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Reducing the City's Carbon Footprint: An Investigation of Solar Water Heaters and the Rebound Effect in Cape Town Social Housing

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Abstract: Solar Water Heaters (SWHs) can have short greenhouse gas emission payback periods as shown in various life cycle studies. Thus, it is believed that replacing electric geysers with SWHs will reduce a household's carbon footprint. This conclusion, however, does not take the rebound effect into account, where money saved from spending less on electricity for water heating, is spent eventually, either on more electricity, or on other goods and services with an associated carbon footprint. Previous studies conducted on the low-income areas of Kuyasa (Cape Town) and Zanemvula (Nelson Mandela Bay) confirm that for this income bracket the suppressed demand for electricity is so great that the installation of SWHs fails to produce a significant reduction in electricity consumption, confirming the "suppressed demand hypothesis" which provides an accepted basis to classify such projects as sustainable development cases worthy of receiving climate finance. An optimistic assumption about the future of South African cities must however recognize significant upward mobility, which leads to the question of whether SWHs result in a significant decrease in the carbon footprint of households in higher income brackets. The "gap" housing market consists of households that earn ZAR 3500 - 7500 per month: they earn too much to qualify for a Government housing subsidy, but most cannot afford housing in the private sector. Recent social housing projects, providing rental stock for this market, including Steenvilla and Drommedaris in Cape Town, have included SWHs. This work aims to answer the following questions: Does the installation of SWHs in gap social housing schemes result in these households consuming less electricity than households of the same income using electric geysers? If so, what do these households spend this saved money on and how does the carbon footprint of these new goods and services compare? The methodology includes surveys to investigate the electricity consumption and spending habits between Cape Town social housing schemes that use solar water heaters and those that have conventional geysers. Quantitative data on electricity purchases are also used. Preliminary results suggest that for households earning an average of ZAR 6 000 per month, electricity consumption is reduced by approximately 140 kWh/month when SWHs are installed. Survey data suggests that saved money is spent on a wide range of goods and services. The household carbon footprint is however reduced as these goods and services have a lower carbon intensity (at ~ 0.13 kg CO_{2eq}/ZAR) than South African electricity (at ~ 1.24 kg CO_{2eq}/ZAR).

Keywords: carbon footprint; social housing; solar water heaters; rebound effect; Cape Town

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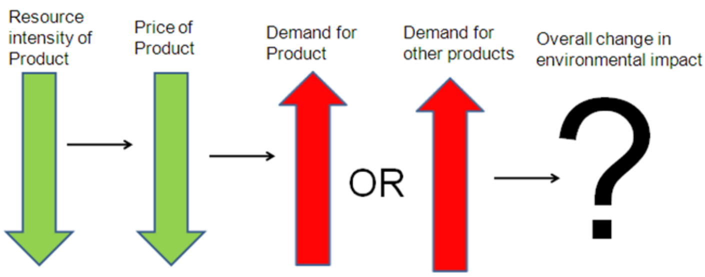
1. Introduction

Social Housing schemes should be conceived to improve the quality of life for their tenants, in the most sustainable way possible. With cities increasingly recognizing their role in climate change mitigation, and the long-lasting energy-use patterns resulting from housing projects, "carbon footprint" concerns are now also becoming a reality in the social housing sector. In sunny climates, one of the most effective and cost-efficient ways of reducing household energy use is the installation of a solar water heaters (SWH). In March 2007, the City of Cape Town issued a draft for a planned by-law that would enforce and regulate the installation of SWHs in new buildings and houses within its jurisdiction [1]. The by-law has yet to be passed, but the South African national electricity utility Eskom now offers significant rebates for such installations [2].

SWHs can have short greenhouse gas emission payback periods as shown in various life cycle studies [3]. On average, electric geysers account for 39% of all household electricity use in South Africa [4]. Thus, it is believed that replacing electric geysers with SWHs will reduce a household's carbon footprint.

This conclusion does not take the "rebound effect" into account (Figure 1). Economists acknowledge that energy efficiency measures such as SWHS will also result in money savings, as the affected households will spend less money on electricity for heating water. This could result in the household buying more electricity (for more hot water or other reasons), or the saved money could be spent on other goods and services [5]. To discover whether or not the SWH has lowered the household's environmental impact requires a full assessment of both the old and the new scenario.

