their energy needs.

Keywords: solar water heaters, abatement cost, annual expenditure, GHG emissions, income groups

1. Introduction

Gauteng, as the economic hub of South Africa, plays a central role in the future energy consumption of the country. With a population of more than 10 million inhabitants, it has the status of a megacity region and is ranked as the 25th largest urban region in the world (StatsSA, 2007). Gauteng covers only 1.4% of the total area of South Africa, but holds more than 21% of the country's total population and contributes more than 37% to the national Gross Domestic Product (GDP) (StatsSA, 2007). The country's energy system is, however, already stressed resulting in a series of power outages in some parts of South Africa in late 2005 (Von Ketelhodt and Wöcke, 2008) and becoming nationwide by 2007 due to the shortage of generation capacity.

Looking at the overall energy consumption in Gauteng, the residential sector is the third largest consumer of energy after transport and industry and the second largest consumer of electricity (EnerKey, 2010). Due to the insufficient generation capacity and coal based electricity conversion, which causes a high environmental footprint, it is clear that there is a need to reduce electricity consumption. However, the demand for energy services in the residential sector is not distributed evenly because of the high income inequality in South Africa. For the same reason, households will have different opportunities to shift to a sustainable living pattern depending on their income. Figure 1 shows that about 60% of the Gauteng population spends 10% (or more) of their household income on water and energy services, the majority of which falls in the lower income groups. Households spending more than 10% of their income on energy services are defined as energy poor (TEA, 2006). This trend is also reflected nationally (CURES, 2009).

The fact that poor households spend a higher share of their income on energy and water underscores the assumption that poor households have fewer financial resources available to invest in energy efficient technologies with high upfront investment costs although these will save costs in the long run. On the other hand, the smaller number of high income households have the financial ability and, due to their far higher overall energy consumption, the responsibility to share the provincial burden.

The electric geyser is the main technology used for water heating in South Africa and is the standard technology installed when new houses are being built, including being offered in Reconstruction and Development Programme (RDP) houses for lower income households (Table 1).

Table 1: Technology share for water heating by energy carrier and income group for Gauteng, 2007 (%)

Source: own calculations based on statistics from Eighty20 (2008), StatsSA (2005a), StatsSA (2005b) and StatsSA (2007)

	Poor income	*Low income*	*Middle income*	*High income*
Electric geyser	6.1	24.2	77.9	83.9
Electric stove	20.4	23.7	10.8	1.5
Electric kettle	8.5	7.1	0.0	0.0
SWH	0.0	0.8	2.1	4.3
Paraffin	39.5	25.4	0.0	0.0
Wood	6.8	3.8	0.0	0.0
Coal	12.7	10.6	0.0	0.0
Other	6.0	4.4	0.0	0.0
LPG	0.0	0.0	9.1	10.2

Solar energy is one of the attractive alternatives for a country like South Africa with high solar radiation all year round. Furthermore, the recent Gauteng Integrated Energy Strategy (GIES, 2010) has pointed out the relevance of solar energy utilisation for the province. Previous analyses have shown that usage of solar water heaters (SWHs) reduces both the total energy demand as well as the peak consumption by shifting the demand to non-

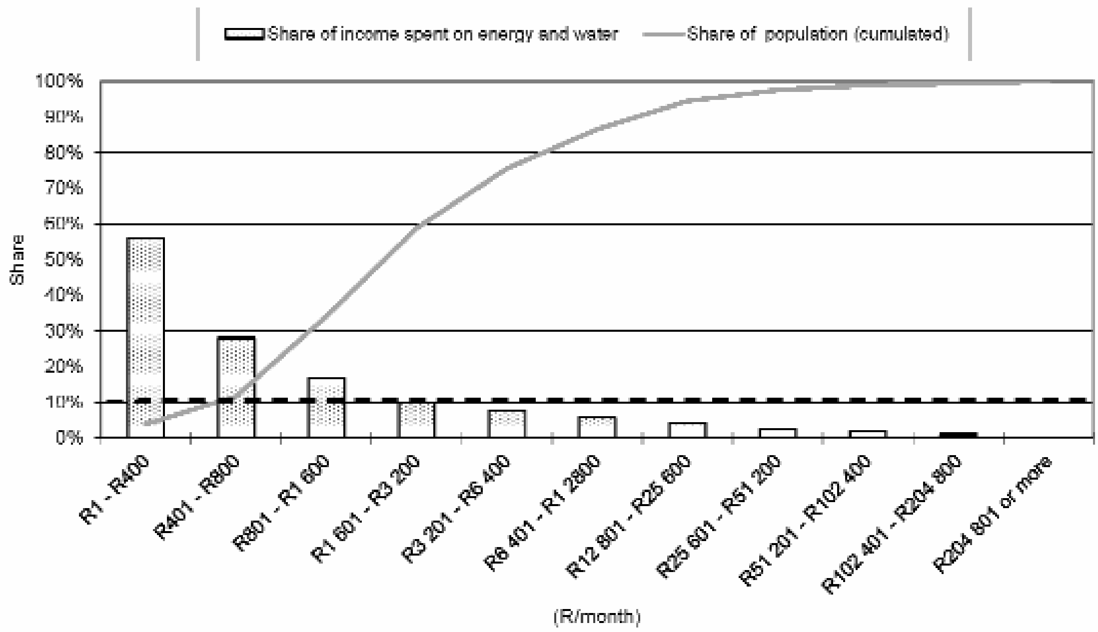

Figure 1: Expenditure in 2009 for water and energy services in Gauteng
(Calculation based on GCRO, 2009)

peak hours (Dobbins, *et al.,* 2009; Tomaschek, *et al.*, 2009; Özdemir, *et al.*, 2009).

2. Aim and scope of this work

This paper aims to describe SWHs, compare them with other water heating technologies and highlight the opportunities for SWHs in differentiated income groups in the residential sector in Gauteng. Therefore, while the focus lies on the solar water heaters, different residential water heating technologies are investigated for their characteristics (Figure 2).

Due to the income inequality in South Africa, the accessibility of goods and the demand for services varies greatly. Especially in Gauteng this becomes even more dominant as it represents the economic hub of South Africa. All the calculations are done for four income groups (see Figure 2) to demonstrate the different demands and accessibility to technologies among the population.

The definition of the income groups used is proposed by the Institute for Future Studies and Technologies (IZT) in Germany (Hector *et al.,* 2009). The basis for the definition is the Statistics South Africa Community Survey 2007, Income and Expenditure Survey 2005 and Travel Survey 2003 (StatsSA, 2007; StatsSA, 2005a; DoT, 2003). IZT classified the groups based on accessibility to household goods and service demand, because income level largely determines the ability of households to purchase goods and appliances. A main issue of the classification is that many South African surveys use different groups for income levels, or adjust the groups over time. Therefore, IZT redistributed the groups found in the statistics to four standard income groups, which can be used for all surveys mentioned above (Hector, *et al.,* 2009).

The definition of the poor income group is based on the Poverty line / Indigence defined by the South African Department of Social Development in 2006 as a criteria for a child support grant: R800 per month and household or R9 600 per year. The other three groups are grouped based on the Gini coefficient and the penetration of appliances (Hector *et al.,* 2009). The average household size was calculated as 2.6, 3.4, 3.8, and 3.3 persons based on the Community Survey 2007 (StatsSA, 2007) for the income groups poor, low, medium and high respectively.

All the economic data in this paper is given in R_{2007} unless stated otherwise. The inflation adjustment is based on the Consumer Price Index (CPI) available at Statistics South Africa (StatsSA, 2010), i.e. 1.000 R_{2007} = 1.246 R_{2010}. The structure of this paper follows the diagram given in Figure 3.

