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AN INVESTIGATION OF CARBON FOOTPRINT REDUCTIONS ACHIEVABLE IN CAPE TOWN SOCIAL HOUSING CONSIDERING REBOUND EFFECTS

A dissertation submitted to the

UNIVERSITY OF CAPE TOWN

In fulfilment of the requirements for the Degree of

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(CHEMICAL ENGINEERING)

University of Cape Town

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SOUTH AFRICA **January, 2012**

DECLARATION

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ABSTRACT

Various life cycle studies have shown that solar water heaters (SWHs) have short greenhouse gas emission payback periods. Thus, it is believed that replacing electric geysers with SWHs will reduce a household's carbon footprint. It is also believed that living in a well-located area close to jobs, schools, shops and public transport will reduce a household's carbon footprint through reducing fuel consumption via private/public transport. These conclusions, however, do not take the rebound effect into account, where money saved from spending less on electricity or transport, is spent eventually, either on more electricity and transport, or on other goods and services with an associated carbon footprint.

Previous studies into how the rebound effect reduces the expected electricity savings of SWH installation have been conducted on the low-income areas of Kuyasa (Cape Town) and Zanemvula (Nelson Mandela Bay). These studies confirm that for this low 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 recognise 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 3 500 – 7 500 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, are well-located and have installed SWHs.

This work aims to answer the following questions: Does the installation of SWHs in gap-income social housing schemes result in these households consuming less electricity than households of the same income using electric geysers? Does the building of gap-income social housing schemes in well-located areas close to jobs, schools, shops and public transport result in their tenants having a reduced transport-related carbon footprint? If so, what goods and services do these households buy with the money that they have

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consequently saved on electricity and transport, and how does the carbon footprint of these new goods and services compare?

The methodology includes surveys to investigate the electricity consumption, transport use and spending habits between Cape Town gap-income housing schemes that use solar water heaters and those that have conventional electric geysers. Quantitative data on electricity purchases are also used for some housing schemes. The surveys also compare well-located gap-income housing schemes with poorly-located ones.

The electricity expenditure results suggest that for households earning an average of ZAR 6 000 per month, electricity consumption is reduced by approximately 150 kWh per month in summer when SWHs are installed. The direct rebound effect towards buying more electricity is small, in the region of 20%.

Transport expenditure results were surprising in that poorly-located households travelled less than well-located ones, but evidence points towards these communities being less socially sustainable than well-located communities who have more work and education opportunities available in the area.

The rebound effect results suggest that some of the money saved on electricity via the installation of SWHs is spent on additional transport. This is still favourable as in South Africa; the carbon-intensity of money spent on transport is significantly lower than money spent on electricity. The rest of the 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 significantly lower carbon intensity (averaging at ~ 0.054 – 0.066 kg CO_{2eq}/ZAR) than South African electricity (at ~ 1.25 kg CO_{2eq}/ZAR), and also have a lower carbon intensity than South African transport (averaging at ~ 0.154 kg CO_{2eq}/ZAR).

It is recommended that all future social housing schemes should make use of SWHs or heat pumps, and that the new national building regulations and standards should be made stricter incrementally to enforce the use of SWHs. It is also recommended that policy attempts to focus on city densification in South Africa should be encouraged, and therefore the new approach to social housing which prescribes a minimum density and a good location should be continued.

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GLOSSARY

CBD	Central Business District
EIO-LCA	Economic Input Output Life Cycle Assessment
GBP	Great British Pound (currency)
GDP	Gross Domestic Production
LCA	Life Cycle Assessment
RDP	Reconstruction and Development Programme
SWH	Solar Water Heater
USA	United States of America
ZAR	South African Rand (currency)

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1 INTRODUCTION

1.1 Background

There are high numbers of low-income earners migrating to Cape Town. The population of Cape Town has grown by 36.4% between 1996 and 2007 (City of Cape Town, 2008). In the specific case of Khayelitsha, South Africa's second largest township, the population grew by approximately 30% between 1996 and 2001 (Khayelitsha Population Profile, 2005). The City of Cape Town aims to provide housing for these people. "*Currently 8335 housing opportunities are being created each year. Government wants to increase this to 12000 new housing opportunities per year by 2012.* " (City of Cape Town (CCT), 2007a)).

In addition to plans for housing provision, the City of Cape Town aims to address sustainability issues, and is planning to pursue both an Energy and Climate Change strategy, and a City Densification strategy.

The Energy and Climate Change Strategy is Cape Town's approach to use more sustainable energy in order to minimise the environmental impacts of improving its citizens' quality of life (City of Cape Town (CCT). 2007b). An important part of this strategy is encouraging and enforcing the use of Solar Water Heaters (SWHs) via the Solar Water Heater Advancement Program. 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 Cape Town (City of Cape Town (CCT). 2007c). In 2011, new building regulations and standards were passed to make the by-law redundant, as they also aimed to enforce the use of SWHs (Walsh, 2011).

Solar Water Heaters would significantly reduce household energy use of paraffin or electricity to heat up water, which is the second biggest use for direct energy in the residential sector ((City of Cape Town (CCT). 2007d)). In the average 4 person household, an electric geyser typically accounts for 39% of the electricity consumption (Eskom 2011a). The national electricity utility Eskom now offers significant rebates for such installations (Eskom 2011b).

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In addition, Local Government is starting to realise that Cape Town's urban layout is too low-density and sprawled for public transport to operate in a financially sustainable manner. Cape Town is a very car dependent city, which means that transport accounts for 54% of Cape Town's total energy use (Cape Town State of Energy Report, 2003). The Energy and Climate Change Strategy acknowledges that city densification should help to reduce Cape Town's overall fuel consumption, and in August 2009, the City of Cape Town released a "draft for comment" of its "Cape Town Densification Strategy" (City of Cape Town (CCT). 2009).

This draft points out that Cape Town is a low-density city suffering from urban sprawl. Even informal settlements and low-income housing schemes within Khayelitsha tend to favour the "one house one plot" approach. Most housing developments continue to occur where the informal settlements are building up on the outskirts of the city, even though there is suitable land available closer to the central business district (CBD). In fact, the land area covered by Cape Town grew by 40% between 1977 and 2006 (Swilling, 2010). The Densification Strategy points out that if Cape Town pursued building high-density urban settlements with a well-located mixed land use strategy, this would result in the following benefits:

- less distance for people to travel on a daily basis as they live closer to work
- easier and more profitable to provide public transport as more passengers would be available at every station/bus stop/taxi rank
- easier for Government to provide utilities/facilities/services such as waste removal, piped water, electricity
- High density settlements are thought to be safer due to "more eyes on the street".

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Households who earn a total income of less than ZAR 3 500 per month qualify for a full housing subsidy via the "Breaking New Ground" (BNG) program, which is a revised continuation of the "Reconstruction and Development Program" (RDP). The fully subsidized houses tend to have a low density "one house one plot" approach, resulting in 50-60 dwellings per hectare (Goven, 2010), which unfortunately does little to alleviate Cape Town's urban sprawl.

Households that earn between ZAR 3 500 and ZAR 7 500 a month are referred to as the "gap income bracket". These households earn too much to qualify for a government housing subsidy, but most cannot afford housing in the private sector. Recent social housing projects aim to provide rental stock for this market (Nevin, 2011). Social Housing schemes fall partly under the control of local government, and therefore their development provides a unique opportunity for the city to implement policies that address both the Energy and Climate Change and City Densification strategies.

One of the requirements of social housing is that it should be in well-located areas close to schools, shops, public transport and other community facilities (Nevin, 2011). Recent housing schemes have been high-density 3 - 4 storey flats. This ensures that many households can take advantage of the well-located housing opportunity. Several recent social housing schemes also make use of solar water heaters (Wiseman, 2011)

At first glance, the interventions mentioned above (city densification via well-located Social Housing Projects, and solar water heaters) appear to lower the affected household's environmental load at the same time as improving the quality of life of the inhabitants. This is because the people in the household will use less fuel to travel to work, and less electricity to heat up their water, saving money which they can spend on other needs, and reducing emissions.

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This conclusion does not take into account the "rebound effect". The rebound effect (Davis *et al*, 2010; Jones, 1993) acknowledges that these interventions will also result in money savings, as the affected households will spend less money on public transport and fuel/electricity, but that some of that saved money would be spent on a higher consumption of the same energy services (i.e. more hot water, more travel). Another portion of this saved money could be spent on other goods and services, and one should quantify and compare the environmental load/impact of this new way of spending the money. To discover whether or not the intervention has lowered the household's environmental impact requires a full assessment of both the old and the new scenario.

In summary, hundreds of social housing projects stand to be built or upgraded in Cape Town over the next decade in order to provide accommodation for the growing number of low-income households. Local Government understands the global recognition that low-carbon lifestyles are imperative and is starting to make changes to its housing schemes that aim to improve the quality of life of low-income people as sustainably as possible. However, there is no tool available to assess the effectiveness of measures to reduce future energy consumption – and therefore the implied “carbon footprint” - of the possible or proposed solutions.

1.2 Objectives of this Study

The purpose of this study is to contribute new knowledge in the field of sustainable urban development, particularly relating to energy consumption resulting from housing policy choices as regards location, densification and solar water heaters.

Specific objectives include:

- To determine the extent to which solar water heaters and housing scheme location choice and density would lower the future carbon footprint of new and upgraded households in the gap income bracket.
- To consider direct and indirect rebound effects, and to investigate whether or not they significantly reduce the environmental benefits of placing housing schemes in high density, well-located areas, and if they reduce the environmental benefits of installing solar water heaters.

1.3 Scope and Limitations of Report

This study focuses on existing households in the “gap” income bracket for data, and the findings are intended to develop a body of knowledge that can inform Local Government about how to implement future housing schemes.

Although the consumption of low-income households is not as high as that of high-income households, this choice of income bracket is motivated by the fact that Local Government can make more far-reaching housing policy decisions for the “gap” income bracket through how it implements major social housing schemes.

The geographic scope of the study is limited to Cape Town. Cape Town is a good base for this study because:

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- It has people living in social housing/subsidized flats who are situated relatively close to the city centre as well as those that are relatively far.
- Cape Town has low income flats without renewable energy or energy efficiency interventions, but it also has flats that do have these interventions, especially Solar Water Heaters.

However, the ideas and findings from this report can be applied to other cities hoping to pursue major low-income housing projects.

1.4 Dissertation Outline

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Chapter 2 of the dissertation presents the Literature Review. This section deals with the work that others have already published in the areas of relevance to this research, and this past research is combined to create the background to the research undertaken by this study.

Chapter 3 of the dissertation develops the Methodology. This section builds on what has been learnt from the literature review to form the key questions that this research work aims to answer, about how much the rebound effect reduces the carbon footprint savings of solar water heaters and well-located housing at the gap income-bracket level. The methodology then describes the research strategy, which involves combining survey results and hard data on electricity purchases, and comparing the resulting carbon footprints between 4 chosen sets of flats, as depicted in Figure 1-1.

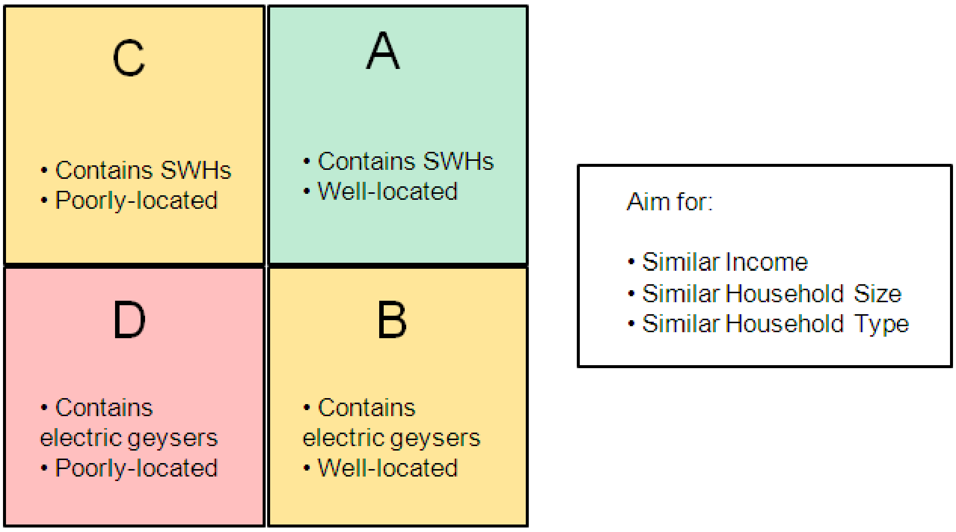

Figure 1-1 2X2 Matrix Explaining the 4 Sets of Flats to be Surveyed

Chapter 4 first addresses how comparable the 4 chosen sets of flats are in terms of income, flat size and household size, and also attempts to uncover reasons why the electricity consumption, and transport habits, of the flats may differ apart from their location or use of solar water heaters. The survey results and electricity purchase data are then analysed to uncover the electricity consumption and transport expenditure of the 4 different sets of flats, and suitable carbon footprint factors are found to convert these results into carbon footprints.

Chapter 5 compares two methods to estimate the carbon footprint of the indirect rebound effect, where money saved via the installation of solar water heaters is spent on other goods and services, besides electricity or transport. The carbon footprints of the 4 groups of flats are then compared on the basis of the highest average amount of money spent on electricity and transport per month.

Conclusions are drawn and then Recommendations are made in Chapter 6.

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2 LITERATURE REVIEW

This chapter aims to provide an understanding of the published work and studies that form a backdrop to the research work to be presented in this dissertation. These past studies combine to form the basis of understanding that leads into the new research questions that this dissertation aims to address.

The first section aims to create a general understanding of the sustainable cities and household consumption literature, and also describes some of the tools and indicators used to evaluate environmental impact and sustainability.

The second section of the literature review puts Cape Town as a city into context with regards to its rapid urbanisation and urban sprawl, along with its car dependency and its struggling public transport systems. The gap income bracket is explained, along with the need for social housing schemes in Cape Town. This section of the literature review also summarises solar water heater technology, and discusses the use of solar water heaters in South Africa.

The final section of the literature review discusses the rebound effect, an economic theory that explains how money saved though an energy efficiency intervention can be spent on the same energy resource (direct rebound effect), or other goods and services with an associated environmental impact (indirect rebound effect). This reduces the perceived environmental benefit of the energy efficiency intervention in question. Two studies are highlighted where solar water heaters were provided to low-income communities in South Africa, and how the rebound effect resulted in negligible electricity savings in these communities due to a suppressed demand for hot water and electricity.

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2.1 Sustainable Urban Development and how it is assessed

2.1.1 Sustainable Development

Many definitions of sustainability and sustainable development have been suggested in the literature, with the original and most widely quoted being that of the Brundtland Commission of the United Nations in 1987, that "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (United Nations, 1987).

The emergence of sustainability concerns has its roots in both rapid population growth and rapid economic growth during the 20th century, with the global population quadrupling and resource extraction increasing eight-fold in the course of that century (UNEP-IRP, 2011). The ecological effects of these pressures include significant impacts on the climate, projected to accelerate in the 21st century, and a disastrous decline in the health and diversity of ecosystems (Millennium Ecosystem Assessment, 2006).