Figure 1 The Rebound Effect



Previous studies (described below) conducted on the low-income areas of *Kuyasa* (Cape Town) and *Zanemvula* (Nelson Mandela Bay) confirm that for this income bracket the suppressed demand for electricity is so great that the installation of SWHs fails to produce a significant reduction in electricity consumption, confirming the "suppressed demand hypothesis" which provides an accepted basis to classify such projects as sustainable development cases worthy of receiving climate finance [6].

Kuyasa CDM was a pilot project where over 2 300 low-income homes in *Khayelitsha* were retrofitted with SWHs, insulated ceilings and energy-efficient lighting [7]. The houses did not have geysers before the project, and a baseline survey [8] showed that households typically used kettles to heat up water, and paraffin heaters for space heating. In a follow-up survey question about whether the households had seen a reduction in electricity consumption, only 35% of the households responded that their electricity consumption had reduced since the energy efficiency measures were installed [8].

SWHs were also installed at low-income homes in *Zanemvula* in Nelson Mandela Bay. Davis *et al* (2010) used pre-paid electricity purchase data to compare the households' electricity purchases before and after the SWHs were installed [9]. Their finding was that a reduction in electricity consumption was only present for households with more than 3 people living in them. For average-sized households (3 people), the effect of the SWH on electricity consumption was negligible, while for households with less than 3 people the installation of the SWH actually resulted in an increase in electricity consumption. The study found that the proportion of households using hot water to wash clothes increased from 3% to 26% after the SWH installation, suggesting a direct rebound in demand for hot water. The study also found that the average number of appliances per household increased, indicating an indirect rebound effect (the saved electricity from not having to heat water is still consumed by the household in other ways) [9].

Kuyasa and *Zanemvula* both showed that for very low-income households, there is a suppressed demand for hot water, and the installation of SWHs sees no significant decrease in electricity consumption. However, an optimistic assumption about the future of South African cities must recognise significant upward mobility, with low-income households finding employment and moving into higher income brackets. This assumption leads to the question of whether SWHs result in a significant decrease in the carbon footprint of households in higher income brackets.

The "gap" housing market consists of households that earn ZAR 3500 - 7500 per month (ZAR stands for the South African Rand currency). Unlike the households of *Kuyasa* and *Zanemvula*, they earn too much to qualify for a government housing subsidy, but most cannot afford housing in the private sector. Recent social housing projects, providing rental stock for this market, such as *Steenvilla* and *Drommedaris* in Cape Town, have included SWHs [10].

This work aims to answer the following questions:

- Does the installation of SWHs in households falling into the gap income bracket result in these households consuming less electricity than households of the same income using electric geysers?

- If so, what do these households spend this saved money on instead, and how does the carbon footprint of these new goods and services compare?

2. Methods

The methodology included surveys to investigate the electricity consumption and spending habits of a Cape Town social housing scheme that uses solar water heaters (SWHs), and comparing this with a similar block of flats using conventional electric geysers. Quantitative data on electricity purchases were then used to investigate if flats with SWHs do spend significantly less on electricity than those with electric geysers.

First, 2 blocks of flats had to be located that would be directly comparable except for one block of flats having SWHs, while the other uses conventional electric geysers.

Ideally, both sets of tenants and flats should have the following similar characteristics:

- Average household income of ZAR 6000 per month
- Flat size (number of bedrooms)
- Flat orientation (warmth, and need for electric space heating)
- Household sizes (average number of people per household)
- Location (both flats should be well-located with respect to schools, churches, public transport and work opportunities)

Working with Cape Town based housing company *Communicare*, two suitable blocks of flats were identified to make the comparison:

Drommedaris, Milnerton (Contains Solar Water Heaters, with electrical back-up geysers)

Drommedaris (Figure 2) is a new social housing scheme built by *Communicare*. It is well-located on Koeberg Road, which is a major taxi route. It is also close to the new bus system that links Milnerton to Cape Town CBD. It is located close to light industry (Paarden Eiland and Montague Gardens) and to the city centre for job opportunities. There is a shopping complex onsite. Schools are nearby, and there is a clinic and library across the road [11].