The technical characteristics of SWHs are investigated and compared with the electric geyser as the reference technology in South Africa and discussed in the third section. In the fourth section, the hot water demand of the province is calculated and compared with the technical hot water potential of SWHs. In the fifth section, the effect of SWH utilisation on demand side management is shown. In the sixth section, the economics of water heating is examined for the different cost categories, annual expenditure and payback periods. The greenhouse gas (GHG) emissions of different water heating technologies are investigated in section seven. Section eight presents the GHG abatement cost calculations for different water heating technologies, followed by the conclusion of all the results in the final section.

The electric geyser is selected as the reference technology although it is not currently the most

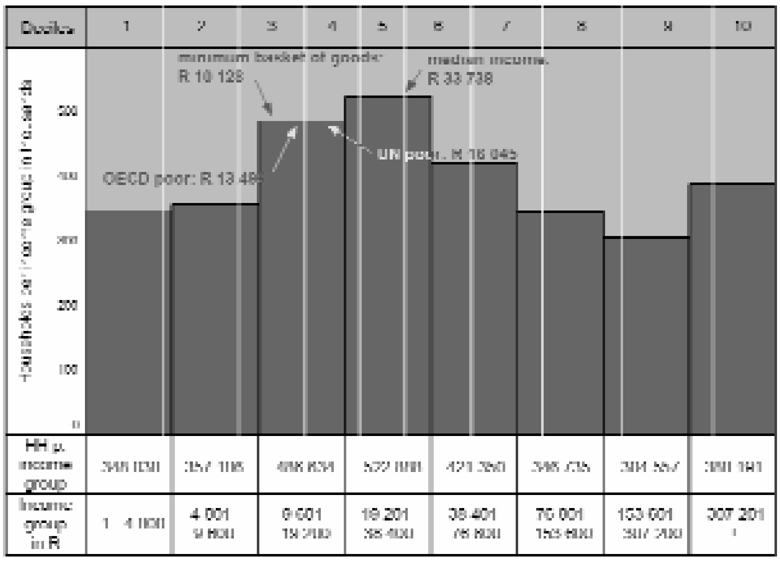

Figure 2: Classification of income groups in South Africa
Source: Hector et al., 2009

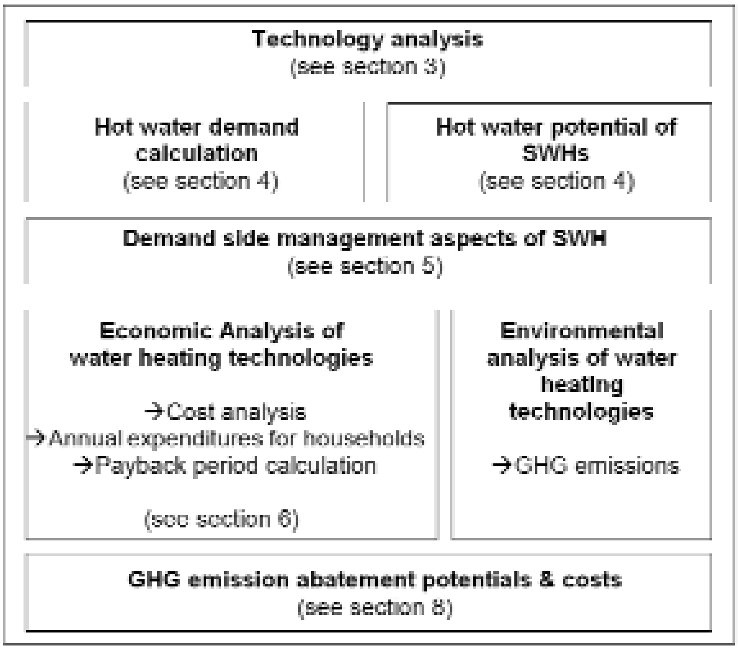

Figure 3: Overview of the analysed aspects in the paper

common technology in all income groups (see also section 1, Table 1). While mid and high income groups use an electric geyser almost exclusively, low and poor income groups use paraffin and electricity for water heating in similar shares to each other and electric geysers to a far lesser extent.

3. Technology analysis of SWHs

There are several types of SWHs currently available in the South African market: unglazed, flat plate glazed, evacuated tube and low cost SWHs. Most of the SWHs have three basic components: a solar collector, a storage tank and a heat transfer medium. The solar collector is utilised to obtain heat from the sun. The storage tank stores the heated water for use when the sun is not available. The heat transfer medium might be water for a direct type or a frost-proof heat transfer fluid for an indirect type. The overall electricity savings, using a SWH instead of an electric geyser are calculated to be about 55% – 85%, depending on type, usage patterns and local solar potential (Ijumba, *et al.*, 2007).

Unglazed SWHs

98% of unglazed solar water heaters are primarily used to heat pools to extend the swimming season (Cawood, 2002; Holm, 2005). Unglazed SWHs typically do not have storage tanks (in the conventional sense at least, since a swimming pool could act as a storage tank) as the demand for hot water and sunshine are almost always concurrent. The advantage of this type is the considerably low investment cost (Sopian, *et al.,* 2004). This type is not investigated in this paper as it is not used for the same purpose as the other SWHs in the residential sector.

Glazed flat plate (FP) SWHs

This SWH type has the following subtypes: integral, direct, indirect, and split collector. In this paper, only indirect SWHs are considered for mid and high income groups, because almost all glazed SWHs in Gauteng are presently of the indirect type. An indirect close-coupled SWH has a heat exchanger in the storage tank and anti-freeze fluid in the solar collector, which makes it suitable for regions susceptible to frost, such as Gauteng. It is suitable to combine with a backup electricity element so that hot water is available at all times (Holm, 2005).

Evacuated tubes (ET) SWHs

Evacuated tubes are typically used for year-round water heating similar to glazed flat plate SWHs. The evacuated tubes are more expensive, but provide a greater efficiency since the heat losses are less. Evacuated tubes were not commercial in South Africa until 2005 (Holm, 2005). However, they are slowly becoming more prominent.

Low cost SWHs (solar hot dog and mobile)

These types of SWHs are low cost options which are not certified by the South African Bureau of Standards (SABS). A solar hot dog is a SWH with an external storage tank (generally 55 l), and is a push-through system. Although the output water temperature might be as high as 70°C, the average temperature is about 45°C, which is not sufficient for many households. Solar hot dog systems can be equipped with a back-up electrical system. However, even with electrical back-up it cannot assure a constant temperature of 65°C at the outlet. Therefore, solar hot dog system with electrical back-up is not investigated further in this paper.

The mobile SWH is a small water heater which does not require any plumbing. The water is fed manually to the 25 l storage and the mobile unit is placed under the sun. As the mobile SWH is not integrated with the household water system, this system is not considered convenient for many households.

4. Hot water demand and SWH potential in Gauteng

The water demand of a household depends on income group and access to water (Meyer and Tshimankinda, 1997a). Table 2 shows households by building type and income group and their corresponding access to water in Gauteng. The higher the income level of the household the greater access to water with high income households averaging 88% access and poor income households have only 56% access. Similarly, the less permanent building types such as informal dwellings are characterized with less access to water, where access to water does not exceed 35% irrespective of income level.

Meyer and Tshimankinda (1997a) analyzed the hot water consumption in Johannesburg for different building types with water access and pointed out a negative correlation between building density and household income. The result shows hot water demands of 25.4, 59.3 and 91.4 litres per capita and day for high, medium and low building densities respectively (Meyer and Tshimankinda, 1997a). Households without access to water typically consume around 2.7 litres per capita and day (Meyer and Tshimankinda, 1997b).

These figures have been allocated to the low, medium and high income groups respectively, taking into consideration the share of households with direct access to water, due to the identified correlation of income and density of living area (Meyer, 2009). The total average specific water demand is calculated as 32.5 l/cap/day, which takes the number of people given access to water as well as average water consumption per building type and income group into consideration. The average water consumption of households with water access is about 46 l/cap/day which is comparable to the value of 50 l/cap/day documented by Jacobs, *et al.*, (2004) and Basson (1983). Table 3 summarizes the results.