There is a widely quoted equation used to describe how a community's population and affluence, as well as the environmental impact of the technologies it uses, can define its overall environmental impact. This is known as the I=PAT equation, where

Impact ($kgCO_{2\ eq}$) = Population (cap) X Affluence (ZAR / cap) X Technology impact ($kgCO_{2\ eq}$ / ZAR)

(Goodland and Daly, 1996)

It is generally accepted that sustainable development relies on the combination of 3 types of sustainability (Goodland and Daly, 1996):

> *Social Sustainability* is achieved through community participation and strong civil society.

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Economic Sustainability is achieved through maintenance of capital, via using profits to invest and being able to keep the business running.

Environmental Sustainability requires that raw materials are not used beyond regenerative capacities, and that nature's sinks for waste are not exceeded.

A popular conception is that these three types of sustainability are concerns of different spheres that must overlap to ensure full sustainability, as illustrated in Figure 2-1 (adapted from Baumann and Cowell, 1999).

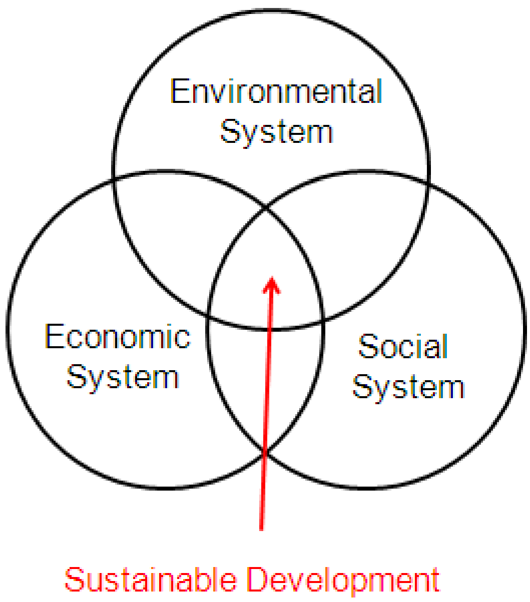

Figure 2-1 The Venn diagram model of Sustainability

However, it is more correct to remember that the economic sphere is entirely nested in and governed by the social sphere, and that all of society is in turn dependent on environmental sustainability, as illustrated in Figure 2-2 (adapted from Mebratu, 1998).

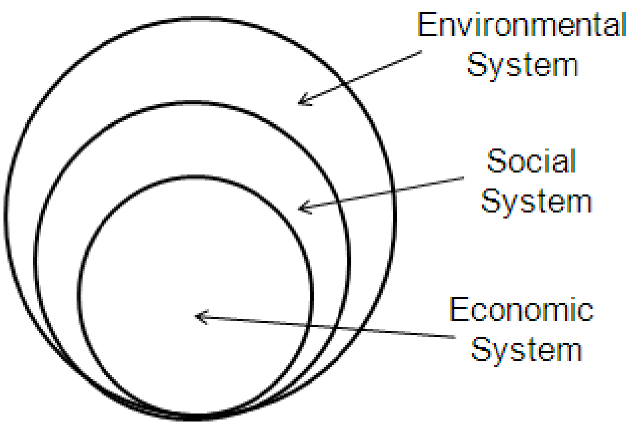

Figure 2-2 The 3 Spheres of Sustainability represented as a Nested System

This latter realisation justifies an insistence on what Goodland and Daly (1996) term "strong" as opposed to "weak sustainability", arguing that there are forms of capital within each sphere that need to be maintained separately. In particular, they argue that there is limited scope for substitution of natural capital by man-made capital – a point that is especially relevant for cities: places characterised by a high density of economic and social capital, a low density of natural capital, and consequently a large dependence on flows of resources from and wastes to the surrounding natural environment.

Mol *et al.* (2005) remind us of the following statement that was made during the World Summit on Sustainable Development 2002: "*Governments, relevant international organizations, the private sector and all major groups should play an active role in changing unsustainable consumption and production patterns. (WSSD 2002, Chapter III, point 14)*"

This statement refers to sustainable consumption in addition to sustainable production, and recommends that all countries need to promote both. Cities account for a large percentage of society's consumption, and the following section summarises some of the steps that can be taken to make cities more sustainable.

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2.1.2 Sustainable Cities

Although cities only occupy approximately 2.7% of the Earth's surface, by 2010 they accounted for roughly 50% of the world's population, along with 80% of global energy consumption, 70% of total waste generation and 60% of greenhouse gas emissions (Ceron *et al*, 2011).

Pieterse (2010) proposes that it is useful to add an additional 2 types of sustainability to economic, social and ecological sustainability, and then integrate all 5 forms of sustainability together to fully understand sustainability in the city context. The other 2 types of sustainability are:

1. Physical Sustainability – this is defined as the capacity and aptitude of the urban built environment and techno-structures to support human life and productive activities.
2. Political Sustainability – this refers to the quality of governance systems guiding the relationship and actions of different actors among the other four dimensions. It involves the democratisations and participation of civil society in all areas of decision making.

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Evans and Martin (2006) agree that an interdisciplinary approach is needed to address the problem of the sustainable city, and that not enough is being done to achieve this interdisciplinary focus.

In his critique of the N2 Gateway housing scheme in Cape Town, Swilling (2006) recommends the following strategies that could make cities more sustainable:

- Renewable energy (in the energy sector) AND energy efficiency (at the household level)
- Recycling from home
- Sustainable transport / public transport
- Sustainable construction materials (for the building of new houses)
- Local sustainable food (Neighbourhood food projects)
- Sustainable water use and re-use of treated sewerage.

Two of Swilling's (2006) recommendations are relevant for this dissertation. These are renewable energy interventions and sustainable transport.

While most renewable energy proposals such as solar and wind electricity generation are decided by national scale projects, there are other types of renewable energy technologies that can be implemented at much smaller scales within cities, such as:

- Solar water heaters
- Bio-gas anaerobic digesters
- Creating Energy and Heat by incinerating Waste

An example of the installation of solar water heaters on a large scale is at Kuyasa. Kuyasa (2011) describes a CDM project in Khayelitsha, Cape Town where low-income houses were provided with solar water heaters, insulated ceilings and compact fluorescent light bulbs (CFLs). The Clean Development Mechanism (CDM) is one of 3 "flexibility mechanisms" offered by the Kyoto Protocol, and allows industrialised countries the opportunity to achieve a part of their greenhouse gas emissions reduction targets by investing in developing countries (Winkler and Thorne, 2002). Each of the three interventions should result in a household reducing its direct energy consumption, because solar water heaters reduce the fuel required for water heating, insulated ceilings reduce fuel required for space heating and CFLs reduce the fuel required for lighting.

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The other relevant strategy that cities can take is to try and shift commuters from modes of transport with high environmental impacts to those with lower impacts. Copenhagen (2010) has implemented programs to encourage its citizens to make use of bicycles and its integrated public transport system. The city has pursued other means of becoming more environmentally sustainable as well; the city sent 20 times less waste to landfill in 2009 than it did in 1988. It achieved this by improving its recycling separation, and incinerating waste to create electricity and heat for space heating.

Transit-oriented Development is the practice of designing high-density mixed-used urban areas that encourage its citizens to make use of public transport. These areas are designed to be within walking distance of public transport nodes. UNISDR (2011) used Curitiba (Brazil) as a case study for a city that had been highly successful in planning a future based on transit-oriented development. It lists some findings on what made Curitiba successful.

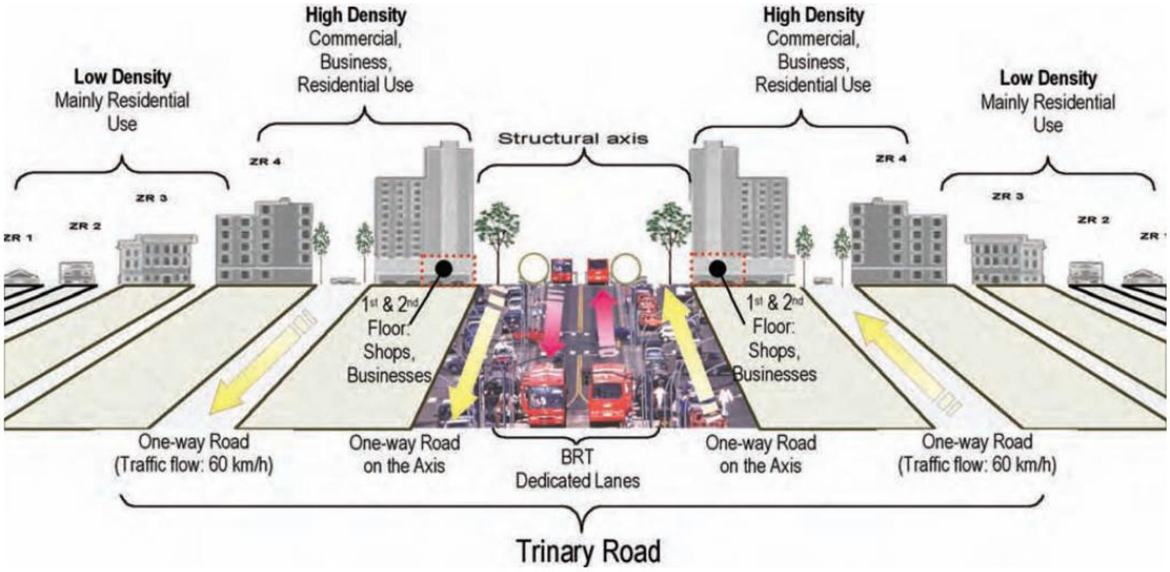

Figure 2-3 Curitiba: Maximising the use of Public Transport via Transit-oriented Development (UNISDR, 2011)

Transit-oriented development takes time, but Curitiba had a master plan that was developed in the 1960s. This meant that different administrations leading the city still stuck to the same direction for urban planning. Part of this was attributed to a municipality-independent body that supervised urban planning and ensured consistency despite changes in political leadership. This highlights the importance of political sustainability when a city pursues a long-term strategy to pursue environmental sustainability.

A major lesson from Curitiba is that the master plan in the 1960s aimed to react to the predicted population growth. The planners knew that it could lead to traffic and urban sprawl if they did not have a plan that integrated land use with transport. Instead of expanding outwards at the same urban density of 1960, Curitiba was able to become denser. In fact, in 1960 the urban density was 836 people / km^2, but by 2008 this density was 4 232 people / km^2. This increase in density almost matches the population growth for the city, meaning Curitiba did not expand into new land to a great degree. This is important, as there is a clear connection between a city's urban population density and its transport-related energy consumption, as illustrated by Figure 2-4, taken from Newman and Kenworthy (1989).

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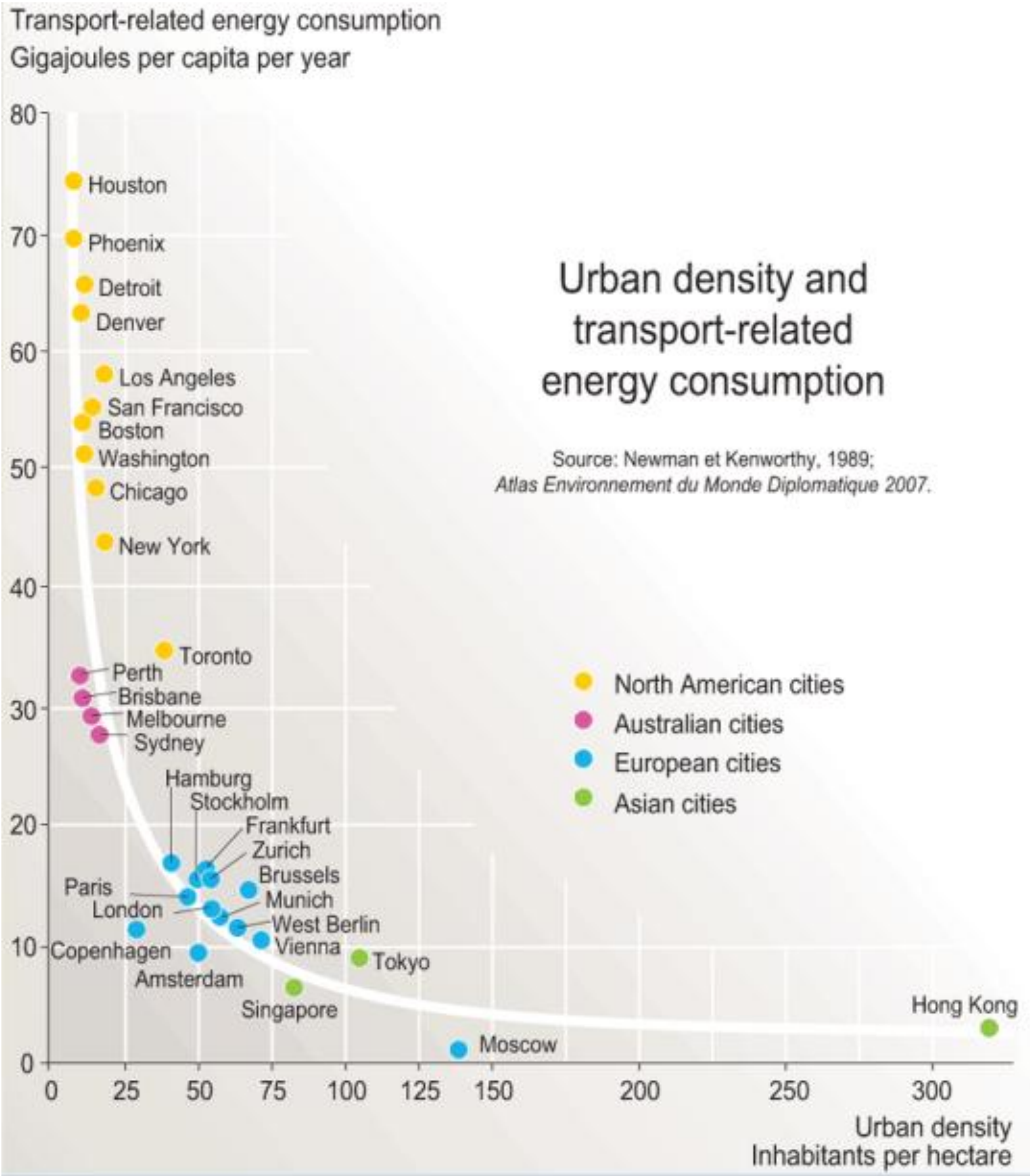

Figure 2-4 Urban Density and Transport-related Energy Consumption (Newman and Kenworthy, 1989)

The City of Cape Town's draft on its Densification Strategy (City of Cape Town (CCT). 2007c) explains that a population density of 25 dwellings per hectare is the internationally accepted minimum at which public transport becomes efficient and sustainable.

Kennedy *et al* (2009) conducted a study of 10 different cities, which also confirmed that the cities with the lowest densities yielded the highest greenhouse gas emissions from transport fuels. The paper goes on to conclude that a city's density, its electricity consumption and source of electricity (either 'dirty' such as coal-fired electricity or 'clean' such as hydropower) and its industrial/heating fuels consumption are the key factors in determining its greenhouse gas emissions per capita. Both solar water heaters and transit-oriented development address one of these key factors, and are the focus of this dissertation's research.