Figure 2 The Drommedaris Social Housing Scheme

Sakabula, Ruyterwacht (Contains electric geysers)

Sakabula (Figure 3) is an older block of flats built by *Communicare*. It is within easy reach of trains, taxis and bus routes. It is close to several industrial circles, shopping malls and other work opportunities. Shops and schools are within walking distance [11].

Figure 3 The Sakabula Flats

Survey Questionnaire

Surveys were conducted at both *Drommedaris* and *Sakabula* to determine if there were any differences between the two groups of flats, besides the type of hot water geyser, that may contribute to a significant difference in average electricity consumption.

The survey aimed to find the income of the households, and the expenditure on transport, rent, school fees, and food and groceries. The survey also aimed to find what the households thought of as major marginal spending categories. These are goods and services that they would want to buy more of if they had more money, and cut back on if they had less money. Table 1 summarizes the survey questionnaire.

Table 1 Summary of Survey Questionnaire

1	Household size in terms of number of adults and number of children
2	Number of bedrooms
3	Electricity and Direct Energy use • Type of geyser • Space heating (Type of heater and how much it is used) • List of appliances
4	Transport • mode of transport to work, shops and school • distance • regularity • cost
5	Marginal Categories of Spending (rebound effect) • If the household had ZAR 100 **more** to spend each week, what would they spend it on? • If the household had ZAR 100 **less** to spend each week, what would they cut back on? • Specific questions on items such as meat, electricity, transport
6	Income and Budget • Income • Electricity expenditure • Transport expenditure • Food and groceries expenditure • Rent • School fees

Electricity Consumption Data

Communicare was able to compile and provide electricity purchase data for the separate flats from both *Drommedaris* and *Sakabula* for the months of January, February and March 2011. This allows for a direct comparison between the two blocks of flats to see if the SWHs at *Drommedaris* cause a significant decrease in electricity consumption during the summer months.

Evaluating the Carbon Footprint of South African Electricity

South African electricity is mostly provided by coal fired power plants, and because of this, it has a relatively higher Carbon Footprint per kWh than electricity in other countries that use a higher proportion of cleaner energy. The main sources of South Africa's electricity production are listed in Table 2.

Table 2 The major Components of South Africa's Electricity Mix

SOURCE	Percentage (%)
Coal fired Power Plant	89
Hydropower (reservoir power plant)	4.87
Hydropower (pumped storage plant)	1.2
Natural gas (turbine)	0.03
Nuclear	4.9

[12]

Notten (2010) has combined these figures to create a SimaPro database for the South African electricity mix [13]. This simple life cycle assessment gives a Carbon Footprint of approximately 1.0 kg CO_{2eq} / kWh of South African electricity. This Carbon Footprint is slightly higher than what Eskom publishes in its own annual report [12], as it also takes into account the emissions from upstream coal mining.

At an electricity retail price of ZAR0.80/kWh, this carbon footprint is approximately equal to 1.24 kg CO_{2eq}/ZAR.

3. Results and Discussion

The results from the surveys at *Drommedaris* and *Sakabula* are summarised in Table 3.

Table 3 Survey Results showing major Similarities and Differences between Drommedaris and Sakabula Flats

	Drommedaris (16 respondents)	**Sakabula (14 respondents)**
Type of Geyser	**Solar water Heater, with electric geyser back-up**	**Only Electric geysers**
Average income (ZAR/month)	6 200	6 000
Average rent (ZAR/month)	2 120	2 050
Average expenditure on food and groceries (ZAR/month)	1 375	1 650
Average expenditure on transport (ZAR/month)	660	535
Average school fees (ZAR/month)	450	300
Average household size (people/flat)	**3.3**	**4.5**
Average flat size	2 bedrooms	2 or 3 bedrooms
Need for heaters for space heating	Both groups of tenants mostly did not use heaters at all. Those that did only used heaters in winter, and so this should not affect the electricity purchase data, which was for the 3 summer months of Jan-Mar 2011.	