To determine the energy demand for water heating the formula below was applied:

$$Q = mc_p \Delta T \quad (1)$$

Where Q is the required energy to heat the water, m is the mass of heated water, c_p is the specific heat of water (4.183 kJ/kg/K), and ΔT is the temperature

Table 2: Households with access to water (%)
Calculations based on StatsSA (2005b)

Type of main dwelling	*Poor income*	*Low income*	*Middle income*	*High income*	*Total*
House on separate stand	76	76	91	93	82
Flat in block of flats	95	95	98	98	96
Townhouse	92	93	97	98	96
Dwelling in backyard	49	48	69	73	53
Room on shared property	50	48	70	69	52
Informal backyard dwelling	29	28	35	33	29
Informal dwelling in informal settlement	10	10	15	14	10
Traditional dwelling	34	36	58	54	40
Workers' hostel	74	67	60	52	68
Average	56	61	87	88	69

Table 3: Hot water demand in Gauteng
IER (2011)

	Poor	*Low income*	*Middle income*	*High income*	*Total*
Range of income (R/HH/a)	1–9 600	9 601–76 800	76 801–307 200	307 201+	
Number of people (cap)	1 849 558	4 871 484	2 428 964	1 301 707	10 451 713
Average specific hot water demand (l/cap/d)	15.3	16.5	51.9	80.9	32.5 (av.)
Total warm water consump -tion (Gl/a)	10.3	29.3	46.0	38.4	124.1

difference. Thus, the required energy to heat 1 litre of water is 199.5 kJ. For lower income households, the average temperature is documented as averaging 50°C for outlet temperature, also for solar water heaters (City of Cape Town, n.d.).

Meyer and Tshimankinda (1997) measured an average inlet temperature of 17.3°C in Johannesburg. The typical thermostat setting of an electric geyser in Gauteng is 65.0°C. The results of the calculations are shown in Table 4. The total energy demand for water heating in Gauteng then totals 8 777 GWh/a or 31.5 PJ/a. The electricity portion of this demand totals 7 039 GWh/a or 25.3 PJ/a. This value is cross checked with a top-down approach by taking the total electricity consumption of 61 997 GWh/a in Gauteng in 2007 (StatsSA, 2009) with a residential share of approximately 25% (IER, 2011) and a share of electricity for warm water consumption in the household sector of approximately 40% (City Power, 2009) which estimates a total of 6 200 GWh/a and deviates less than 12% from the calculated value.

For the technical potential of SWHs of the residential sector in Gauteng, the roofs are assumed to be utilized exclusively for SWHs and not for photovoltaic. The potential is calculated using Equation 2:

$$P_S^{Hotwater} = P_s^{roof}.\eta_{SWH} = A_R^{available} I_S \eta_{SWH}$$

$$= A_R^{total} F_a^{roof} I_S \eta_{SWH} \qquad (2)$$

Where, $P_S^{Hotwater}$ is the potential of hot water obtained from solar energy (PJ/a), P_s^{roof} is the total potential of solar radiation on residential building roofs (PJ/a), η_{SWH} is the efficiency of a SWH, I_S is the available solar irradiation for the Gauteng region (7 700 MJ/m^2/a), F_a^{roof} is the availability factor for SWHs on residential building roofs, is the total residential roof area for SWH in Gauteng (km^2) and $A_R^{available}$ is the total residential roof area of households suitable for SWHs in Gauteng (km^2).

The total residential roof area (A_R^{total}) is calculated for each income group and building type. The detailed floor and roof areas for different building types and other details are presented in Table 5. The identified main building types are: house on separate stand, flats, semi-detached house, dwelling in backyard (StatsSA, 2007).

All required variables to calculate the SWH potential in Gauteng are listed in Table 6. The availability factor (F_a^{roof}) for solar energy on residential building roofs considers the shading, obstacles on the roof (e.g. chimneys) and other constraints. This factor is fairly uncertain, which depends on several aspects such as climate and vegetation (Denholm and Margolis, 2008). The availability factors for residential buildings are given as 15.5% for German conditions (Kaltschmitt, 1990) and between 22 and 27% for US conditions (Paidipati, *et al.,* 2008). Due to lack of data for South African conditions, it is conservatively assumed that the availability factor for South Africa is the lowest available in the literature (i.e. 15.5%).

The results show that it is technically possible to obtain 136.3 PJ/of solar energy to heat water in Gauteng. This amount of energy could heat approximately $683 \cdot 10^9$ litres of water from 17.3°C (input cold water temperature) to 65.0°C (required output water temperature) (Meyer & Tshimankinda, 1997a).

The calculated technical potential of SWHs ($683 \cdot 10^9$ litres of hot water) is more than five times the calculated hot water demand ($124 \cdot 10^9$ l/a) which means that the hot water demand in Gauteng could be satisfied with SWHs. Therefore, the solar energy potential is sufficient to meet the hot water demand in Gauteng. As the calculation is based on a highly uncertain availability factor, the technical potential may vary considerably with different availability factors. However, even the conservative availability factor taken (lowest available in the literature) results in enough hot water for Gauteng Province, which shows the robustness of the result.

Table 4: Final energy consumption for hot water demand in Gauteng

Own calculations

	Unit	*Poor*	*Low income*	*Middle income*	*High income*	*Total*
Tin	°C	17.3	17.3	17.3	17.3	-
Tout	°C	50	50	65	65	-
ΔT	°C	32.7	32.7	47.7	47.7	-
Av. annual specific final energydemand for hot water	GJ/a/HH	3.3	4.3	19.3	26.9	13.5 (av.)
Number of households	HH	705 224	1 430 872	651 292	388 191	3 175 579
Total final energy demand for hot water (inc. electricity)	PJ/a GWh/a	2.3 650	6.2 1 725	12.6 3 496	10.5 2 906	31.6 8 777
Total electricity demand for hot water	PJ/a GWh/a	0.9 262	3.5 973	11.5 3 193	9.4 2 611	25.3 7 039

Table 5: Calculation of the residential building roof area in Gauteng region suitable for SWHs

IBP (2009) and own calculations

Dwelling type	*Roof type*	*Floor area m^2/HH*	*Roof area m^2/HH*	*Roof slope degree*	*% of HH*	*No. of HH*	*Roof area km^2*
			High income group				
Separate house	Hipped	240	171	30	8.76	278 129	47.48
Flat	Flat	82	27	0	0.81	25 880	0.71
Semi-detached house	Hipped	200	231	30	1.43	45 258	10.45
Other*	-	-	-		1.23	38 924	0.00
			Mid income group				
Separate house	Pitched	140	161	30	13.63	432 750	69.82
Flat	Flat	82	21	0	2.34	74 335	1.52
Semi-detached house	Hipped	110	110	30	1.98	62 821	6.91
Other*	-	-	-		2.56	81 386	0.00
			Low income group				
Separate house	Pitched	50	58	30	22.02	699 119	40.37
Flat	Flat	82	10		2.73	86 655	0.89
Semi-detached house	Pitched	45	52	30	0.88	27 853	1.45
Other*	-	-	-		19.44	617 245	0.00
			Poor income group				
Separate house	Pitched	28	30.89	25	10.22	324 533	10.02
Flat	Flat	82	8.20		1.08	34 441	0.28
Semi-detached house	Pitched	28	30.89	25	0.44	14 064	0.43
Other*	-	-	-		10.46	332 186	0.00
Total	**-**	**-**	**-**		**100.00**	**3 175 579**	**190.34**

a) All formal settlements are assumed to have access to water
b) Houses that are not suitable for SWHs (e.g. informal settlements)

Table 6: Parameters for technical solar potential calculation

Parameter	*Value*	*Unit*	*Source*
F_a^{roof}	0.155	-	Kaltschmitt, 1990
I_S	7 700	MJ/m^2/a	Holm, 2005
ηSWH	0.60	-	Own calculation*
A_R^{total}	190.34	km^2	Table 3
$A_R^{available}$	29.50	km^2	Own calculation
P_s^{roof}	227.2	PJ/a	Own calculation
$P_S^{Hotwater}$	136.3	PJ/a	Own calculation

* To supply hot water throughout the day, electrical heating is necessary as a backup power. This subject is investigated in section 5.