2.1.3 Describing Environmental Load at Household Level

Whilst sustainable development crucially relies on national policy directions (e.g. on taxation, agriculture or energy supply), and on city strategies for providing infrastructure sustainably, this has been argued by many observers to be insufficient, with an additional focus on household consumption also necessary. This argument originates from the observation that studies for many different countries have shown that *"in total 70–80% of national energy use and greenhouse gas emissions may be related either to household activities directly or to activities required to deliver goods and services to households and to manage the waste flows generated by households" (*Mol *et al.*, 2005).

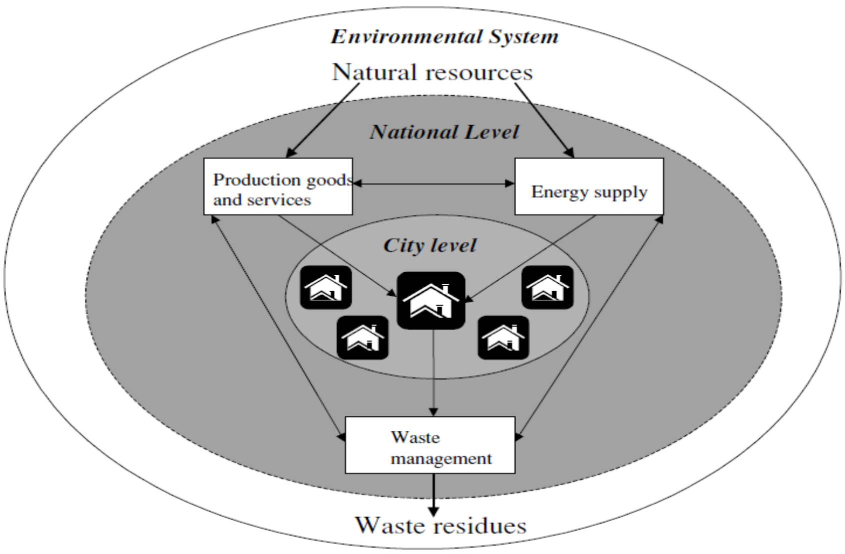

Figure 2-5 System description of household energy and material metabolism (Mol *et al*, 2005)

Figure 2-5 (taken from Mol *et al* (2005)) demonstrates how households are directly responsible for a large fraction of overall energy consumption, but that households are also indirectly responsible for the energy consumed by the production and waste sectors, as these sectors exist mostly to provide goods and services to households.

From the figure one can see that if a household consumes more goods, the production sector will have to consume more energy to provide these goods, and this will result in a negative impact on the environment. Similarly, if a household produces more waste, the waste management sector will have to consume more energy to dispose of it which will lead to a negative environmental impact. Extra emissions from the landfill site or from incineration will make this negative impact worse. Finally, if a household directly consumes more energy, this will generally have a negative environmental impact too.

The following two papers demonstrate how increases in household consumption patterns have led to increases in CO_2 emissions at country level, despite improvements towards making the production and energy sectors more sustainable.

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- Munksgaard *et al*. (2000) found that the overall CO_2 emissions for Denmark increased by 7% during the period from 1966 to 1992. This was despite substantial energy conservation in the energy supply and manufacturing sectors. The real reason for the increase in national CO_2 emissions was attributed to a 58% increase in Danish Household consumption. The conclusion from the paper was that *"overall growth in private consumption - but not changes in the composition of consumption - is the key to understanding the increase in CO_2 emissions."*

  What Munksgaard *et al* (2000) are saying is that they did not perceive big increases in certain sectors of household consumption, but rather that almost all of the sectors of household consumption had increased, and had all contributed to the increase in national CO_2 emissions. Nevertheless, the paper recommends shifting the commodity mix towards less CO_2 intensive goods.

- Kim (2002) presented very similar findings for Korea. From the results, he concluded "*that households are the most significant contributors for the generation of CO_2 and SO_2 because of the direct impact of their energy consumption and the indirect impact of their demand for products"*. He also claimed that so far, technological improvements had not been strong enough to offset the negative environmental impact of increased household consumption patterns. As a result, the CO_2 emissions for Korea increased between 1985 and 1995.

Kim (2002) goes on to recommend that the government simultaneously emphasize technological development and consumer policies that induce more environmentally conscious consumption patterns.

Both papers make it clear that it is highly unlikely that the environmental impact can be reduced without focussing on the root of the problem, which is increasing household consumption patterns.

2.1.4 Challenges to Addressing Household Consumption

It is widely accepted that technology must be made more energy-efficient and less harmful for the environment in the future. It is also argued by many that society must try to slow down the population growth rate, and this has actually been achieved in many countries, including most developed or OECD countries and China. The "I=PAT equation" mentioned in Section 2.1.1 informs us that a nation's affluence also plays an important role in determining its overall environmental impact, but what effect has this had on economic policy?

Many observers, including Pieterse (2010) point out that our society is following an economic model focussed on wealth generation, where GDP growth is considered to be the most important indicator. Unfortunately this involves a continual expansion of consumerist lifestyles, which combined with growing populations is worsening the overall environmental impact of society, despite efforts to reduce the carbon intensity of the economy.

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Swilling (2010) states that economic policy is starting to react to the global ecological crisis in Europe and starting to realise that the future cannot include economic growth without consideration for the environment. Nobel prize-winners Stiglitz and Sen headed a French-initiated commission which recommended that GDP is no longer an adequate measure of a nation's progress or success. They suggested that GDP be replaced by a Happiness Index instead (Stiglitz *et* al, 2008).

Swilling (2010) helps to conceptualize a 'green economy'. This would be "an economy that grows by reducing rather than increasing resource consumption." Swilling (2010) also tries to propose a focus on "non-material growth" that places more importance on the following assets, rather than merely trying to chase material-based economic growth:

- Culture
- Liveability
- Education
- Improved health
- Environmental quality
- Safety
- A sense of place*
- Individual and collective capabilities for enhancing wellbeing and freedom

In a similar tone, Jackson and Michaelis (2003) point out that society's presumptions make the reduction of household environmental load *appear* to be a very difficult task. They then go on to explain how research shows that these presumptions are not true, and that reducing household environmental load is feasible, with their core argument being:

1. Current government policy presumes that increasing levels of economic consumption are a pre-requisite for improving the quality of life. Research has shown this to be false. A shift in government policy would be justified to place more emphasis on other contributors to quality of life, such as health, community engagement and meaningful work.

2. Current thinking presumes that individuals have the freedom to buy goods that best suit their needs. Research does not support this presumption. Individual choice is constrained by various social, institutional and cultural factors. This means that consumers may find themselves "locked in" to unsustainable consumption.

3. Most current thinking suggests that it would be infeasible for government to change individual consumer behaviours, but research does not support this opinion. Government plays a vital role in shaping the cultural context (lock-in) within which individual choice is negotiated.

The overriding message from the research of Jackson and Michaelis (2003) is that it should be possible to reduce household environmental load without having a negative impact on

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the consumers' quality of life. However, it is extremely important that this process starts with government.

2.1.5 *Tools and Indicators for Calculating and Comparing Environmental Impact*

In order to compare two or more products, scenarios or lifestyle choices on an environmental basis, one needs a tool to gather data on these products or scenarios with the aim of quantifying and comparing the environmental impacts of each. This should lead one into making an informed decision about which product or scenario to choose.

Firstly, there are different tools that enable one to make an inventory of the environmental load of each of the different products or scenarios. Secondly, there are also different methods of converting the environmental load into environmental impacts. Finally, there are also many different indicators that combine certain impacts into a single figure that can be used to convey this information to the public so that they can understand the direct comparison between the different products or scenarios.

Choosing which tools and indicators to use is not trivial. This section aims to describe some of the most common ones: Life Cycle Assessment, Carbon Footprint, Material Input per Service unit (MIPS) and the Factor X indicator, Ecological Footprint and the Economic Input-output Life Cycle Assessment.

Life Cycle Assessment (LCA) is "a methodological framework for estimating and assessing the environmental impacts attributable to the life cycle of a product". (Rebitzer *et al*, 2004)

Robért (2000) explains that LCA is a way of evaluating all processes involved with a certain product or service from "the cradle to the grave". This means that LCA makes an inventory of the environmental loads from the resources, transport, manufacturing, use and disposal of the product.

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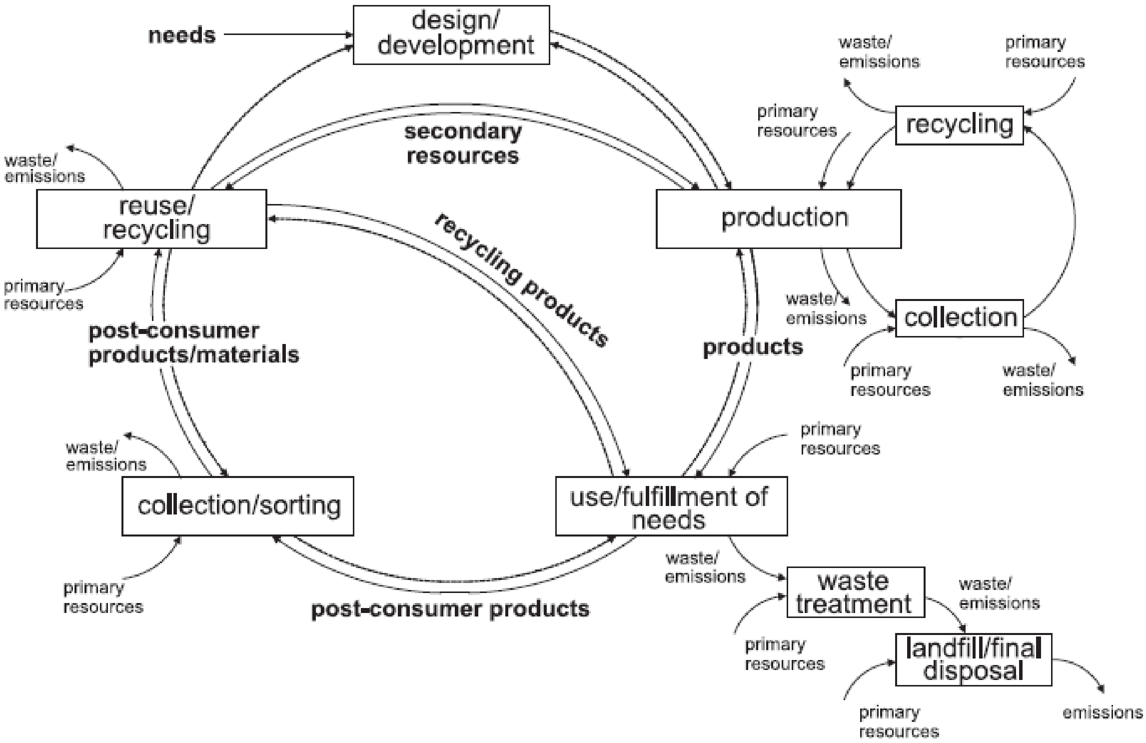

Figure 2-6 A generic Life Cycle of a Product *(Rebitzer et al, 2004)*

Curran (2000) explains the 4-part approach to LCA that has become accepted:

- State the specific purpose of the study and identify the boundaries (Goal and Scope Definition)
- Life Cycle inventory (LCI) – quantify energy use, raw material inputs and environmental releases for each stage of the life cycle.
- Interpreting the results of the inventory into impacts on human health and the environment. (Life Cycle Impact Assessment, LCIA). This interpretation is not trivial, and there are different methods for converting the inventory into the following impacts (taken from Rebitzer *et al*, 2004):

    - Climate change (Global warming Potential)
    - Stratospheric ozone depletion
    - Tropospheric ozone (smog) creation
    - Eutrophication
    - Acidification
    - Toxicological stress on human health and ecosystems
    - The depletion of resources

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- Water use
- Land use
- Others

- Evaluate opportunities to reduce energy and raw material use, as well as environmental releases, to reduce environmental impacts along the life cycle (Improvement Analysis).

In summary, LCA is an extremely effective but data intensive way to compare two products, processes or activities with the same function. LCA can give information about how replacing one product, process or activity with another would reduce certain environmental impacts but may increase others, if the LCA is done correctly. This makes LCA the most rigorous tool in comparing the environmental impacts of two products, but also the most difficult to understand and to convert into a single indicator for policy-makers to understand.

Ceron *et al* (2011) provide a recent study making use of a full LCA to investigate the potential energy savings and environmental impact reduction that could be achieved through eco-technology and urban green spaces interventions in a social housing district in Merida, Mexico. This study chose to focus on the Global Warming Potential impact to calculate and present results in the form of carbon footprints as a single indicator.

Carbon footprint: This is an indicator of environmental impact that has gained popularity in recent years. It is currently very policy-relevant because of the link between greenhouse gas emissions and climate change. In Cape Town, the Energy and Climate Change Strategy (City of Cape Town (CCT). 2007b) expresses targets in terms of carbon footprints. Kennedy *et al* (2009) provide another recent study making use of carbon footprint indicators in their comparison of the greenhouse gas emission of ten global cities. The carbon footprint is expressed in kilograms of carbon dioxide equivalent (kg $CO_{2\ eq}$).

It has been suggested that the term *carbon footprint* should only be used for analyses that include carbon emissions. However, it is now common for non-carbon emissions that have an impact on climate change to be included as well such as nitrous oxide. Methane, nitrous oxide and other emissions are converted into “carbon dioxide equivalents”. This means that the term *carbon footprint* shows something very similar to the “Global Warming Potential” impact of a full LCA (Weidema *et al*, 2008), depending on the scope of the study.

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This means that the carbon footprint does not have the same ability to compare trade-offs as a multi-impact LCA; investigating how changing from one product to another can reduce some environmental impacts while increasing others. The benefit of using a single, highly policy-relevant indicator is that it becomes easier for the public and policy makers to understand the direct comparison between two products, scenarios or lifestyle choices.

MIPS/Factor X: Factor X tells us by what factor a production/energy process must reduce resource intensity to become sustainable (Reijnders, 1998).

The Factor X is usually calculated via a tool called MIPS, which stands for Material Input per Service unit (Ritthoff *et al, 2002*). In a similar way to a life cycle assessment, MIPS attempts to calculate the use of resources from the point of their extraction from nature. However, with MIPS, all data is measured in the amount of tons moved in nature. All material consumption that occurs during manufacture, product use, recycling or disposal is calculated back to resource consumption. Even energy consumption and transport are converted into moved tons by factors that are expressed in terms of t/MWh or t/km.

Factor X is therefore an indicator of by how much the total material consumption of a process must be reduced for it to be considered sustainable. While this is a very useful tool in that it is easy for people to understand, it deals mainly with technological improvements that need to be made in the production sector and doesn't deal with sustainable consumption as much. Like all other single figure indicators, Factor X does not allow insight into how a particular method of reducing a process's resource intensity may increase some other environmental impacts.

A recent use of the MIPS indicator to evaluate the sustainability of occupants of social housing in Finland was reported by Lettenmeier *et al* (2011).

Ecological Footprint: This is an indicator most commonly used to compare the environmental load of different populations. It is one of very few indicators that is consumption based rather than production based. The consumption of the population in question is converted into a single index: the land area that would be needed to sustain that population indefinitely. If this required land amounts to more than the productive land that is

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actually taken up by the population, then that population is deemed unsustainable (Lenzen and Murray, 2003). As such, this indicator is focused more on "regenerative" than on "absorptive" capacities of the environment, with the exception of its inclusion of a much-discussed method related to energy provision and related CO_2 absorption. An example of the regenerative capacity of land is its ability to regrow food that society consumes. An example of the absorptive capacity of land is its ability to absorb CO_2 emissions, which depends on many factors, including what type of vegetation is on that land. It must be recalled that not all non-renewable resources can be substituted by renewable ones, and the ecological footprint does not display how different forms of capital should be maintained separately as recommended by Goodland and Daly (1996).