Appliance ownership	Both groups of tenants had a full list of appliances, including: • Television • Fridge • Oven/microwave and stove • Kettle • 4-6 overhead lightbulbs

The two sets of flats are very similar in terms of size and spending patterns. The significant difference between the two sets of flats is that *Sakabula* tends to have more tenants per flat, both adults and children. It was decided to isolate the 5 responding *Drommedaris* households that had 4 or more people in them, and it was discovered that these households do not spend significantly more on electricity than the smaller households of the same income from *Drommedaris*.

The conclusion should be that the two blocks of flats are worthy of being compared to each other.

Quantitative Data on Electricity Purchases

The results of the electricity purchase data from January to March 2011 is provided in Table 4.

Table 4 Quantitative Data on Electricity Purchases (January, February, March 2011)

	Drommedaris (16 flats)	**Drommedaris households with 4 or more people (5 flats)**	**Sakabula (14 flats)**
Average Household size (people / dwelling)	3.3	4.6	4.5
Average income (ZAR/month)	6 200	6 370	6 000
Average Electricity Purchases Jan-Mar 2011 (ZAR/month)	184.50	186.70	320
Average Electricity Purchases Jan – Mar 2011	230	230	370

(kWh/month)			
Average Electricity Carbon Footprint (kg CO_{2eq} /month)	230	230	370

The flats at *Sakabula* consume significantly more electricity than the flats at *Drommedaris* which leads to the conclusion that for the ZAR 6 000/month income bracket, SWHs do reduce a household's carbon footprint due to electricity consumption by 38%, or 140 kWh / month, for the summer months studied (January to March).

Rebound Effect Categories

The households in *Drommedaris* do not spend as much money on electricity as the households at *Sakabula*. It needs to be determined where the money saved on electricity is being spent instead. Table 5 summarizes what households felt they would spend extra money on if they could, or would have to cut back on if they needed to save.

Table 5 Marginal Spending Categories Identified by Survey

Rebound Category	Number of Mentions in Surveys (Drommedaris and Sakabula)
Electricity	12
Transport	3
Meat	3
Groceries	14
Take outs / junk food	4
Entertainment / alcohol	6
Luxuries	5
Appliances	2
Education	3
Clothes	5

Total	57

A major result is that many of the households felt that they would spend extra money on purchasing more electricity. This does not show within the electricity purchase data, which indicates that the *Drommedaris* tenants save almost 38% on electricity compared to *Sakabula* tenants. Because a geyser typically uses 39% of a household's electricity [4], a rebound effect of spending more money on electricity would only be visible if *Drommedaris* tenants saved significantly less than 39% of the *Sakabula* electricity consumption. This suggests that during the summer months (January to March) there is *very little rebound* towards buying more electricity.

The other major categories of spending that were mentioned were groceries, clothing and entertainment / alcohol, but many different categories were mentioned as well. This leads to the assumption that the indirect rebound effect may follow the average expenditure profiles of South Africans in the gap income bracket.

Strategies for Estimating Carbon Footprint of the Indirect Rebound Effect

1. *Top-down average South African Carbon Footprint*

The average South African Carbon Footprint is 8 700 kg CO_{2eq} /annum/person [14]. The average income per household in South Africa is ZAR 56 000/annum and the average household size is 3.8 [15].

The average carbon footprint per household =

$$8700\,\frac{\text{kgCO2eq}}{\text{annum.cap}} \times \frac{3.8\text{cap}}{\text{household}} = \frac{33100\text{kgCO2eq}}{\text{annum.household}} \qquad (1)$$

The average carbon footprint per Rand spent =

$$\frac{33100\text{kgCO2eq}}{\text{annum.household}} \div \frac{\text{ZAR}56000}{\text{annum.household}} = \frac{0.59\text{kgCO2eq}}{\text{ZAR}} \qquad (2)$$

This is a worst case scenario as it includes the carbon footprint of South Africans spending money on electricity, and the rebound effect of buying more electricity has already been estimated as 0%. In addition, it must be recalled that the households in question have a higher income than the average South African household, and will therefore spend a lower proportion of their money on direct energy, reducing the carbon footprint of each additional Rand spent [16-17].