5. Demand side management potential of SWHs

Hot water demand varies over time of day, week and season. The water consumption in Gauteng is highest in winter and lowest in summer (Meyer and Tshimankinda, 1997a).

The hot water demand is calculated for 4 seasons and 9 different daily time periods. These particular 'time slices' can be identified as representative of fluctuation characteristics in the South African grid, including the morning and evening peaks. This makes it possible to calculate the actual DSM potential for shifting demands as well as the potential for reducing the peak demand.

Hot water demand for a typical working day in summer and in winter is presented in Figure 4. The demand curve has two peaks with the former being between 6am and 9am and the latter being between 5pm and 7pm. The first peak is about 40% higher than the second one.

The resulting electricity consumption of an electric geyser and that of a SWH FP in a mid-income household is presented in Figure 5 for an average winter and summer day. The calculated electricity consumption of SWHs is based on measurements by SESSA and Eskom (2008). As a result of SWH utilisation, the peak electricity consumption reduces by 70% between 6 am and 9 am for a summer day

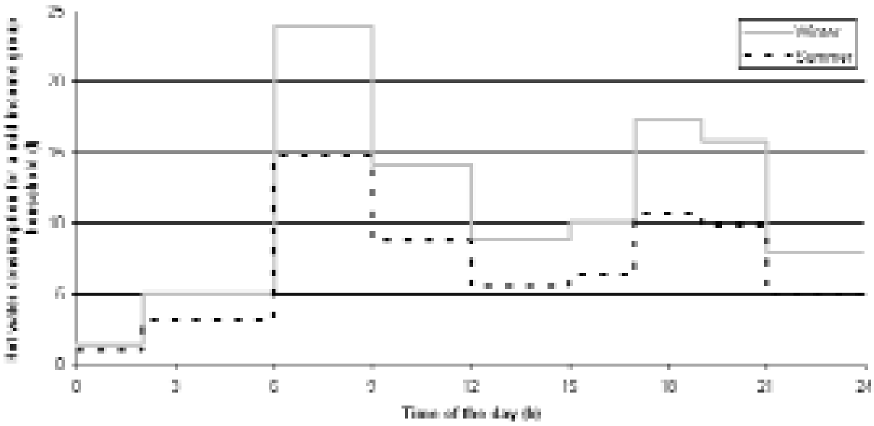

Figure 4: Daily hot water consumption for a mid-income household for different seasons

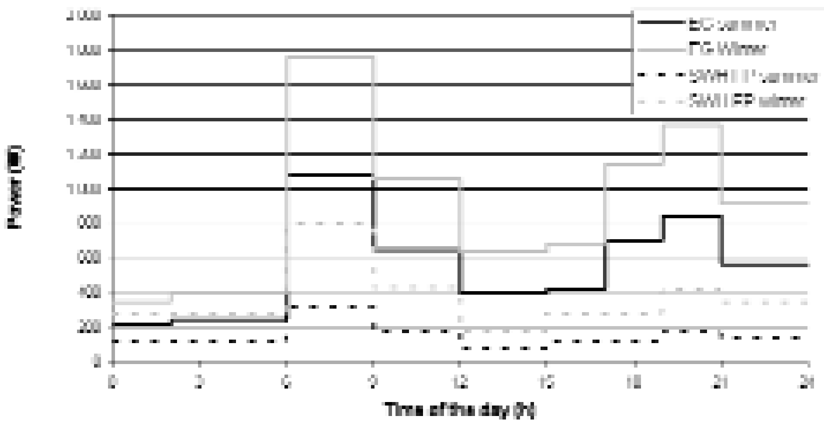

Figure 5: Electric power required for a mid-income household for different seasons and water heaters

and by about 55% for a winter day. Thus, SWHs have significant potential to reduce the electricity consumption in households, especially during peak periods.

6. Economic analysis of water heating technologies

In this section different water heating technologies are compared in terms of their costs. The analysed water heating technologies and annual hot water demands for the different income groups are presented in Table 7. Based on the survey results of StatsSA (2007), it can be stated that inconvenient water heating technologies (such as paraffin, coal or wood stoves) are not significantly utilized by the mid and high income groups. Furthermore, it is assumed that SWHs with evacuated tubes are too expensive for the poor income group. The selection for the analysis was also made to focus the calculation on the most suitable options.

Technology specific data for economics and energy consumption

Investment costs (including the profit margin, installation and VAT), operating and maintenance (O&M) costs, and the energy consumption of different technologies are presented in Table 8. Annual O&M costs are calculated as 2% of the investment costs excluding the installation costs. The electricity and fuel consumption are calculated based on the hot water demands for the different income groups and technology specific efficiencies.

The paraffin stove, which is commonly used by the poor and low income groups, has one of the lowest investment costs. However, paraffin is considered to be a dangerous fuel due to fire risks and poisoning through internal consumption, particularly by small children (Lloyd, 2009). Other technologies costing less than R200 for the poor and low income groups are the kettle, coal and wood stoves. The electric geyser, flat plate SWHs, SWH hot dogs without backup and LPG stoves have relatively higher investment costs between R2 300 and R3 300. Mobile SWHs have investment costs of around R1 100.

Low cost SWHs (e.g. mobile SWH and hot dog SWH without backup) use only solar energy, which have the disadvantage that hot water is only available when the sun is shining. Kettles are assumed to have an efficiency of 100%. Thus, the electrical

Table 7: Analysed water heating technologies for different income groups
(StatsSA, 2007; Eighty20, 2008; own calculations)

Income group and annual hot water demand	*Water heating technology*	*Frequency of use in analysed technologies in 2007*
High (110 091 l/HH/a)	Electric geyser	84%
	SWH FP (certified)	4%
	SWH ET (certified)	0%
	Heat pump (air)	0%
	LPG stove	10%
Mid (82 249 l/HH/a)	Electric geyser	78%
	SWH FP (certified)	2%
	SWH ET (certified)	0%
	Heat pump (air)	0%
	LPG stove	9%
Low (52 618 l/HH/a)	Electric geyser	24%
	SWH (Hot dog w/o electricity backup)	1%
	SWH FP (certified)	0%
	Kettle	7%
	Paraffin stove	25%
	Coal stove	11%
	Wood (commercial) stove	4%
	LPG stove	0%
Poor (24 105 l/HH/a)	Electric geyser	61%
	SWH (mobile)	0%
	SWH (Hot dog w/o electricity backup)	0%
	SWH FP (certified)	0%
	Kettle	9%
	Paraffin stove	40%
	Coal stove	13%
	Wood (commercial) stove	0%

energy input is the same as the energy requirement to heat the water. The LPG stove and the electric geyser have efficiencies of 88% and 70% respectively due to losses during storage, which increases the energy consumption. The other technologies, like the paraffin stove, coal stoves and firewood for water heating have efficiencies between 25% and 55%, which result in correspondingly higher fuel consumption.

The characteristics of mid and high income level heating technologies are similar. However, the high income group requires a higher water heating capacity and has a higher hot water demand per capita. The LPG water geyser alternative has the lowest investment costs for both income groups. LPG is followed by the electric geyser, the most common technology in South African households. The investment costs of the flat plate and evacuated tube SWHs are more than double compared to the electric geyser. The heat pump investment costs are even higher than those of SWHs, which likely contributes to the low frequency of use. However, the comparison of water heating technologies for mid and high income groups shows that the heat pump has the lowest energy consumption followed by SWHs. LPG water heater and electric geysers have the highest energy consumption.