Demand for resource production and waste assimilation are converted into hectares of land by dividing the total amount of a resource consumed by the yield per hectare, or by dividing the waste emitted by the absorptive capacity per hectare. The United Nations Food and Agriculture Organisation is one of the main contributors to the international statistics that allow these land yields to be calculated (Ewing *et al*, 2008).

The ecological footprint of any consumption activity can be calculated as:

Ecological footprint = (annual demand in tonnes / national yield in annual tonnes per ha) X yield factor X equivalence factor

The yield factor compares national average yield per hectare to the world average yield in the same land category, while the equivalence factor captures the relative productivity among the different land and sea types (Ewing *et al*, 2008).

The major benefit of the ecological footprint is that it is easy for the public to understand (Moffatt, 2000). However, not every environmental impact can be converted into land area, such as the *"contamination of nature from the use of scarce elements or persistent compounds foreign to nature."* (Robért, 2000).

It is therefore important to understand what impacts the ecological footprint won't be able to take into account if it is used as an indicator. These impacts include non-ecological impacts

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that affect social sustainability, the depletion of non-renewable resources, and the release of radioactive substances, among others (Ewing *et al*, 2008)

Eaton *et al* (2007) provide a study using ecological foot printing to compare the resource consumption and waste absorption of the mainly urban area of Swindon with the nearby rural area of Wiltshire in Southern England.

Economic Input Output Life Cycle Assessment (EIO-LCA)

EIO-LCA estimates the resources (material and energy) required by activities in our economy and also estimate the environmental emissions that results from these economic activities. EIO-LCA is a technique of performing life cycle assessments where industry transactions of materials from one industry to another are combined with information about the environmental emissions from each industry to give information on the environmental impacts throughout an entire supply chain (Carnegie Mellon University Green Design Institute, 2008).

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One of the biggest challenges when performing a conventional life cycle assessment is where to draw the boundaries of the system or product life cycle being studied, because each industry is dependent (directly or indirectly) on many other industries. The Input and Output analysis of an EIO-LCA allows for the assessment to capture all of the interdependencies across the economy, making EIO-LCA a very powerful tool if the data is available (Hendrickson *et al*, 1998).

EIO-LCA is very useful for providing an estimate of how much environmental impact can arise from spending a certain amount of money on a certain industry. As global warming potential is one of the impacts assessed by EIO-LCA, it is possible to acquire information on the quantity of emissions that arise from a certain amount of economic activity in a certain industry, and this can be expressed in kg CO_{2eq} / ZAR (ZAR is the South African Rand currency).

2.2 Cape Town in Context

Figure 2-7, sourced from the City of Cape Town (2011), shows 2007 data for Cape Town's energy consumption and carbon emissions by sector. Transport is the biggest energy consumer with 50%, while direct residential energy use is the second biggest energy user with 18%. Transport is a particularly large consumer in Cape Town, especially when compared to 2006 data which shows that transport is only responsible for 27.7% of South Africa's energy consumption (City of Cape Town, 2011).

Direct residential energy use may be the second largest consumer of energy, but South African electricity is very carbon-intensive, being mostly derived from coal (Eskom Integrated Report, 2010), and this results in residential direct energy use being the most carbon intensive sector.

Section 2.2 gives a background to solar water heaters, and how they could reduce the electricity consumption of households in Cape Town. The Section also describes some of the reasons why Cape Town's transport consumes a significantly larger proportion of energy than the national average.

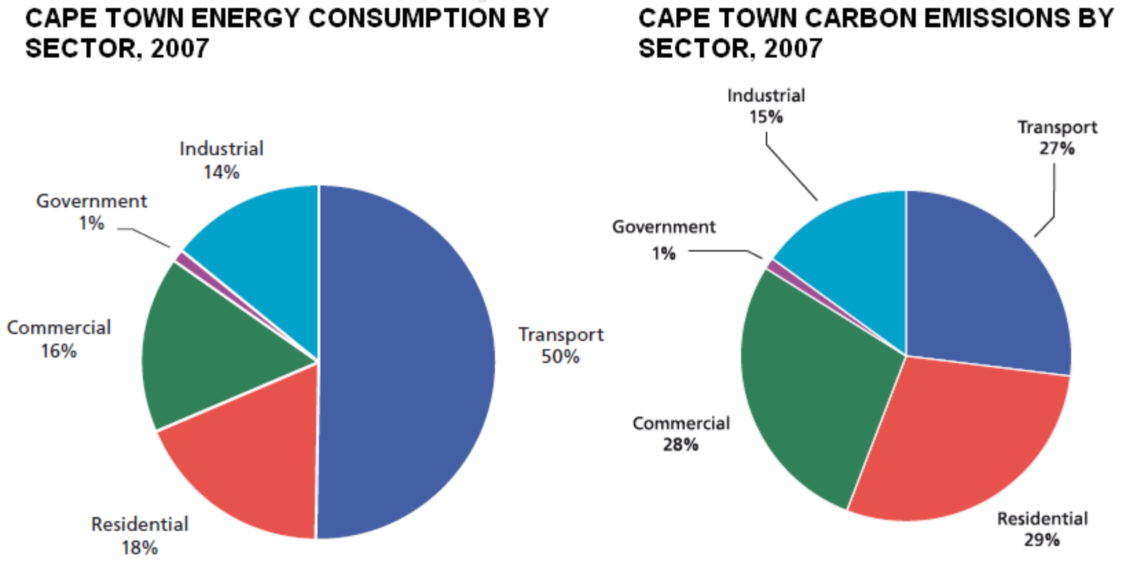

Figure 2-7 Cape Town's Energy Consumption and Carbon Emissions by Sector (City of Cape Town, 2011)

2.2.1 *Household Energy Use and Solar Water Heaters*

As indicated in Figure 2-7, direct residential energy use is the sector responsible for the largest percentage of carbon emissions in Cape Town. In the average 4 person household, an electric geyser typically accounts for 39% of the electricity consumption (Eskom 2011a), and Cape Town's Energy and Climate Change Strategy (City of Cape Town (CCT). 2007b) is encouraging the use of solar water Heaters (SWHs) to reduce direct household energy use.

Most SWHs in South Africa are characterised by a solar collector panel and an insulated storage tank. The solar panel either heats up water directly which is then stored in the tank, or it heats up an antifreeze fluid that is then used to heat up the water in the storage tank (Visagie and Prasad, 2006). SWHs should not be confused with solar photovoltaic cells that generate electricity from solar power.

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SWHs reduce the need for households to use electricity or other energy sources (mainly paraffin, wood or coal for low-income households) to heat up their water. If a housing scheme can provide SWHs, then they are thought to improve the quality of life of low-income people. Prasad (2007) tells us that *"Solar Water Heaters have been identified as a means whereby renewable energy could significantly contribute towards alleviating poverty, through improving the general welfare of households as well as developing productive activities to generate employment."*

Solar Water Heaters are also thought to be the best way of increasing the energy efficiency of the residential sector. Hughes and Haw (2007) point out energy efficiency improvements in the residential sector will be seen through reducing demand for energy to heat water, to provide lighting and for cooking. Of these options, targeting water heating gives the largest savings and is best achieved through installing solar water heaters.

Prasad (2007) points out that South Africa is an ideal place for SWH use as the average daily solar radiation is between 4.5 and 6.5 kWh/m^2. Prasad (2007) goes on to say that between 1978 and 1983, the Centre for Scientific and Industrial Research (CSIR) developed effective strategies to encourage homeowners to install SWHs, and by 1983, the industry was flourishing, and approximately 27 000m^2 of SWHs were installed in 1983 alone.

Unfortunately, soon after this the projects were discontinued, and the SWH market collapsed.

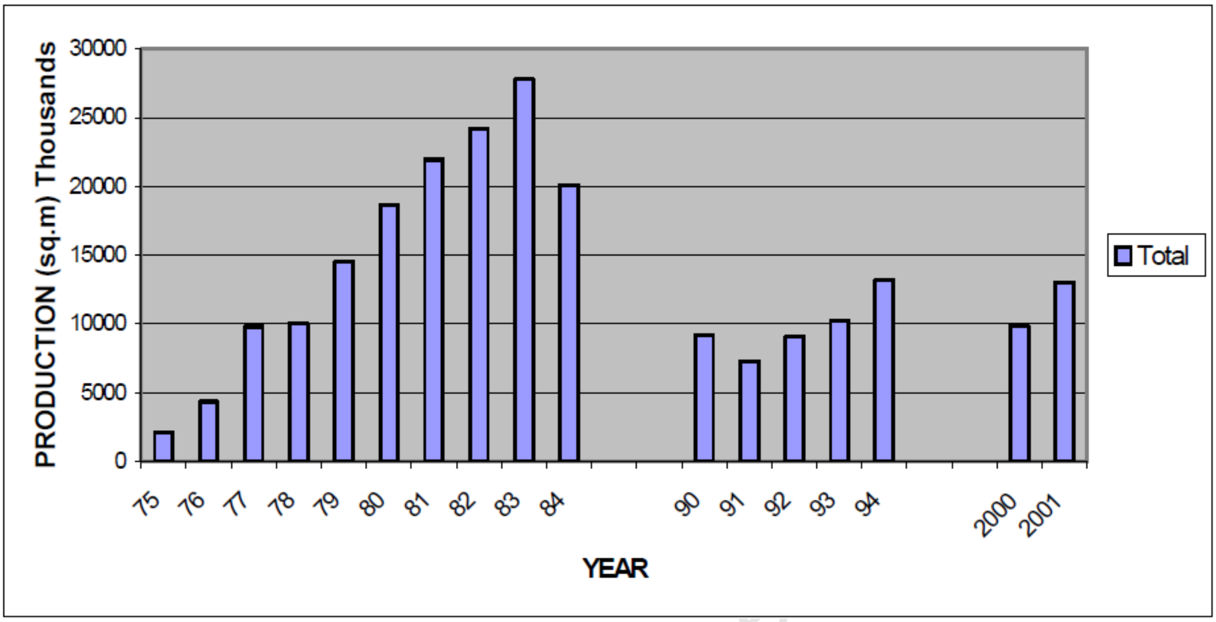

Figure 2-8 SWH market in South Africa (Prasad, 2007)

Many pressurised SWH systems have been available for wealthier users in South Africa for a long time, but there has been a lack of robust, cheap options for the majority of the population until more recently. Pilot testing at typical RDP houses in Khayelitsha used direct heating 100 litre closed-couple systems with integrated electrical backup heating elements. These were shown to work well, yielding either 85 litres above 45°C or 95 litres above 40°C. Figure 2-9 shows what these SWHs look like (Morris *et al*. 2003).

Figure 2-9 100 litre close-coupled SWH in Khayelitsha (Morris *et al*, 2003)

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Visagie and Prasad (2006) point out that the SWH industry is a mature industry in South Africa, but in the past it has been hampered by the fact that Eskom's coal-fired electricity is cheap, and that there have been no building codes to enforce their use. This was set to change when the City of Cape Town drafted a by-law in March 2007 that would enforce and regulate the installation of SWHs in new buildings and houses within Cape Town (City of Cape Town (CCT), 2007c). However, this by-law has become redundant, as new building regulations and standards (NBR part XA and SANS204) have been set in place that will enforce the use of SWHs (Walsh, 2011). Another encouraging development is that South Africa's national electricity utility Eskom has been offering rebates to households that install SWHs since 2008 (Eskom, 2011b). It was reported in April 2011 that Eskom had helped finance the installation of approximately 60 000 SWH units through the rebate programme (Engineering News, 2011).

Life cycle assessment (LCA) studies have been conducted on SWHs in many different countries. A useful indicator is the greenhouse gas emissions payback period. SWHs require a certain amount of energy and greenhouse gas emissions during their manufacture, and the greenhouse gas emissions payback period describes how long the SWH must operate, replacing conventional electricity, until it has replaced enough electricity use to compensate for the greenhouse gas emissions that went into its manufacturing stage.

The greenhouse gas emission payback period depends on the type of electricity that is used to manufacture the SWH, as well as the type of electricity that the SWH's energy will be replacing, which in turn is dependent on where the solar grade glass is manufactured, and where the SWH is finally installed. The greenhouse gas emissions payback period is also dependent on the amount of solar energy available in the place where it is installed, and on various assumptions that are made during the LCA study. Finally, the greenhouse gas emissions payback period improves with improving technology, so more recent studies tend to show SWHs to be more environmentally beneficial than older studies.

All of these differences mean that different LCA studies will give different answers for the greenhouse gas emissions payback period of a SWH. Ardente *et al* (2005) estimated a greenhouse gas emissions payback period of approximately 2 years for their study in Italy,

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while Jabbar and Asif (2006) reported a greenhouse gas emissions payback period of approximately 6 months for an 80*l* built-in storage solar heater system in Pakistan.

It is possible to adapt LCA studies to estimate the greenhouse gas emissions payback period if SWHs were to replace South African coal fired electricity. In 2009, several MSc. students from the University of Cape Town Chemical Engineering Department wrote assignments on this exercise, and calculated greenhouse gas emissions payback periods of between 3 – 5 months, depending on what assumptions they made (Ras, 2009) (Kasozi, 2009). These studies assumed that the SWH would be operating for a family of 4, who would need 200l/day of hot water (Tewari, 2009). These results align well with those cited above – noting South Africa's particularly carbon-intensive electricity.

There is thus sufficient evidence to claim that SWHs will reduce overall greenhouse gas emissions during their lifetime effectively or even very effectively so, depending on the solar insolation received and the carbon-intensity of electric power replaced.

The student reports cited above however also indicated that while SWHs would be beneficial in reducing greenhouse gas emissions and the use of non-renewable energy resources, they could perform worse on some environmental impact categories when compared to Eskom's coal fired electricity. These impact categories include aquatic eutrophication and mineral extraction (Kasozi, 2009).

Rankin and van Eldik (2008) conducted an investigation into the economic viability of both SWHs and heat pumps in South Africa. Some of their findings are described below.

- For households using conventional electric geysers, heating water typically accounts for 30 - 50% of the household's total electricity bill. In comparison, Eskom states that for the average 4 person household, an electric geyser typically accounts for 39% of the electricity consumption (Eskom 2011a).
- Unfortunately, the high capital cost of installing a SWH, combined with the relatively low cost of electricity in South Africa, means that it takes approximately 8 years for a SWH to pay for itself via the electricity it saves. This makes the technology unappealing to most poor South Africans if they would have to pay for it themselves. The Eskom SWH rebate only covers approximately 20-30% of the capital cost, reducing the financial payback time to approximately 6 years. It must be noted that since the conclusion of

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their study, Eskom electricity tariffs have increased by over 120% (Eskom, 2011c; Eskom, 2008) and this should make SWHs appear more financially attractive.

- In addition, while SWHs are typically able to heat 100% of the household's hot water requirement in summer, solar irradiation levels are usually too low to make this possible in winter. This means that most high-income families that choose to install SWHs use their old electric geysers to back them up.