2. *Bottom-up analysis of Statistics South Africa Expenditure Data*

Table 6 gives data showing how South Africans in the 8th and 9th income deciles spend their money [15]. If one were to approximate the carbon footprint for each category of marginal spending as a household increases in wealth from the 8th to the 9th income decile, one would be able to estimate the approximate carbon footprint of an additional South African Rand (ZAR) spent. The result is 0.42 kg CO_{2eq} /ZAR.

However, the electricity footprint and marginal spending on electricity should be removed from the calculation, as the rebound of spending more on electricity has already been estimated to be 0%. When the calculation is repeated, excluding the carbon footprint and expenditure on electricity, the remaining marginal spending categories have an average carbon footprint of approximately 0.13 kg CO_{2eq} /ZAR.

Table 6 Estimating the Carbon Footprint of Additional Spending via the Indirect Rebound Effect

	SA Income decile 8 – Expenditure (ZAR/annum)	**SA Income decile 9 – Expenditure (ZAR/annum)**	**Percent of additional spending (%)**	**Approximate kg $CO_{2eq.}$/ZAR**	**Carbon Footprint Reference**
Food and non-alcoholic beverages	9225	11990	5.2	0.08	[19]
Alcoholic beverages and tobacco	773	1117	0.6	0.077	[17]
Clothing and footwear	3419	4793	2.6	0.07	[17]
Housing, water, electricity, gas and other fuels	12321	26634	27.0	1	[12]
Furnishings, household equipment and routine maintenance of the dwelling	4008	6398	4.5	0.2	[17]
Health	863	1717	1.6	0.082	[17]
Transport	9015	24690	29.6	0.17	[18]
Communication	2048	3875	3.4	0.025	[17]
Recreation and culture	2114	4603	4.7	0.095	[17]
Education	2142	2935	1.5	0.093	[17]
Restaurants and hotels	1102	2304	2.3	0.04	[17]
Miscellaneous goods and services	7851	16659	16.6	?	
Other unclassified expences	174	310	0.3	?	
Total	**55055**	**108025**	**100**	**0.42**	

[12] *Mostly electricity*

[17] Adapted from Vringer and Blok (1995) energy intensities

[18] Calculated from survey data, using carbon footprints for train, bus, taxi and petrol [17]

[19] Adapted from Guardian-UK (2010)

The overall Effect of Solar Water Heaters on the Carbon Footprint of a Household

Using the ZAR 320/month that the average household with electrical geysers spends on electricity as a functional unit, Figure 4 shows the electricity purchases of households with SWHs (*Drommedaris*), and the extra money spent on other goods and services such as food, transport and clothing.

Figure 4 Comparing tenants with SWHs to tenants with electrical geysers on a functional unit of ZAR 320 spent per month