The fuel prices in South Africa for different years are presented in Table 9. All the presented prices include 14% VAT except for paraffin, which is not taxed in South Africa (Mncube, 2006). The prices used for the calculations are derived from sources in 2009.

The electricity price has been historically extremely low in South Africa, although it has increased in recent years; it still remains much lower than other countries. Further increase in the electricity price is determined by the National Energy Regulator of South Africa (NERSA) in February 2010 for the time period until 2012/13 (NERSA, 2010). The traditionally low electricity price might explain the high dependency of the energy system in South Africa on electricity.

There is a considerable difference between bulk production prices and household prices for paraffin and coal. This difference includes transport and distribution costs and is assumed to be constant for all years. The paraffin price doubled in 2008 compared to 2001, but then it decreased in 2009 almost to 2001 levels. The price increase in 2008 corresponds to the worldwide oil price increase in 2008.

Compared to coal, the wood prices are lower per kg but higher per GJ. This is due to the fact that wood has a significantly lower energy density than

Table 8: Costs and energy consumption of different water heating technologies

Sources: Alt-e Technologies 2009, Bosch 2009, Cawood and Simelane 2004, DOE 2009, Eskom 2009, FHES 2009, Green 2004, Home Comfort 2009, Hudu 2009, ITS Solar 2009, Oorja 2009, Solar Heat 2009, Spalding-Fecher 2003, Stiebel Eltron 2009, Thorne 1996, UJ 2009, UNISOL 2009, Waterlite 2009 and own assumptions and calculations

Income group	*Water heating technology*	*Investment costs (R)*	*O&M costs (R/a)*	*Electricity consumption (GJ/a/HH)*	*Fuel consumption (GJ/a/HH)*
High	Electric geyser	8 721	152	38.5	0
	SWH (flat plate)	19 672	357	15.4	0
	SWH (evacuated tube)	21 063	340	14.2	0
	Heat pump (air)	31 273	576	13.7	0
	LPG geyser	7 444	123	0	30.6
Mid	Electric geyser	7 005	117	23.4	0.0
	SWH (flat plate)	15 130	244	9.4	0.0
	SWH (evacuated tube)	18 490	309	8.7	0.0
	Heat pump (air)	18 655	333	8.4	0.0
	LPG geyser	5 762	90	0.0	22.0
Low	Electric geyser	3 322	55	6.2	0.0
	SWH (Hot dog w/o elec. backup)	2 318	46	0.0	0.0
	SWH (flat plate)	15 130	244	2.5	0.0
	Kettle	168	3	4.3	0.0
	Paraffin stove	26	0	0.0	7.9
	Coal stove	0	0	0.0	10.9
	Wood stove	0	0	0.0	17.4
	LPG stove	4 202	60	0.0	4.9
Poor	Electric geyser	3 322	55	4.7	0.0
	SWH (mobile)	1 136	23	0.0	0.0
	SWH (Hot dog w/o elec. backup)	2 318	46	0.0	0.0
	SWH (Flat plate)	15 130	244	1.9	0.0
	Kettle	168	3	3.3	0.0
	Paraffin stove	26	0	0.0	6.0
	Coal stove	0	0	0.0	8.3
	Wood stove	0	0	0.0	13.3

Table 9: Average energy carrier prices in Gauteng

Fuel	*Energy density*[f]	*Location*	*Unit*	*2001*	*2005*	*2008*	*2009*
LPG[a]	49.35 MJ/kg	Household	R/GJ	168.68	213.03	453.19	352.75
			R/kg	8.32	10.51	22.37	17.41
Paraffin[b]	37.0 MJ/l	At gate	R/GJ	90.44	113.97	183.39	107.46
			R/l	3.35	4.22	6.79	3.98
		Household	R/GJ	127.96	151.49	220.91	144.98
			R/l	4.73	5.61	8.17	5.36
Electricity[c]	-	Household	R/GJ	60.47	120.51	156.88	196.4
			Rc/kWh	21.77	43.38	56.48	70.72
Coal[d]	24.3 MJ/kg	Power plant	R/GJ	4.09	4.44	4.04	4.04
			R/t	99.51	107.88	98.08	98.08
		Household	R/GJ	41.17	41.52	41.11	41.11
			R/t	1 000.52	1 008.90	999.09	999.09
Wood[e]	15.0 MJ/kg	Household	R/GJ	44.47	44.84	44.40	44.40
			R/t	667.02	672.60	666.06	666.06

Notes:

a) LPG: Liquefied petroleum gas price values include 14% VAT. The sources for the years 2001, 2005, 2008 and 2009 are from NER (2001), Ekurhuleni (2005), Sabinet (2008) and Shell (2009) respectively.

b) Paraffin price values exclude VAT since paraffin utilization is not taxed in South Africa (Mncube, 2006). Paraffin at gate refers to the price at refinery output and does not include the transport and distribution costs. All the 'at gate' prices are taken from SAPIA (2009). The household paraffin price is taken for the year 2005 from Mncube (2006). The distribution and transport costs are taken as constant and other paraffin household prices are found with this approach.

c) The presented electricity prices include distribution of electricity and 14% VAT. The sources for the years 2001, 2005 and 2008 are from NER (2001), DME (2005) and Tshwane (2008) respectively. The electricity prices in 2009 are calculated according to NERSA (2010).

d) Coal prices for power plant and households include 14% VAT. Coal price for power plants for the years 2001, 2005 and 2008 are from NER (2001), DME (2005) and Johannesburg (2008) respectively. Coal price for households differs considerably from the coal price for power plants. The household coal price is taken for the year 2005 from Mncube (2006). The distribution and transport costs are taken constant and other coal household prices are found with this method. The prices for the year 2009 is taken same as 2008 both for power plant and household coal.

e) The household wood price is taken for the year 2005 from Mncube (2006). Wood prices for other years are calculated with the help of household coal prices. It is assumed that the wood and coal prices are coupled to each other. These numbers are presented in italic.

f) The energy densities are taken from DME (2005) except for wood taken from FNR (2007)

coal. It should be noted that wood can be collected at no cost. However, there is little information available for Gauteng on the share of commercial and collected wood. The collected wood share is expected to be low since Gauteng is a more urbanised area.

Annual expenditure on water heating

The annual expenditure on water heating includes the annualised investment, O&M, and the electricity and fuel costs. Assuming a lifetime of 15 years for all technologies and a discount rate of 8.0% (Winkler, *et al.,* 2002), the annual hot water expenditure for high and mid income households is presented in Figure 6 and Figure 7 respectively for different water heating technologies.

The results reveal that the high and mid income groups have similar expenditure characteristics. However, the high income group has a higher hot water demand. For both income groups, the LPG water heater is by far the most expensive technology to use due to the high fuel costs. A notable result is that the most common technology used in South Africa, i.e. the electric geyser, is not the cheapest technology. Although the electric geyser has one of the lowest investment costs, it has a relatively high total cost. The highest share of the annual costs for the electric geyser is due to electricity consumption. This share will be even more significant when the electricity price increases in the future as decided by NERSA (2010).

The annual hot water expenditure for low income households is presented in Figure 8. Usage of paraffin results in one of the most expensive water heating alternatives, which is commonly used by the low income group. One of the explanations for this might be that it has very low investment cost. Truran (2009) mentions some of the factors that influence paraffin use by low income households as 'portability, affordability, availability, lack of access to alternatives such as electricity, and low set-up costs'. On the other hand, the price of paraffin has recently risen drastically, which might have an effect of switching to another fuel in future. The cheapest water heating technology is the coal stove, which has the lowest investment costs and a relatively cheap fuel cost. However, one should note that coal poses a health threat when used indoors. Water heating using commercial wood or a kettle has similar costs of about 800 R/a. On the other hand, a household that collects (non-commercial) wood has the lowest expenditure of all, but requires a significant amount of time devoted to collecting.