Rankin and van Eldik (2008) proceed to use a simulation to estimate the electricity savings and financial payback periods for both SWHs and Heat pumps. The table below describes the SWHs and heat pumps that they modelled, and the capital costs shown have already had the Eskom rebate deducted.

Table 2-1 Typical Costs and Capacities of Solar Water Heaters and Heat Pumps

	Solar type	Solar cost	Heat pump type	Heat pump cost
2 users	200 L, 2.45m^2	R13 200	2.4kW	R7000
3 users	200 L, 2.45m^2	R13 200	2.4kW	R7000
4 users	300 L, 4.52m^2	R17 700	2.4kW	R7000
5 users	300 L, 4.52m^2	R17 700	2.4kW	R7000

Rankin and van Eldik (2008)

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The simulation demonstrated that both heat pumps and SWHs should result in significant reductions in electricity usage for heating water, as can be seen in Figure 2-10.

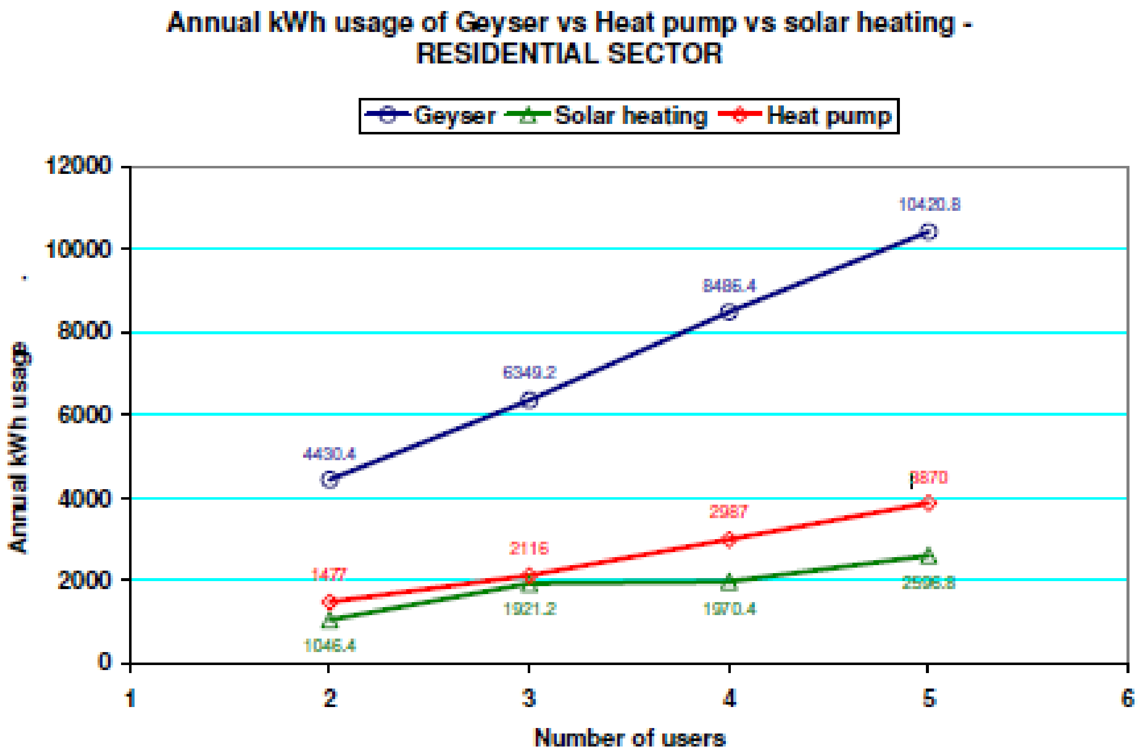

Figure 2-10 Simulated Electricity Savings via Solar water Heaters or Heat Pumps. (Rankin and van Eldik, 2008)

Rankin and van Eldik's (2008) electricity savings for a household of 4 people conflict with the calculations of Guma *et al* (2008). Guma *et al* (2008) calculated that a Solar water heater in Cape Town delivering 200 litres of hot water per day to a family of 4 people could reduce the carbon footprint of the household by approximately 2000 kWh / annum, or 500 kWh / person / annum. This electricity saving is approximately equivalent to 5.5% of the average South African person's total Carbon footprint of 8 700 kg $CO_{2\ eq}$ / person/annum (Millennium Development Goals, 2011).

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2.2.2 Cape Town Urbanisation

Transport is the sector that consumes the largest amount of energy in Cape Town (City of Cape Town, 2011) and the following three sections explain this by looking at Cape Town's urbanisation, its urban sprawl, and its struggling public transport systems.

By 2007, the population of Cape Town had grown by 20.9% since 2001 and 36.4% since 1996 (City of Cape Town, 2008), representing annual growth rates of 2.41% and 3.16% for the periods 1996 – 2001 and 2001 – 2007 respectively. In the specific case of Khayelitsha, an area containing informal settlements and RDP housing schemes on the outskirts of Cape Town, the population grew from 252 342 in 1996 to 329 002 in 2001, representing an annual growth rate of 5.31%. Approximately 40% of this population growth is attributed to people moving to Khayelitsha from outside the Western Cape, and 90% of these people came from the Eastern Cape (Khayelitsha Population Profile, 2005).

The combination of continued immigration and population growth means that there are many new families that need to be housed in Cape Town. Many of these people are too poor to buy a house through the private housing market, and the Government's subsidised public housing schemes are currently too slow to provide accommodation for everyone. Because of this, a sizeable percentage of Cape Town's population lives in informal settlements, and this informal population is increasing. There were 23 000 families living in informal settlements in Cape Town in 1993, and 109 000 families in 2007 (Goven, 2010).

This means that local government still has a long way to go to provide housing for remaining households that continue to live in informal settlements – The national government policy on sustainable human settlements indicates that this needs to be done as sustainably as possible.

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2.2.3 *Cape Town Urban Sprawl*

Cape Town has a long way to go before it reaches an overall population density of other cities that have been able to adopt an efficient public transport system. Unfortunately, Cape Town is a city that suffers from urban sprawl, with an extremely low average population density. This is demonstrated in Table 2-2:

Table 2-2 Population Densities of various cities

City	Population Density (inhabitants/km^2)
Mumbai	32 814[a]
Curitiba	7 660[a]
Hong Kong	6 590[a]
London	4 800[a]
Cape Town	**1 425** [b]

a – Counter currents (2010)

b – About.com (2010)

Cape Town is not merely a low-density city, but it is also badly laid out in that the majority of the most densely populated suburbs are located far from the city centre or CBD with very low density suburbs between them. This is demonstrated in Figure 2-11:

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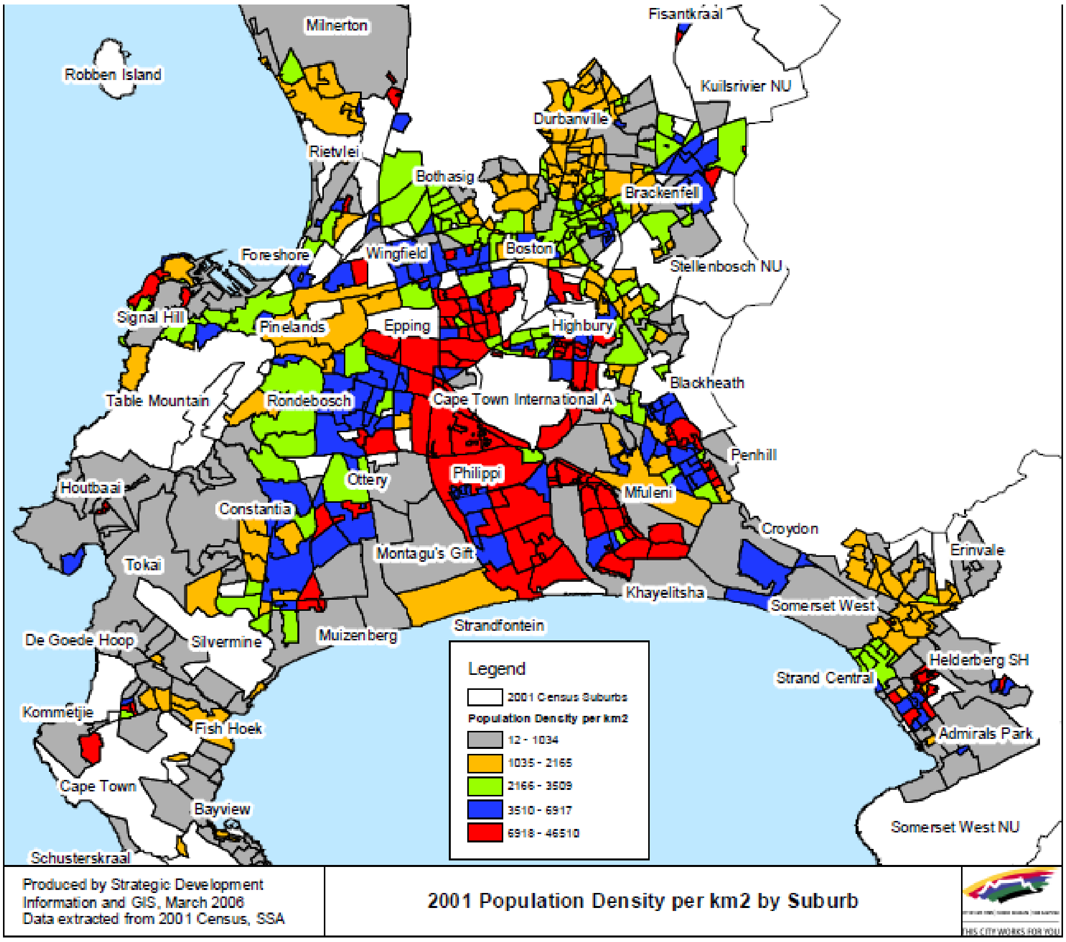

Figure 2-11 Population Densities in Cape Town by Suburb (Census 2001 data)

University of

A city like Greater London is laid out better. The areas closest to the city centre are the most densely populated (UK Stats, 2010), meaning that more people have a shorter distance to travel to where they work. There are historical reasons, along with rapid urbanisation on the city's periphery, to explain why Cape Town's denser areas are located so far from the CBD, but the important point is that Cape Town's poor layout and overall low density is a major reason for the environmental and economical unsustainability of its public transport systems.

Figure 2-12 below confirms that it is Cape Town's poorer households that are clustered together in informal settlements on the Cape Flats who have comparatively longer distances to travel to places of work such as the CBD (Swilling, 2006).

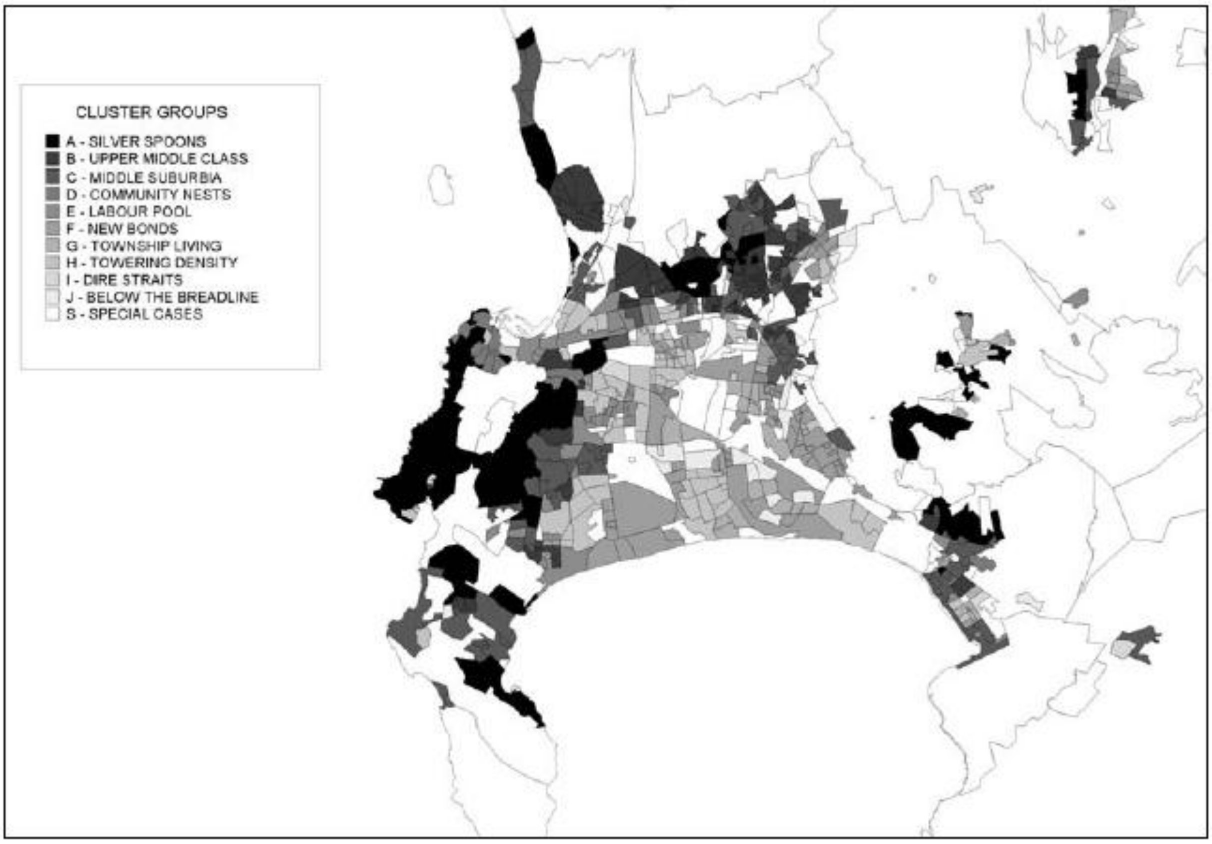

Figure 2-12 Cape Town Income Demographics by Suburb (Swilling, 2006)

Swilling (2010) points out that the land area covered by Cape Town increased by 40% between 1977 and 2006, indicating an average annual growth rate of 1.16%. This has led to the creation of over 50 new suburbs and areas in the last 25 years, including new middle and upper class suburbs such as Sunset Beach and Blouberg Sands, as well as poorer areas such as Lwandile, Imizamo Yethu (Hout bay) and Harare (Khayelitsha). Comparing population and land cover growth rates, it is evident that while Cape Town's population density is slowly increasing, this happens mainly on the periphery of the city and therefore is not solving the problem of urban sprawl.

2.2.4 *Transport and City Densification*

Transport accounts for 50% of Cape Town's total energy use (City of Cape Town, 2011).

Local government recognises public transport as a basic need (City of Cape Town, 2007e). However, unlike the provision of other basic needs like water, electricity and housing, there has been a real underinvestment in urban public transport in South Africa. This means that the three main modes of public transport (minibus taxi, rail and bus) operate in isolation of one another (Schalekamp, 2010).

Table 2-3 Passengers Carried by Different Modes of Public Transport in Cape Town

Mode	1991	1998 AM	2000			
			Morning	Interpeak	Evening	Total
Minibus Taxi		100 000	152 000	172 000	130 000	454 000
	12.20%	24%	34.40%	47.30%	35.30%	38.70%
Rail		265 000	249 000	160 000	205 000	614 000
	55.10%	62.40%	56.30%	44.00%	55.70%	52.30%
Bus		60 000	41 000	32 000	33 000	106 000
	32.70%	14.10%	9.30%	8.70%	9.00%	9.00%
Total		**425 000**	**442 000**	**364 000**	**368 000**	**1 174 000**

Note: Includes all recorded boardings, including transfers between vehicles and modes, but excludes taxi boardings not made at ranks.