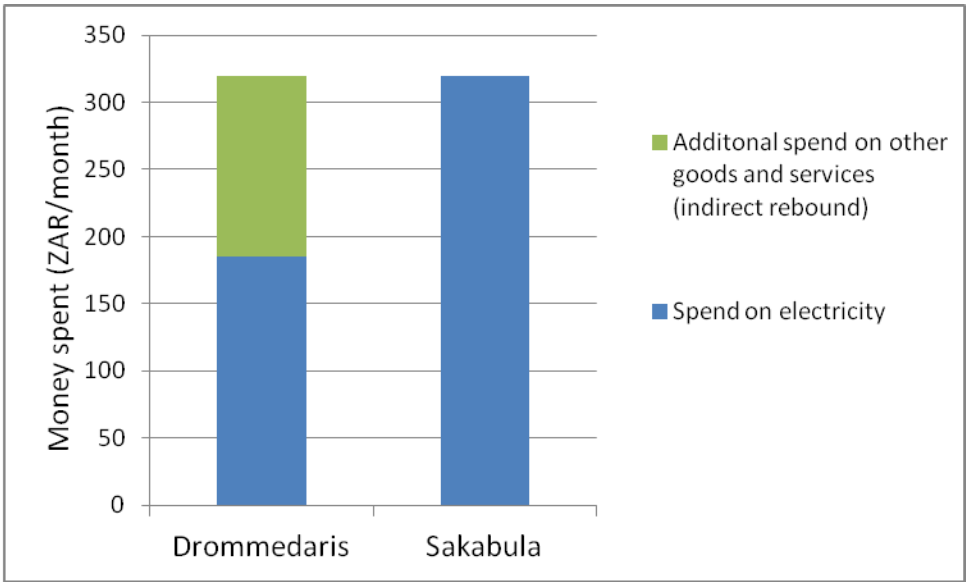
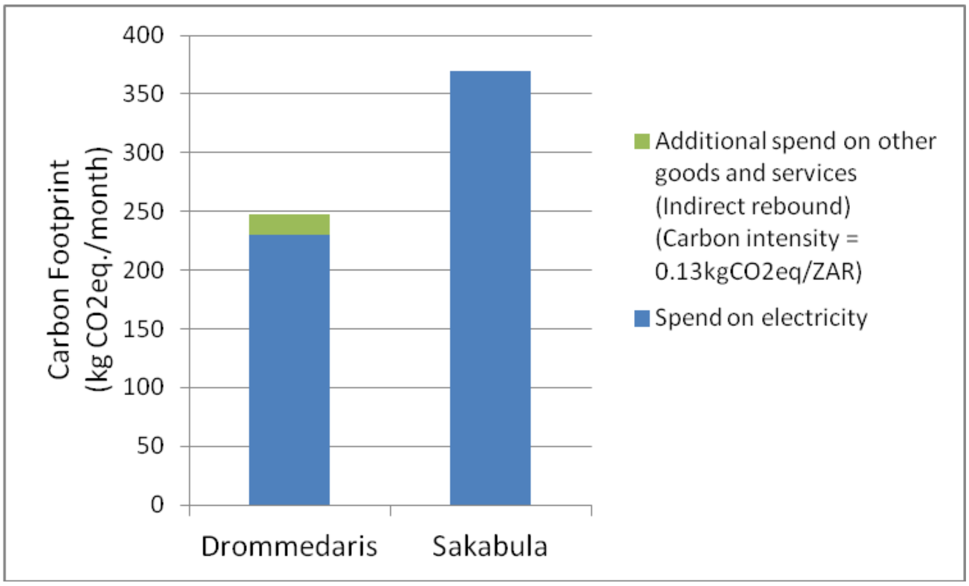


Figure 5 shows the electricity carbon footprint of households with SWHs, and the carbon footprint of spending extra money on other goods and services such as food, transport and clothing.

Figure 5 The relative carbon footprint of tenants with SWHs compared to tenants with electrical geysers



The Carbon footprint due to electricity is 370 kg CO_{2eq} /month for the households with conventional electric geysers, which is equal to 13.4% of the household's entire carbon footprint. This matches well with literature [20].

Despite the additional spending on other goods and services, installing a SWH reduces the Carbon footprint of a household (income ZAR 6 000/month) by 120 kg CO_{2eq}/month during the summer months in Cape Town. This is approximately equal to 4% of the household's total carbon footprint.

It must be remembered that this calculation is only valid for the summer months in Cape Town. From January to March the solar irradiation levels average 6.95 kWh/m^2.day for a tilted flat plate collector [21]. In winter, from May to August, the solar irradiation levels average only 4.46 kWh/m^2.day, meaning that the SWHs will not work as well, and the electrical back-up geysers will need to provide a larger percent of the energy required to heat water. It should also be remembered that the overall electricity consumption will increase in winter due to space heating and more lighting.

4. Conclusions

The preliminary results presented in this report suggest that for households accommodated in social housing, earning an average of ZAR 6 000 per month, electricity consumption is reduced by approximately 140 kWh/month in the summer months when SWHs are installed. Survey data suggests that saved money is spent on a wide range of goods and services. The household carbon footprint is still reduced as these goods and services have a lower carbon intensity (at ~ 0.13 kg CO_{2eq}/ZAR) than South African electricity (at ~ 1.24 kg CO_{2eq}/ZAR).

This results in those social housing units provided with SWHs reducing their carbon footprint by approximately 120 kg CO_{2eq} /month, which is equal to approximately 4% of the household's total carbon footprint. These savings will not be as high in winter however, when Cape Town's solar irradiation levels average 4.46 kWh/m^2.day, which is significantly less than that of the summer months, averaging 6.95 kWh/m^2.day.

Acknowledgments

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Conflict of Interest

The authors declare no conflict of interest.

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