Utilization of certified flat plate SWHs for water heating have significantly high costs. A non-certified SWH (hot dog) has the lowest costs. However, one should bear in mind that this technology does not guarantee a continual hot water supply. Using

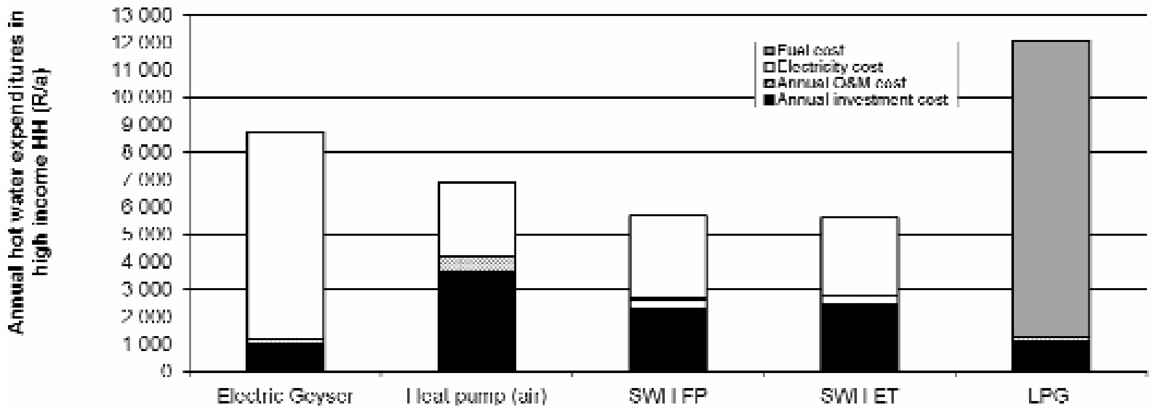

Figure 6: The annual expenditure for water heating in high income group

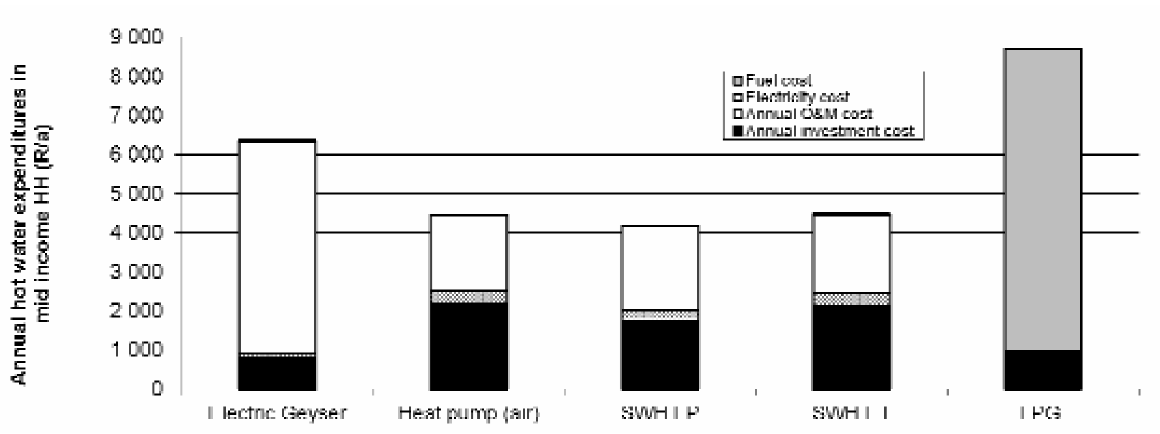

Figure 7: The annual expenditure for water heating in mid income group

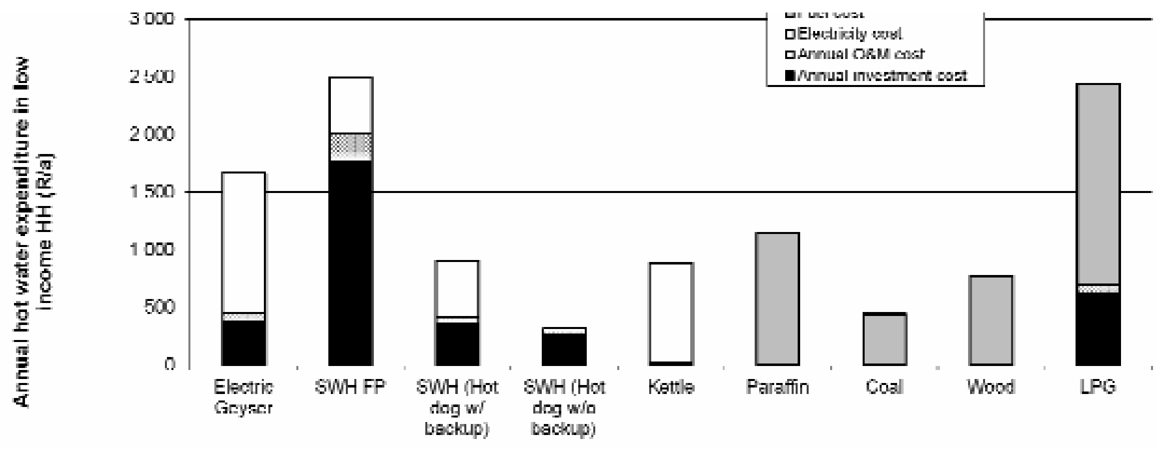

Figure 8: The annual expenditures for water heating in low income household

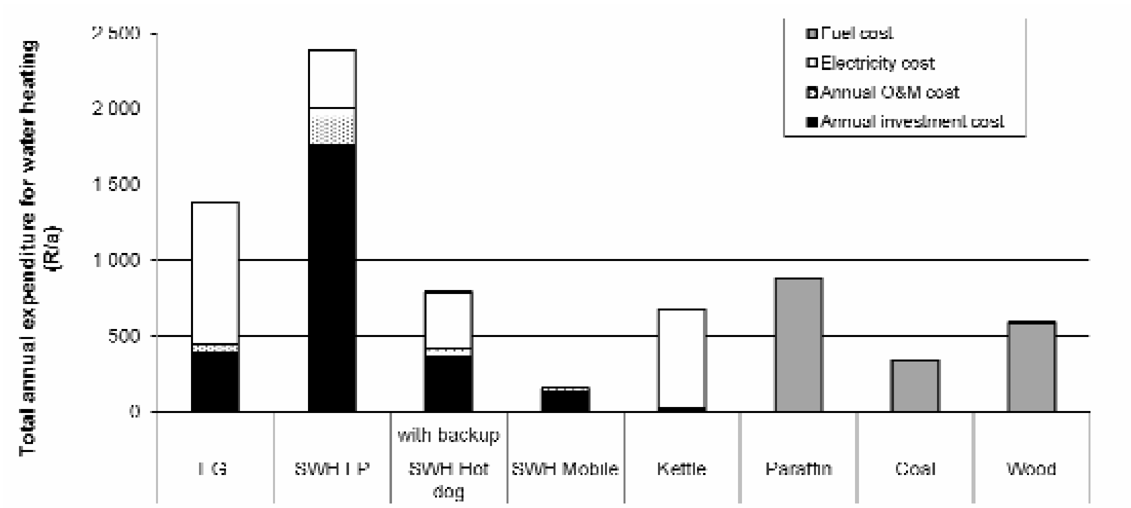

Figure 9: The annual expenditures for water heating in poor household

wood or a kettle is also cheaper than the reference technology (electric geyser).

Aside for the lower hot water demand, the poor income group has a similar expenditure pattern (Figure 9) as the low income group. Hence, the overall cost decreases correspondingly.