Source: Arup (PTY) Ltd for the City of Cape Town, Public Transport in Cape Town, 2002

Table 2-3 shows that the percentage of passengers using rail and bus transport decreased from 1991 to 2000. This decrease was especially pronounced for bus transport. On the other hand, the percentage of people using minibus taxis increased over the same time period.

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Even more noticeable is the increase in private motor usage. In 1994, 123 985 cars were counted travelling into the Cape Town CBD between 07:00 and 19:00. By 2001, that number had increased to 157 452 (City of Cape Town (CCT), 2001b). This represents an annual growth rate in private car usage of 3.41%, which exceeds the population growth rate of the city. On average, urban car travel uses nearly twice the energy of urban bus travel per person per kilometre, and 6.6 times more than electric train travel, and therefore contributes more to local and global air pollution (Newman and Kenworthy, 2007).

There are numerous problems associated with cities that rely on car transport too much, including environmental issues like smog, toxic and greenhouse gas emissions and greater storm-water problems, as well as economic issues like the high infrastructure costs in low density suburbs and the loss of what could have been productive land to roads and parking spaces, and finally social issues such as the lack of access for those without cars, road rage and loss of public safety (Newman and Kenworthy, 2007). These problems all sound very familiar to the sprawling city of Cape Town, and any development that can reduce car usage in favour of public transport is very relevant.

Swilling (2010) calls for a "radical transformation of Cape Town's transport sector", and presents different statistics to how Cape Town transport has changed in recent years.

According to Swilling (2010), Cape Town has seen an increase in car ownership that has exceeded the population growth rate of the city. This has resulted in a sharp increase in traffic, especially during peak period. Swilling (2010) also points out that the use of rail had decreased from 27% to 13% and the use of buses had decreased from 16% to 7% between 1991 and 2004. It is believed that this is largely due to the inconvenience of using Cape Town's public transport. The use of minibus taxis has increased along with private car use, as these are thought to be more convenient.

The figures presented by Swilling (2010) are shown in Table 2-4. It must be pointed out that the percentages given for each mode of transport do not add up to 100% for the year 2004, but that the figures confirm the trends cited above of increasing proportional use of minibus taxis and private cars, and the decreasing proportional use of rail and bus transport.

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Table 2-4 Change in Transport Modes for Cape Town

Year	Private Transport	Public Transport			Walk/other
		Rail	Buses	Minibus Taxi	
1991	44%	27%	16%	6%	7%
2004	48%	13%	7%	13%	13%

(Swilling, 2010)

The car-dependency of Cape Town may already have had a big economic impact on the city. Newman and Kenworthy (2007) remind one that "*freeway traffic carries 2,500 people per hour, a bus lane carries 5,000–8,000, a light rail or BRT can carry 10,000–20,000 and a heavy rail system carries 50,000 people per hour—20 times as many as a freeway. It is no wonder that freeways fill so quickly. Likewise, most car-dependent cities require five to eight parking spaces for every car. All this space costs money and is simply unproductive land.*" Some parking lots do make money and enable productivity, but it can be argued that the land could be used in a more eco-efficient way if the area was not as car-dependent.

The fact that Cape Town is such a car dependant city has contributed to it being a very low density, sprawling city. Ironically, the low density of Cape Town is now a very big hurdle to moving towards sustainable public transport.

The City of Cape Town's draft on its Densification Strategy (City of Cape Town (CCT). 2007c) points out that public transport is not viable in cities that suffer from urban sprawl, because there are not enough passengers per station/bus-stop. This means that a city like Cape Town will depend on private vehicles and will suffer traffic and poor air quality as a result.

The draft goes on to explain that a population density of 25 dwellings per hectare is the internationally accepted minimum at which public transport becomes efficient and sustainable. The average population density of Cape Town is currently far below this at approximately 3.75 dwellings per hectare. In fact, by this standard, only those areas indicated in red on the map of Cape Town in Figure 2-11 can be considered suitable for sustainable public transport.

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In Chapter 11 of "*Counter Currents"* (Goven, 2010), Gita Goven explains her design to upgrade the informal settlement of Kosovo in Philippi, Cape Town. Her medium density approach of mixing 3 storey social housing with row housing ensured that none of the people living in Kosovo would have to move to a different location, and this would keep the social fabric of the community intact. The proposed development would cost R17 500 per housing unit more than the norm, which is the dominant low-density RDP housing approach.

Goven (2010) goes on to explain that a lower density housing approach would result in some households having to be moved to different locations, and that research by del Mistro showed that relocating some of the households to a site over 5 km away from Kosovo would result in a state subsidy of R16 600 per annum per commuter because of the additional subsidised public transport costs. Goven closes the argument by saying "*clearly it is more cost-effective for the state to pay for well-located higher density housing units at a once-off additional cost of R17 500 per unit"* (rather than pay the transport subsidy every year). (Goven, 2010)

While it is unfortunate that the past has led to Cape Town becoming a very low density, sprawling city, resulting in a disproportionally large use of energy in the transport sector when compared to the rest of the country, it is very important that the future does not follow the same path, and that Cape Town takes steps to increase its population density in an attempt to reduce the average commute for its citizens.

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2.2.5 Social Housing in Cape Town

The "gap" housing market consists of households that earn ZAR 3500 - 7500 per month (ZAR ≡ South African Rand). They earn too much to qualify for a full 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 (Nevin, 2011).

The social housing schemes that are to be pursued in South Africa are based on similar schemes in the United Kingdom, France and Holland. The idea is to publically provide housing for rental to low-income tenants.

In Cape Town, the first two social housing flats built under this new approach (Drommedaris and Steenvilla) have been completed, and are considered a success. They have the following details in common:

- Some of the flats are made available to households that would qualify for Government subsidies. (Households that have an income of less than R3500 per month).
- The rest of the flats have been made available to households that fall into the "Gap" income bracket, earning between R3500 and R7500 a month.
- Households that earn more than R7500 per month are not allowed to apply to rent one of the apartments of these flats.
- Both social housing projects have solar water heaters providing hot water, with electrical geyser back up.
- One of the main criteria of social housing is that it is well-located and high density, with easy access to shops, schools and public transport. This is the case with both Drommedaris and Steenvilla.

(Nevin, 2011)

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2.3 The Rebound Effect

2.3.1 Theory

"Does technological innovation to improve the efficiency of energy-using products and systems lead to lower energy consumption and hence reduced environmental impacts? The answer given by economists since the mid-19th century is 'no'." (Herring and Roy, 2007)

If a product or service undergoes improvements to make it less resource intensive, it should mean that there is less environmental impact per unit. However, it must also be taken into consideration that if the product/service becomes less resource intensive, it is likely to drop in price as well. This drop in price may result in an increased demand for the product or service, which would reduce the positive effect of the improvement that made it less resource-intensive in the first place. This effect is known as the "Rebound Effect" (Jones, 1993).

The terms "rebound effect" or the equivalent "take-back effect" originated in the economic literature. In terms of environmental literature, it was first applied to the narrow case where "the direct increase in demand for an energy service whose supply had increased as a result of improvements in technical efficiency in the use of energy" (Greening *et al*, 2000).

Herring and Roy (2007) explain that *direct* 'rebound' or 'take-back' effects caused by energy efficiency improvements that lower the implicit price of energy, lead to greater consumption of the same energy source or product. There could also be secondary or *indirect* effects of reducing energy costs through efficiency, where consumers spend more money on other products or services.

Davis (2008) uses the following equation to explain the direct rebound effect in terms of energy savings:

$$\textbf{Rebound effect} = \frac{\textbf{expected savings} - \textbf{actual savings}}{\textbf{expected savings}}$$

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A rebound effect of 0% would imply that the energy efficiency improvements did not lead to increased consumption of the product at all.

A rebound effect of 100% would imply that the energy efficiency improvements led to increased consumption to the extent that no energy is saved at all.

It is possible to have a rebound effect of over 100%, and this can be referred to as the "backfire effect" (Davis 2008).

It would be beneficial to use the concepts behind the rebound effect for this study. If a housing development is built closer to the city and the effected population did not have to travel as far to get to work, they would save money on transport to work. This saved money could be spent on transport to other places (direct rebound effect), or it could be spent on entirely different products and services (indirect rebound effect).

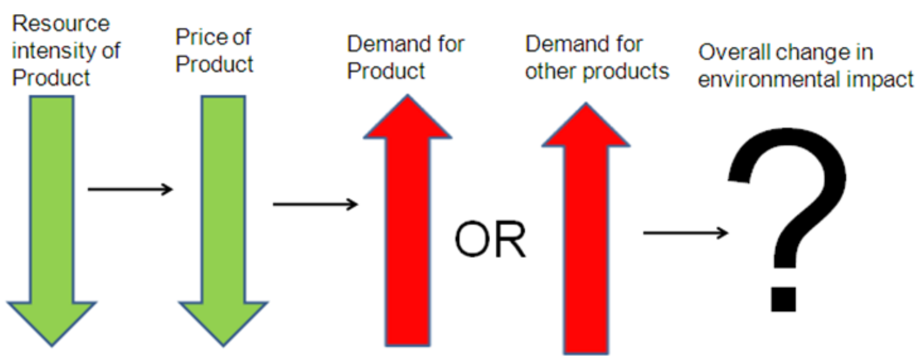

Figure 2-13 Explaining the Rebound Effect

Table 2-5 has been taken from Davis et al (2010), who in turn adapted it from Greening et al (2000). It shows that 5 studies have been consulted and show that energy efficiency interventions for water heating (such as solar water heaters) result in an estimated rebound effect of 10 – 40%.

Table 2-5 Typical Rebound Effects from past Studies (Davis et al, 2010)

Device	Size of Rebound (%)	Number of Studies
Space heating	10-30	26
Space Cooling	0-50	9
Water heating	10-40	5
Residential lighting	5-12	4
Home appliances	0	2
Automobiles	10-30	

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Greening et al (2000) do go on to point out that the range of methods used to explore this was not wide enough and the results should be seen as inconclusive. It is also very important to consider the income bracket of the households studied. Low income households should have a higher direct rebound effect if they had a “suppressed” demand for hot water.

2.3.2 Past Studies into the Rebound Effect in South Africa

There have already been at least two studies to determine the effect of Solar Water Heater roll-out on a low-income household’s energy consumption.

Kuyasa (Cape Town)

Kuyasa CDM was the first Clean Development Mechanism (CDM) project successfully implemented in South Africa (Kuyasa, 2011). Kuyasa is a section of Khayelitsha where the community had received fully subsidised RDP houses, and the CDM project involved providing the following upgrades to these houses:

- Installation of a ceiling
- Installation of Solar Water Heaters (without electrical back-up)

- Rewiring of electricity and roll-out of energy saving compact fluorescent light bulbs (CFLs).

The project is generally regarded as a success. A baseline survey (Wesselink, 2010) was carried out before the project implementation and it showed that the houses did not have electric geysers and had to use electric kettles to heat water. Because of the lack of ceilings, the houses used to get very cold in winter and despite being very poor, 63% of the 1771 households surveyed had to resort to heating their houses, of which 87% used paraffin heaters.

A follow-up survey was also conducted (Wesselink, 2010), where 679 of the households were asked if they felt like their electricity consumption had changed since before the project was carried out. The responses are shown in Table 2-6 below:

Table 2-6 Kuyasa Follow-up survey information (Wesselink, 2010)

KUYASA		
Response to Question about how Electricity Consumption had changed since Solar Water Heater Installation		
	Number	Percent
Not sure/uncertain	54	8.0
More than before	8	1.2
Same as before	367	54.1
Less than before	239	35.2
No reply	11	1.6
TOTAL	**679**	**100**

It needs to be considered that the other interventions would theoretically have reduced the household's energy consumption as well. The ceilings that were installed would have moderated the temperature of the houses better, so that there would be less need for space heating of the households in winter. However, as the majority of those households that used heaters used paraffin as a fuel, the ceilings were unlikely to directly reduce electricity consumption.

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The CFLs would have reduced the electricity requirements for lighting.

Even with all 3 energy interventions summed together, 54% of the respondents stated in the follow-up survey that their electricity bills were the “same as before”, while only 35% stated that their electricity bills were “less than before”.

The majority of respondents who claimed that their electricity consumption had decreased claimed that it was due to the installation of the solar water heaters. The majority of households that claimed their paraffin/fuel consumption had decreased attributed this to the installation of the ceilings.

Only 35% of respondents saying that their electricity consumption had reduced would initially strike one as a disappointing result. However it must be remembered that the households did not have electric geysers before the interventions were installed, and this means that the solar water heaters were satisfying what had previously been a *suppressed demand* for hot water. This means that the solar water heaters had improved the quality of life of the households, but not at the expense of increasing their electricity consumption.

Zanemvula

Davis et al (2010) researched a SWH roll-out program at RDP-style houses in Zanemvula near Nelson Mandela Bay. The SWHs were installed without electrical back-up. The study compared electricity purchases from before the SWH was installed, with electricity purchases for the same household from after the SWH was installed. The research collected actual data for electricity purchases from the pre-paid electricity vendor for the area.

Their findings were that the rebound effect played a very significant role for households with such a low income. In fact, 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 Solar Water Heater 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.

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The study goes on to suggest that for the low-income households of Zanemvula, there was a *suppressed demand* for hot water. Several other findings from the reports support this:

- The proportion of households using hot water to wash clothes increased from 3% to 26% after the SWH installation, confirming a direct rebound in demand for hot water.
- The average number of appliances per household increased, indicating an indirect rebound (the saved electricity from not having to heat water is still consumed by the household in other ways).

2.3.3 Suppressed Demand

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It is a common sustainable development argument understood that the provision of cleaner technologies to poor communities which have suppressed demand for energy services, does not lead to a reduction in the carbon footprint, as it allows the community to use more of such services than before (Nissing and von Blottnitz, 2010).

In fact, there is a condition that allows for suppressed demand to be considered in projects implemented under the Cleaner Development Mechanism (CDM). Winkler and Thorne (2002) point out that the CDM rules allow *'for baselines that account for emissions "above current levels due to specific circumstances of host parties". This provision lends support to crediting of growth in demand for energy services where it is currently suppressed as a result of poverty and/or lack of infrastructure or suppressed demand. The question is whether the existing level of consumption is the baseline or the future expected level of consumption including "development" advances in provision of energy services and as a result of poverty alleviation is the baseline. '*

Kuyasa and Zanemvula both showed that for very low-income households, there is a suppressed demand for hot water, and consequently that the installation of SWHs in such communities does not lead to significant decreases in electricity consumption but also that such projects fulfil the requirements of sustainable development and of Greenhouse gas (GHG) mitigation.

An optimistic disposition on the future of South African cities must recognise significant upward mobility, with low-income households finding employment and moving into higher income brackets. This disposition is supported by the finding that 12 000 new black middle class families are *"moving out of the townships and into the suburbs of South Africa's metro areas every month (UCT Unilever Institute)"* (National Planning Commission, 2011)

From this perspective, it makes sense to pose the question of whether there is a suppressed demand for hot water and electricity, and whether the installation of SWHs would result in a significant decrease in the carbon footprint, for households in higher income brackets, such as the gap income-bracket.

2.4 Summary of the Literature

It must be noted that the majority of the world's population have substandard living conditions and must aim for an improved quality of life. However, it must also be noted that the population is already drawing too many resources from the planet, and conventional development to improve quality of life will usually worsen the environmental burden of the human population on the planet. It is for this reason that interventions that address the double dividend of trying to improve quality of life at the same time as trying to reduce the environmental impact are so important.

Two interventions have gained prominence in Cape Town in recent years. The first is city densification in an attempt to shorten commute distances and make using public transport more convenient and sustainable. The City of Cape Town has issued a draft for a city densification strategy. Such a strategy appears to be possible, as shown by the Brazilian city Curitiba that is often cited for its work in sustainable transit-oriented development (UNISDR, 2011). A large part of the city's success must be attributed to the fact that its population density has increased by approximately 500% since the master plan for transit-oriented development was adopted in 1960.

The other intervention is the installation of large numbers of solar water heaters, as a prominent component of the City of Cape Town's Energy and Climate Change Strategy. Life Cycle assessment studies confirm that such solar water heaters have very short greenhouse gas emissions payback periods, especially in South Africa, with high amounts

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of solar irradiation available and where 89% of the electricity they replace is generated from coal.

The rebound effect is an economic term used to explain why energy efficiency interventions such as the ones described above often do not result in the households or communities reducing their environmental impact as much as originally expected. When an energy efficiency intervention is implemented, and energy is saved, this usually results in money being saved as well. The direct rebound effect describes the scenario where this saved money is spent on the same energy that the energy intervention reduced in the first place. The indirect rebound effect describes the scenario where the saved money is spent on other goods and services, but it must be remembered that these other goods and services are also likely to have some environmental impact attributed to them.

There have been two known studies into the effect that installing solar water heaters has on the electricity consumption of low-income households in South Africa. Both the studies of Kuyasa (Wesselink, 2010) and Zanemvula (Davis *et al*, 2010) were conducted on households in South Africa's poorest income bracket where the households earn a total income of less than ZAR 3 500 per month and therefore qualify for fully subsidized housing. Both studies indicated that at such low household incomes, the suppressed demand for electricity is so great that the installation of solar water heaters does not reduce the average electricity consumption of the households by much or at all. Davis *et al* (2010) went on to describe that the behaviour of the community changed, in that more people started using hot water to wash clothes, and more people started using other electrical appliances too.

These findings lead to the question of whether the rebound effect plays a significant role on the expected reduction in electricity consumption when higher income households install or are provided with solar water heaters. Davis (2010) has already expressed a desire to investigate the rebound effect of higher income households, but these households typically do not live in housing developments where solar water heaters can be rolled out en masse. Households in these income brackets can typically make the decision about whether to install solar water heaters individually.

The one other income bracket where the mass roll-out of solar water heaters is a real possibility is the gap housing income bracket. This comprises households that earn between ZAR 3 500 and ZAR 7 500 per month, which means that they do not qualify for a

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full government housing subsidy, but still struggle to afford housing in the private sector. Two new social housing schemes have been recently constructed in Cape Town to help provide affordable rental stock for this income bracket, Steenvilla in Steenberg and Drommedaris in Milnerton, both of which have installed solar water heaters. This means that there is the opportunity to compare the electricity consumption of households in the gap income bracket who use solar water heater with those that use conventional electric geysers.

Both Steenvilla and Drommedaris are also very well located, close to shops, schools, public transport and potential places of work. This is one of the criteria for social housing. However, there are also people in the gap housing bracket living in similar 3 to 4 storey flats in poorly located areas on the periphery of the city. This means there is also the opportunity to investigate how living in well-located areas affects the transport-related carbon footprint of Cape Town households in the gap income bracket.

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3 METHODOLOGY

There is a global need to reduce the environmental impacts resulting from household consumption. Household energy use (including energy for transport) is a particular area that requires attention due to the link between greenhouse gas emissions and climate change. Local governments can play a big role here in a far-reaching way by making decisions about housing schemes that are yet to be built. This will help the future tenants not to be locked into unsustainable levels of electricity and transport fuels usage. By choosing to install solar water heaters instead of electric geysers, the housing scheme could reduce its tenants' electricity consumption, and by building housing schemes in well-located areas the tenants' use of private/public transport could also be decreased.

In Cape Town, there is increasing numbers of low-income earners who are living in informal housing. This means that unlike cities in the developed world (which dominate the literature on sustainable cities), there is still a lot of scope for new housing projects, and for government to influence household consumption by assisting these housing schemes to provide a sustainable lifestyle for their tenants.

Encouragingly, the City of Cape Town (often in partnership with social housing companies like Communicare and SOHCO Amalinda Housing) is pursuing the interventions of city densification and providing solar water heaters because these interventions will improve the quality of life of the people affected, but also because they believe it will reduce the environmental load of the affected inhabitants. However, no quantitative analysis has actually shown that this has the desired effect for the gap-income group, while taking into consideration the rebound effect.

Quantifying the environmental impact of different existing households may provide valuable insight into how future housing schemes should be built, especially if the findings can be converted into an easily understood indicator (Carbon footprint / Ecological footprint) that would help housing policy decision makers to understand the environmental impacts of their housing schemes.

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As already stated in chapter 1, this dissertation investigates the effect of location (reduced transport distances) and domestic energy technology choices (installing solar water heaters) on the environmental impact of an average gap-market household, while taking the rebound effect into account. It aims to establish whether these interventions actually reduce consumption or whether they merely shift consumption towards other resource intensive products and services. This chapter begins by presenting the key research questions informed by the literature review in chapter 2, proceeds to outline the general methodology of locating different sets of flats and conducting expenditure surveys, gives an overview of the selected flats and explains the questions asked by the household expenditure survey, describes how hard data on electricity purchases was made available for two sets of flats in the study, discusses the ethical considerations for carrying out the research, and finally tests the methodology through a preliminary survey.

3.1 Choosing Carbon Footprint as the Impact Indicator

It is important to note that for the scope of this dissertation it would be impossible to conduct a detailed life cycle assessment for every category of spending that is going to be analysed. It was therefore important to choose a simpler indicator of environmental impact, and preferably one that policy-makers in South Africa would find easy to understand, and one where data would be available for a wide range of goods and services.

Many publications in South Africa make use of the carbon footprint as an indicator to compare the environmental impact of forms of energy as well as goods and services. Cape Town's Energy and Climate Change Strategy (City of Cape Town (CCT). 2007b) makes use of the carbon footprint as its main environmental impact indicator, and in an attempt to be consistent and relevant; this dissertation makes use of the carbon footprint indicator in the hope that its results will be easily understood.

It must be recalled from chapter 2 that the carbon footprint only gives an indication of a product or service's global warming potential. The carbon footprint gives no insight into other environmental impacts such as eutrophication, acidification or toxicological stress on human health and ecosystems.

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3.2 Key Research Questions

The following three key questions are posed:

1. *By how much would installing solar water heaters in social housing schemes reduce emissions from household energy use?*

   This question can also be phrased as "What is the electricity consumption of ordinary gap-income houses compared to ones that have solar water heaters?"

2. *By how much would building social housing schemes in well-located areas closer to the city centre reduce people's transport emissions, if at all? Would it also result in the inhabitants saving money on transport?*

   In order to answer this key question, the following information needs to be investigated:

   - Where do low-income earners who live in poorly-located areas on the outskirts of the city work? How do they travel?
   - Where do people, of the same income, but who live in well-located areas closer to the CBD work? What, if any, are the benefits in travel distance to work?
   - What are the benefits in terms of money saved due to not having to travel as far?

3. *If people save money on transport and electricity, what major products and services do they spend this extra money on instead? What is the comparative environmental impact of these products and services?*

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3.3 Outline of Research Methodology

This study attempts to address the key questions in a four-step process.

1. For the purpose of this study, it has been decided to survey households with an average monthly income of approximately ZAR 6 000. Assuming a monthly rent of ZAR 2 000 per month, this should leave each household with a disposable income of approximately ZAR 4 000 per month to spend on electricity, transport, groceries and other goods and services. In order to prepare for the survey, income and expenditure data must be analysed to assess which main other goods and services are likely to be bought with money saved by reduced transport and electricity expenditure, according to the indirect rebound effect.

2. Undertake a pre-screening process to identify four appropriate groups of households to survey. It is important that each group of households has the same monthly income, spread over a similar average number of people in the household. The four groups should include:

   A. A group of households who live in a well-located set of flats close to the city, with solar water heaters.
   B. A group of households who live in a well-located set of flats close to the city, with only electric geysers.
   C. A group of households who live in a poorly located set of flats on the periphery of the city, with solar water heaters.
   D. A group of households who live in a poorly located set of flats on the periphery of the city, with only electric geysers.

3. Conduct an income and expenditure survey with the identified groups of households that includes questions on transport habits, electricity usage, and expenditure on other main categories. It is important to do many surveys in order to have meaningful results, but at the same time recognize the limited scope available to this dissertation. For this reason it was decided to perform approximately 15 household surveys for each of the 4 groups of flats. This survey is then used to determine if Groups A and B have reduced their overall transport expenses, compared to groups C and D, as a result of living in well located areas. It should also determine if

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Groups A and C have reduced their overall electricity expenses, compared to Groups B and D, due to the installation of solar water heaters. The expenditure on other main items should tell where money has been spent in the case of savings in transport or electricity expenditure, in order to gain insight into the indirect rebound effect.

4. Calculate the relative carbon footprint of the four different household groups. First the carbon footprint due to electricity consumption should be calculated for each of the four groups of flats. Secondly, the carbon footprint due to the transport habits should be calculated for each of the four groups of flats. Finally, the carbon footprint of any spending via the indirect rebound effect should be estimated. These carbon footprints of the four groups of flats should be compared on the basis of the highest average amount paid for electricity and transport. These results should display whether or not living closer to the city centre reduces the carbon footprint of gap-income households. It should also display whether solar water heaters reduce the carbon footprint of gap-income households. Finally, it is important to highlight any scenarios where interventions have reduced overall environmental load at the same time as improving quality of life.

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3.3.1 *Algorithm for Research Method*

Figure 3-1 gives an overview of the research method described above

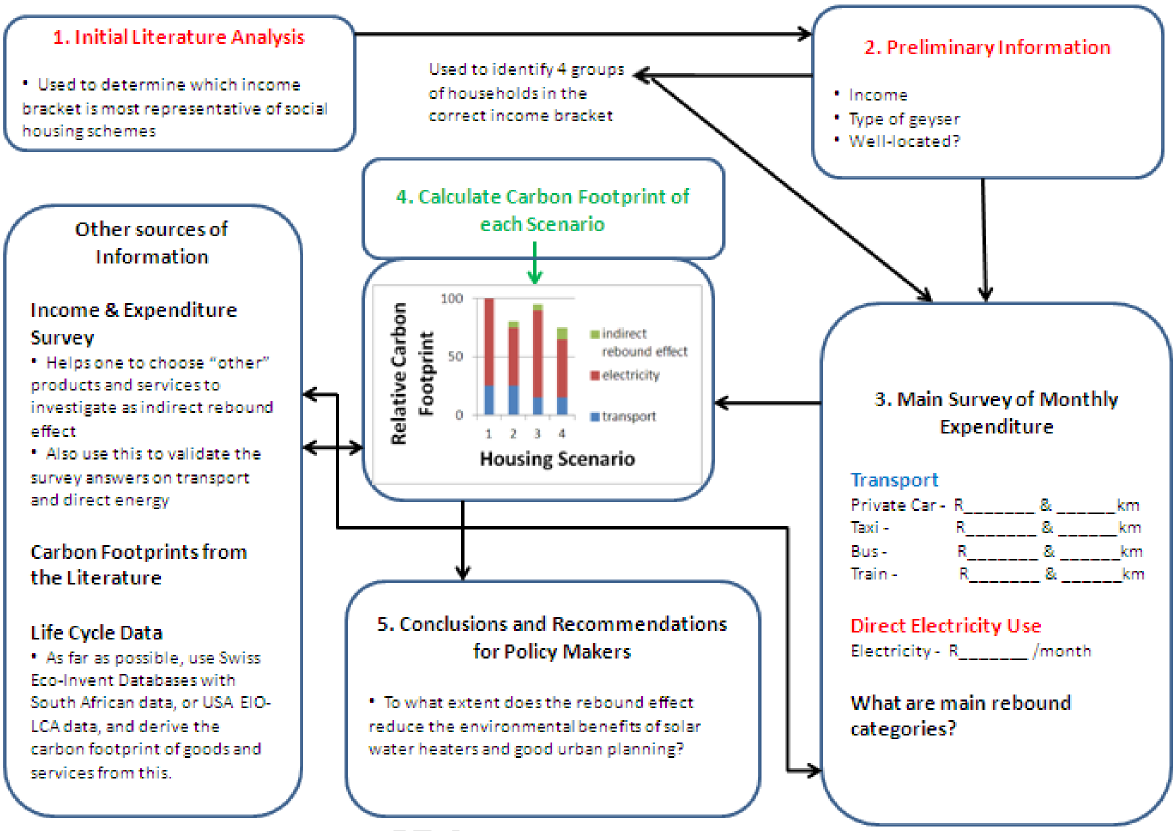

Figure 3-1 General Methodology Algorithm

3.3.2 *Other Sources of Information*

Statistics South Africa (2005 / 2006) provides income and expenditure data that must be analysed to find the other main goods and services that gap-income people are likely to spend extra money on. In addition, the data from Statistics South Africa, which provides data on the expenditures categories for average different income groups across South Africa, can be used to comment on the validity of the survey answers from this study. The limits of these data are that they are collected per income bracket from locations all over South Africa, both urban and rural.

Life Cycle Data for South Africa is gathered and stored using “ecoEditor 2, ecoInvent” as far as possible. In cases where South African data cannot be found, Swiss data is used from the ecoInvent databases. A simple life cycle assessment is used to estimate the carbon footprint of South African electricity.

Carnegie Mellon University Green Design Institute (2008) hosts a free economic input and output lifecycle assessment tool online. This tool uses United State of America (USA) data from 2002. It must be noted that coal is the largest source of electricity generation in the USA (U.S. E.I.A., 2011), but not to the extent that coal-powered electricity dominates the South African grid, and this means that South African specific carbon footprint data, if available, may be more carbon intensive than USA data. This data is used to estimate the carbon intensity of goods and services that are bought as a result of the indirect rebound effect. The carbon footprint factors are expressed in terms of “kilograms of carbon dioxide equivalent per South African Rand spent” for each expenditure category.

3.4 Groups of Flats Chosen for the Study

The next section describes the groups of flats that were chosen for their combination of household income, location and whether or not they have SWHs installed. All 4 groups of flats are located in Cape Town, and should therefore have very similar average solar insolation levels of 4.46 kWh/m^2/day in winter and 6.95 kWh/m^2/day in summer (Synergyenviron, 2011).

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A. Drommedaris, Milnerton (Well-located and contains SWHs)

GPS coordinates: 33°53’59.60” S 18° 29’17.90” E

The Drommedaris Project was conceived by Communicare in 2006. Once the Environmental Impact Assessments and building plans had been approved, and the funding had been secured, the construction started on 13 October 2009. The overall investment into the project was approximately R75 million (Wiseman, 2011).