The average share of expenditure on water heating in each income group is shown in Table 10 for the average income. The calculation is based on the distribution of fuels and technologies statistically used for water heating by each income group (Table 1) and the energy carrier prices (Table 9). The result shows the average share of water heating expenditure increases from 0.42% for high income groups

Table 10: Average share of expenditure for water heating in average income group

Average expenditure for water heating	R/a	1 268	1 508	6 653	8 374
Average income	R/a	4 831	32 383	163 070	806 279
Share of income spent on water heating	%	10.5	1.9	1.6	0.4
Share of income spent on energy*	%	40.9	7.3	3.5	1.0

* Energy includes all end-uses: water heating, space heating, lighting, cooking and appliances

to more than 10% for the income group 'poor'. When comparing how energy expenditure on the whole for all end-uses, the average increases from 1% in high income households to over 40% in poor households. This trend is consistent with the characteristics of the initial findings shown in Figure 1 from the GCRO study and shows the manifestation of the financial burden to consume energy.

Payback period

The electric geyser is selected as the reference technology as it is the most common technology in South Africa. The payback period for different water heating technologies was calculated separately for different income groups.

Figure 10 presents the cumulative expenditure for different technologies utilized by the high income group. The payback period of a flat plate SWH against an electric geyser is between 3 and 4 years for the high income group. The payback period of a flat plate SWH for the mid income group is about 4 years. Karekezi (2002) also found a payback period of 3-5 years for SWHs in Africa. Evacuated tubes have a payback period of 3 and 6 years for high and mid income respectively. This technology is worthwhile in the high income group over the other income groups because it saves more electricity than the flat plate SWH, however, in the other income groups the additional investment costs result in slightly longer payback period. The heat pump requires a much longer payback period of between 6 and 8 years. Due to the higher operating costs of the LPG geyser, the investment in this technology does not pay for itself when compared with electric geyser.

The SWH payback period characteristics for the poor and low income groups are considerably longer when compared as a replacement for an electric geyser (15a) than those for mid and high income groups. This is due to the significant lower hot water consumption. The hot water demand of poor and low income groups is 6% and 30% of the high income hot water demand respectively. However, heating water with wood, coal or a kettle would have considerably lower costs compared to the electric geyser. The disadvantage of using wood, coal or kettle is their low comfort level and the adverse health effects due to indoor air pollution from burning wood or coal.

The electricity price is the most significant factor influencing the payback period. The payback period for a flat plate SWH decreases by 2-3 years with the expected electricity price of 124 Rc/kWh in 2012 for high and mid income groups. The payback period for the evacuated tube SWH also decreases by 2-4 years. The electricity price increase also has a significant effect on the payback periods for the poor and low income groups. Paraffin and coal use is expected to increase in relation to the electricity price.

7. Greenhouse gas emissions of water heating technologies

Both the direct and indirect greenhouse gas (GHG) emissions from various water heating technologies are investigated in this section. The direct emissions only include the combustion of fuel while the indirect emissions only include the emissions responsi-

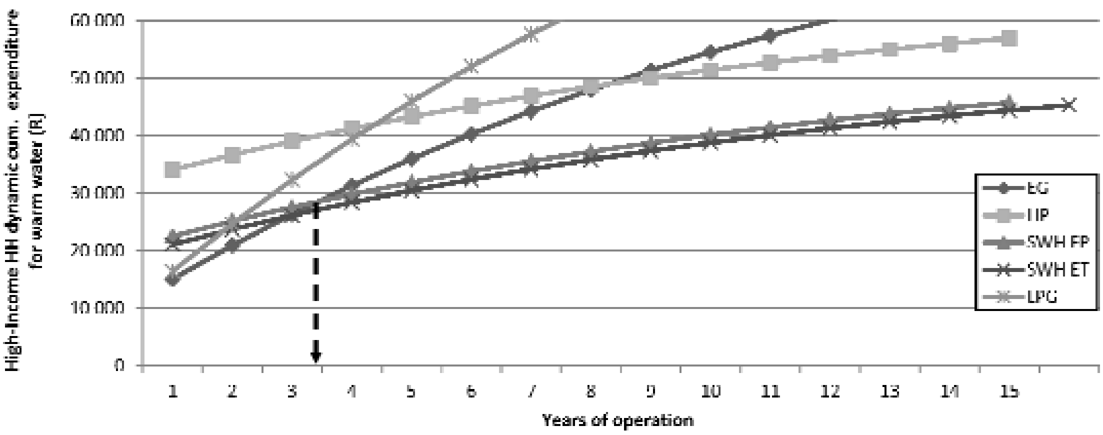

Figure 10: Dynamic cumulative expenditures for water heating by high income group

ble for the fuel/electricity production. The electricity transmission losses in the grid (about 8%) are also considered in this study (Eskom, 2008).

Although it is difficult to get reliable data for the transportation of fuels (e.g. distances, transport load factors etc), the preliminary calculations show that the GHG emissions of fuel transportation are not significant compared to the direct emissions. For example, to transport coal 100 kilometres with a freight train results in 0.09 CO_{2eq}/GJ of emissions (GEMIS, 2009), which is less than 0.1% of the direct emissions. Thus, the transport emissions for liquid and solid fuels are not considered in this paper.

Furthermore, the GHG emissions resulting from the production of the water heaters (e.g. materials, manufacturing, and transport) are not considered. The existing literature shows that the indirect GHG emissions due to SWH production are much less than the indirect emissions due to SWH operation (Asif and Muneer, 2006; Kalogirou, 2004). Asif and Muneer (2006) argue that SWH production may have a carbon emission of about 29 kg, which corresponds to 106 kg of carbon dioxide. As the SWH production emissions are about 0.4% of the indirect emissions from SWH operation, they are not considered further in this study.

The annual CO_{2eq} emissions for the different technologies are presented in Figure 11 and Figure 12 for mid and low income groups respectively. The results for the high and poor income groups are not presented as the characteristics are quite similar to that of the mid and low income groups respectively.

The results reveal that the electric geyser as the reference technology has the highest annual GHG emissions for all income groups. For the mid and high income group, the LPG heater has the lowest GHG emissions followed by the heat pump, ET SWH and FP SWH. The high indirect GHG emissions for the heat pump and the SWH are due to the high national dependency on coal to produce electricity.

As the emissions from the production of SWHs are not included in the analysis, the results for the

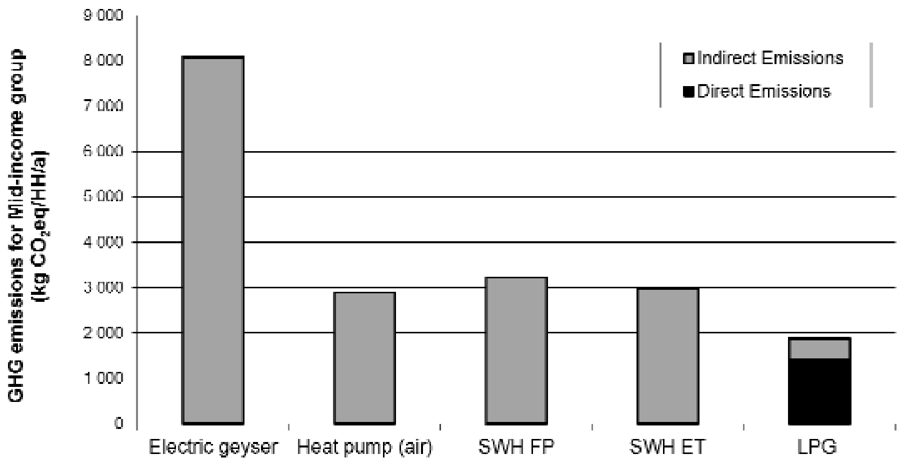

Figure 11: Annual CO2eq emissions of water heating systems for mid income group household

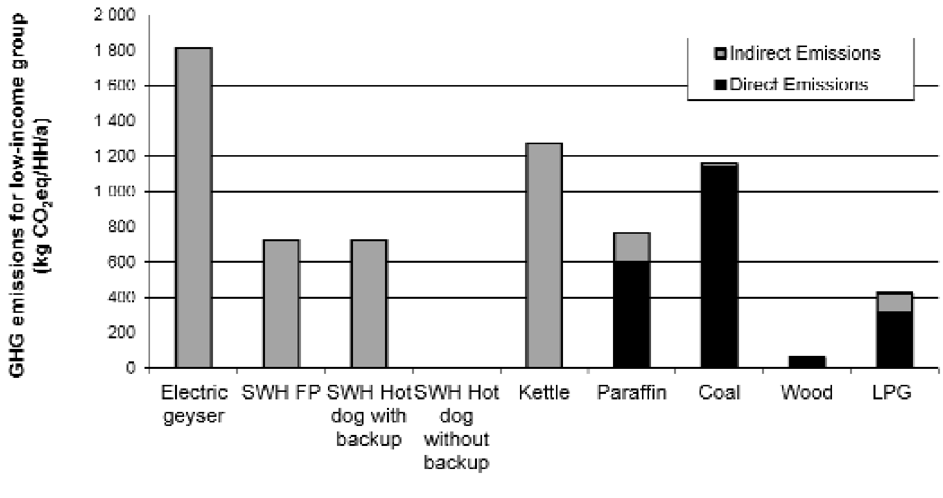

Figure 12: Annual CO2eq emissions of water heating systems for low income group household

low and poor income groups show that the hot dog SWH without electricity backup has no GHG emissions. However, as discussed previously, these emissions are minimal.

The combustion of wood also results in low GHG emissions due to the fact that the direct CO_2 emissions are considered as biogenic and not counted in the balance since they are not increasing the carbon dioxide content of the atmosphere. Therefore, only the direct methane emissions produced from burning wood have to be included in the calculation. Other low cost water heating technologies (e.g. kettle, paraffin and coal stoves), have about 30% less GHG emissions than the electric geyser. The use of a SWH FP or LPG stove show a significant emission reduction of 60% to 75% compared to electric geyser utilisation.

8. GHG abatement costs of water heating technologies

The GHG abatement costs are calculated with the following formula (Diekmann, *et al.,* 1998):

$$C_i^{GHG} = \frac{C_i - C_{REF}}{E_{REF} - E_i} \quad (3)$$

Where C_i^{GHG} is the GHG emissions abatement cost for a technology *i*, C_i is the annual cost of a technology, *i* for hot water supply in R/a, C_{REF} is the annual cost of reference technology for hot water supply in R/a, E_{REF} are the annual GHG emissions of the reference technology in t CO_{2eq}/a, and are the annual GHG emissions of a technology *i* in t CO_{2eq}/a.

The GHG abatement costs for mid and high income households are presented in Figure 13. The results are not shown for low income and poor group since the electric geyser as the reference technology might not be used predominantly by these income groups (cf. Table 7). The results show that for the mid and high income groups, the GHG emission abatement costs are negative (between -350 and -450 R/t CO_{2eq}) for SWHs. Negative abatement costs mean that the abatement of GHG emissions would bring cost savings as a result of the lower costs and emissions associated with SWHs in comparison to the reference technology. The abatement costs for heat pumps are between -250 and -350 R/t CO_{2eq}. LPG stoves/water heaters have the highest abatement costs of just below 400 R/t CO_{2eq}. The expected electricity tariff increase in South Africa in future years would make the already negative abatement costs even lower.

The results show that the GHG emission saving potential of different technologies is between 4 and 9 t CO_{2eq}/a/HH. Different technologies have only slightly different GHG saving potentials as the annual emissions are quite similar except for LPG water heater (Figure 10).

9. Conclusion

In this paper, SWH characteristics were evaluated for the energy system of Gauteng with respect to hot water demand, peak electricity demand reduction potential, costs, GHG emissions, and GHG abatement costs. The analysis was performed for different income groups due to the large difference in energy demand and technologies used by the different income groups in Gauteng. The demand for hot water was analysed based on the income structure of the population. The result shows that a total of 124 million cubic metres of warm water were used in Gauteng in 2007.

The technical potential of SWHs was shown to be at least five times higher than the hot water demand. Although there is a high uncertainty in estimating warm water consumption due to lack of data availability, it can still be concluded that the solar potential is sufficient to meet the hot water demand in the province.

The utilisation of SWHs helps to reduce the peak electricity demand of a household by up to 70%. This reduction could be a significant contribu-

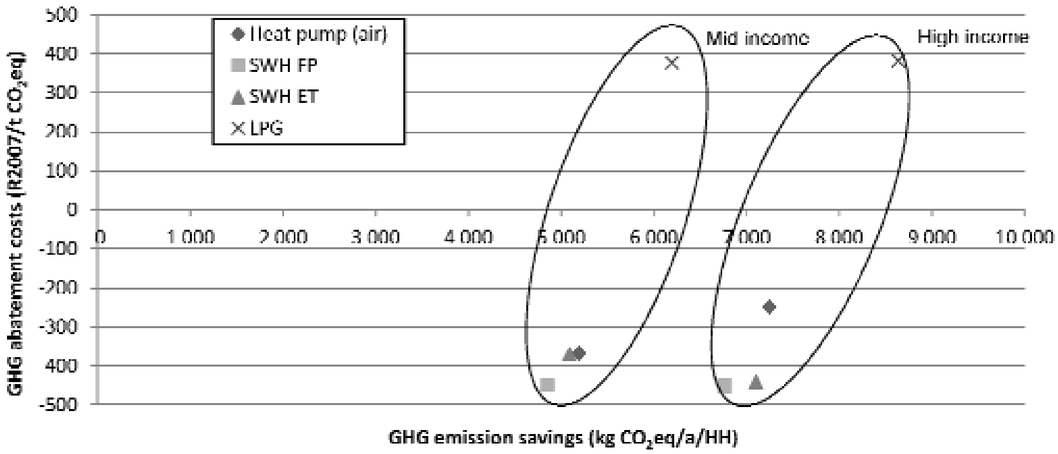

Figure 13: Comparison of different water heating technologies for their GHG saving potential and costs compared to electric geyser

tion to demand side management in Gauteng. Using an economic analysis, SWHs prove to be an appropriate technology for water heating in Gauteng since their use results in the lowest annual expenditure and their payback period is between 3 and 4 years for the mid and high income groups. The payback periods will be even shorter with the expected electricity tariff increases. The annual expenditure in the poor and low income groups is already much lower when low cost water heating technologies are coupled with low cost fuels, such as coal and wood. However, health degradation effects and/or lower comfort levels of these technologies should also be considered.

The environmental effects of different water heating technologies were also investigated in this paper regarding their GHG emissions. This analysis indicated that the reference technology (i.e. electric geyser) has the highest GHG emissions and that SWHs could reduce GHG emissions by up to 60%. The GHG abatement cost calculation shows that SWHs are the most cost effective technology for mid and high income groups to mitigate GHG emissions.

The study also shows that the utilisation of SWHs is suitable for mid and high income groups with respect to economic, environmental and demand side management aspects. One burden is the higher investment costs, which have a payback period of up to 4 years. To overcome the burden of high investment costs, a financing scheme or financial incentives would assist in increasing the uptake of SWHs. On the other hand, the low and poor income groups already use low cost technologies and it is more difficult for SWHs to penetrate into this market. For these groups the motivation to switch to SWHs is not the energy or cost savings, but to provide a decent water heating system, for which incentives are equally required.

It is recommended that further research shall be focused on estimating water and energy consumption especially in lower income households.

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