Most of the land was previously owned by Communicare, but the stretch on Koeberg Road was originally owned by the Republic of SA (Dept of Public Works). This land was made available to Communicare in the early 1990s, with the provision that it had to be used for low cost housing using Government subsidies (Wiseman, 2011).

This project is well-located in that it is located on Koeberg Road, which is a major taxi route. It is also a few hundred metres from the new Bus Rapid Transport (BRT) system. 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 within walking distance, and there is a clinic and library across the road. However, Drommedaris is approximately 5 km away from the nearest train station in Maitland, and its tenants would usually use a minibus taxi trip to reach this train station. It should also be noted that this development is new, and that many of its tenants will be working in the same jobs that they held before they moved into the Drommedaris Flats.

Figure 3-2 Drommedaris Flats in Milnerton

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B. Sakabula, Ruyterwacht (Well-located and contains electric geysers)

GPS coordinates: 33°54'48.44"S 18°33'13.45"E

Sakabula is an older block of flats built by Communicare. It is located in the mixed suburb of Ruyterwacht near the Epping Industrial area. It is within walking distance of a train station, as well as taxi and bus routes. It is close to several industrial circles, shopping malls (like N1 City) and other work opportunities. Shops and schools are within walking distance as well (Wiseman, 2011).

Figure 3-3 Sakabula Flats in Ruyterwacht

C. Amakhaya Ngoku, Masiphumelele (Poorly-located and contains SWHs)

GPS coordinates: 34° 7'47.69"S 18°22'23.70"E

Masiphumelele is an informal settlement located between Kommetjie and Noordhoek in Cape Town's Southern Peninsula. During Apartheid, people in Masiphumelele were constantly moved to Khayelitsha, and the size Masiphumelele remained small at only 400-500 people. Since the end of Apartheid in 1990, Masiphumelele has grown steadily, and one study in 2010 estimated that there was 38 000 people living there (Masicorp, 2011). This means that many Masiphumelele residents have not been living there long.

Amakhaya Ngoku (meaning "Homes Now" in Xhosa) was initiated after a fire destroyed approximately 400 informal homes located on a site that had been zoned for the building of a high school. Because the land only covered 1.3 hectares, only 69 RDP style homes could have been built if that had been the chosen design option. 352 households decided to support the project to house them in 2 and 3 storey apartments containing 2 bedrooms each (Amakhaya Ngoku, 2011).

The proposed project cost approximately R140 000 per apartment, which is double the current subsidy provided to eligible households. This meant that many other funders had to be found, and included funding from Germany, Monaco, the United Kingdom, and large corporations in South Africa. Construction began in November 2008, and part of the planning involved the installation of solar water heaters (Amakhaya Ngoku, 2011).

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At the time of the research for this dissertation, 6 of the proposed 11 blocks of flats had been completed and occupied by families on a “rent-to-buy” basis of ZAR 400 per month. The households are provided with prepaid electricity meters and are eligible for 50kWh free electricity per month in addition to what they buy. According to the tenants, the power cable that runs their televisions is provided externally and they therefore do not have to pay for the electricity that runs their televisions.

The residents of Masiphumelele mainly make use of minibus taxis for transport as the nearest train station is in Fish Hoek approximately 7 km away. The nearest shopping mall is Long Beach Mall in Noordhoek, which is within walking distance. However, it is too far to walk if one is hampered by carrying groceries and so taxis are often used to reach Long Beach Mall.

While the majority of Masiphumelele's residents are very poor, it was hoped that there were at least 15 households within the 6 completed blocks of flats who had regular work, were paying the rent regularly and were comparable to the tenants of the other groups of flats surveyed in this study.

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Figure 3-4 Amakhaya Ngoku, Masiphumelele

D. Ocean View Flats (Poorly-located and contains electric geysers)

GPS coordinates: 34° 8'42.66"S 18°20'49.00"E

The township of Ocean View was originally conceived during the Forced Removals under Apartheid in South Africa. In 1967, Simon's Town was declared a White Group area, and no place existed where the coloured community living there could be removed to. Ocean

View was built and the first people were removed from Simons Town to Ocean View in 1968. Soon afterwards, Noordhoek-Sunnydale was also proclaimed a White Area, and the coloured people living there also had to be relocated to Ocean View. Ocean View has since been identified as one of fifteen high priority areas for action against crime and drug abuse. The area is well-known for gangsterism, drug addiction, alcoholism and high unemployment (Scenic South, 2011). Many of Ocean View's residents have been living there for many years, some even taking over their parents flats when they reach adulthood.

The area of Ocean View contains many 3 storey flats that the tenants rent from the council, mostly for between ZAR 300 and ZAR 400 per month. This is considerably less rent than the tenants of Drommedaris and Sakabula have to pay. The electricity is provided on a prepaid basis.

The nearest train station is in Fish Hoek, approximately 10 km away, but the area is well served by minibus taxis and buses. There are no supermarkets in Ocean View, and the households have to travel to Long Beach Mall in Noordhoek (7 km away) or Fish Hoek, for grocery shopping, and have to make use of minibus taxis to get there.

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Figure 3-5 Council Flats at Ocean View

Figure 3-6 shows where each of the four groups of flats is located in the Cape Peninsula. Amakhaya Ngoku in Masiphumelele and Ocean View flats were chosen as "poorly-located" mainly because of how far they are located from the Central Business District of Cape Town and most of its industrial areas, as well as how far they are from shopping malls and train stations.

Figure 3-6 Map depicting the Flats' locations (courtesy of Google Earth)

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3.5 Household Expenditure Survey

In order to address the key questions for this research, as laid out in chapter 3.1, the survey must attempt to gain the following information from each set of households:

- The modes of transport used by the households, along with monthly distance and cost.
- The amount of electricity purchased and consumed by the households.
- What the households would spend additional disposable income on. This was an attempt to uncover where money that may be saved via reduced electricity consumption or transport requirements might be spent instead via the indirect rebound effect.

At the same time, the survey must try to uncover any reasons why the 4 sets of households may not be comparable. The 4 sets of households should all be very similar in the following ways:

- Similar average household income close to ZAR 6 000 per month. However it must be noted that those households living in well-located areas tend to have to pay higher rent than those situated in poorly-located areas. It is important to compare households based on the disposable income they have available to spend on food, electricity, transport and other goods and services. For this reason, it is important to compare the groups of households on an “income minus rent” basis.
- Similar average household size
- Similar set of appliances
- Similar use of space heaters (preferably used only in winter)

Figure 3-7 describes how the survey answers will be combined with hard data for electricity purchases, and then converted into comparable carbon footprints.

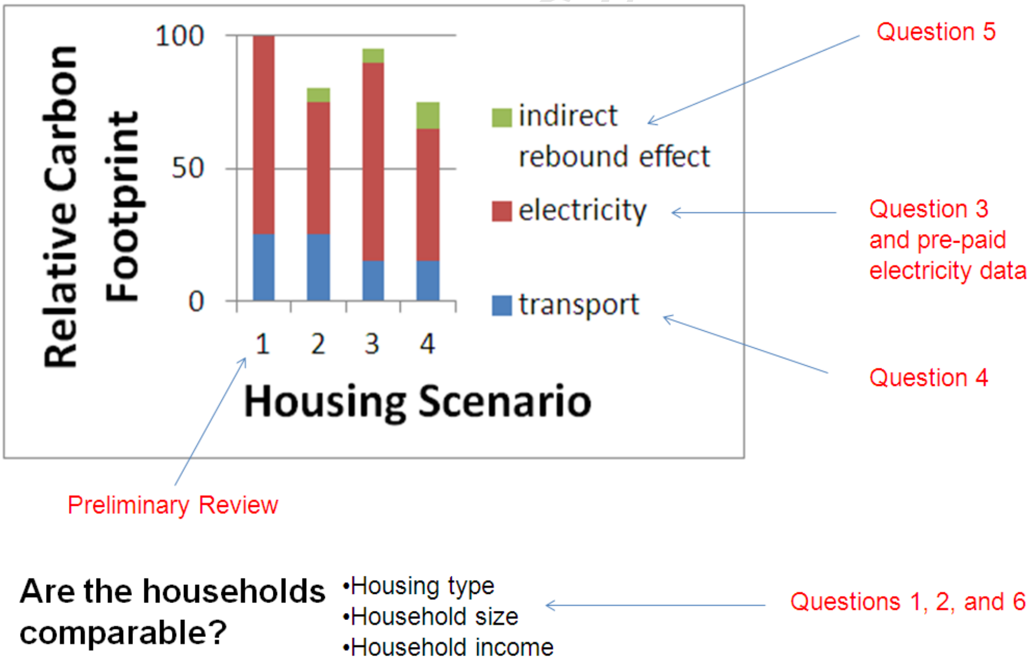

Figure 3-7 Outcomes of the Household Expenditure Survey Questionnaire

3.5.1 *Explanation of the Survey Questionnaire*

1. PERSONAL DETAILS:

Date:			
Number:			
Housing scheme where you live:			
Household Size:	Adults (18+):	School-going Children:	Non School-going Children:

To make the comparison fair, the four groups within this survey will need to be as identical as possible in all respects except for the actual variables that are being studied, namely the type of geyser and/or how well-located they are. The first question investigates household size, in an attempt to confirm that the average numbers of adults and children in the household are similar for all groups.

2. HOUSING TYPE (Please tick):

Flat ☐ Stand-alone house ☐
Number of rooms ______________________

Question 2 seeks to confirm that all groups live in flats of a similar size. If the flats were very different in size, there would be greater lighting requirements and potentially greater heat losses from piping in the larger flats.

3. ELECTRICITY

3.1. HOT WATER

What type of geyser do you use? (Please tick): • Conventional Electric Geyser ☐ • Heat Pump ☐

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- Solar Water Heater ☐
- Solar with Electric back-up ☐
- Gas Geyser ☐

3.2. SPACE HEATING

Would you say your house/flat is: (please tick):

sunny & warm	Medium	cold and dark

Do you use heaters in winter?

Yes	No

If yes, please describe how?

TYPE (electric / paraffin / gas)	**Hours per week**

3.3. ELECTRICAL APPLIANCES

Please tick which appliances you have in your house/flat

Fridge	
Oven	
Stove	
TV	
Radio/CD player	
Kettle	
Toaster	

How many CFL lightbulbs do you use?________________

How many normal lightbulbs do you use?___________________

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Question 3 confirms whether or not the group being surveyed has a solar water heater. It then goes on to explore other reasons that may explain any differences in electricity consumption, such as the need to use heaters, and the range of electrical appliances the household has.

4. TRANSPORT

Does your household own cars or motorbikes/scooters? If so, how many?

- ☐ Cars:________
  type:__________________
  type:__________________
- ☐ Motorbikes/scooters:___________________________
  type:__________________
  type:__________________

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Please fill in the following table for the household members that travel to work/tertiary studies:

Worker	Where	How often	How do you travel	Cost/month
1				
2				
3				
4				

Please fill in the following table for the household members that travel to school:

School student	Where	How often	How do you travel	Cost/month
1				
2				
3				
4				

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How does your household usually do the grocery shopping? Please tick one:

During the main commute home from work ☐

Close enough to walk to shops from home ☐

We have to do a separate trip ☐ , and use the following mode of transport:____________________

How long is the longest commute to work?_____________________________

How do you feel about this?

How much free time do you have per week? ___________________________

What do you typically do with your free time?

Question 4 aims to collect the information needed to calculate the household's transport-related carbon footprint via obtaining the mode of transport used, along with the distance and regularity. It then goes on to ask more qualitative questions about commuting in an attempt to investigate if the tenants of well-located flats have an improved quality of life though reduced time to commute to work/school, and thus more time to devote to family and leisure.

5. MARGINAL CATEGORIES OF SPENDING (DISPOSABLE INCOME)

If you had R100 **more** to spend per week, what would you spend it on?

1.	2.	3.

If you had R100 **less** to spend per week, what would you cut back on?

1.	2.	3.

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What is your estimated monthly household expenditure on the following?

Category	**Do you use/consume:**			**If you had R100 more per month, would you buy more?**		**If you had R100 less per month, would you buy less?**	
	High	**Medium**	**Low**	**YES**	**NO**	**YES**	**NO**
Bread/ cereals							
Entertainment (movies/eat out, etc.)							
Meat							
Dairy (milk, cheese, etc.)							
Toiletries							
Leisure transport							
Vegetables							
Paraffin							
Electricity							
Education							
Insurance							
Clothing							
Airtime							

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Question 5 aims to find the most likely categories for the indirect rebound effect. In other words "where would money, saved either on electricity or transport, be spent instead?" It is then important to combine the different household's answers, and source carbon footprint factors for these categories of spending to estimate the carbon footprint of the indirect rebound effect.

6. BUDGET

What is the household's average monthly income? Please tick:

R2 500 – R3 500	R3 500 – R4 500	R4 500 – R5 500	R5 500 – R6 500	R6 500 – R7 500

Can you give an estimation of your monthly expenses?

- What is your average monthly electricity bill? R________________/month
- What is your average monthly water bill? R________________/month
- How much do you spend on food/groceries? R________________/month
- How much do you spend on transport? R________________/month
- How much do you spend on rent? R________________/month
- How much do you spend on school fees? R________________/month

Any other debt/necessary fees that have to be paid monthly? R________________/month

After you have paid all your monthly expenses, how much money do you have left over to spend on other things?

Disposable income: R______________/month

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Question 6 seeks to establish the average income of the households in each of the 4 groups of flats, and find out the differences in broad categories of spending. This is to ensure that all 4 sets of flats fall into the same gap income bracket of approximately ZAR 6 000 / month, or ZAR 4 000 / month went rent is deducted, and that each flat follows similar expenditure habits.

3.6 Acquiring Electricity Expenditure Data

A. Drommedaris (Well-located and contains SWHs)

Drommedaris is run by the housing company Communicare. Drommedaris receives medium voltage electricity from Eskom, and has its own substation to convert it to low voltage electricity. Communicare then uses a third party company to provide prepaid electricity services (Wiseman, 2011).

The third party company is able to provide data for the number of kilowatt-hours (kWh) of electricity purchased by all of the flats in Drommedaris, as well as the money spent on purchasing this electricity. The electricity is sold at a price of approximately ZAR 0.80 per kWh.

For the purposes of this study, the Drommedaris electricity purchases for January, February and March 2011 were made available for the households that were to be surveyed in Phase A. of Drommedaris (where construction had already been completed and households had moved in by December 2010).

B. Sakabula (Well-located and does not contain SWHs)

Sakabula is also run by the housing company Communicare, and similar to Drommedaris, Sakabula also uses a third party company to provide prepaid electricity services (Wiseman, 2011)

Again, the third party company is able to provide data for the number of kilowatt-hours (kWh) of electricity purchased by all of the flats in Sakabula, as well as the money spent on purchasing this electricity. For the purposes of this study, the Sakabula electricity purchases for January, February and March 2011 were made available so that they could be compared with those of Drommedaris and the other groups of flats.

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C. Amakhaya Ngoku (Poorly-located and contains SWHs)

Unfortunately, no hard data could be acquired for the electricity consumption of the Amakhaya Ngoku flats, and the survey answers had to be used instead. It should be noted that the Amakhaya Ngoku flat tenants qualify for 50 free kWh of electricity if they are low electricity consumers, and their televisions are powered by an external power cable, and therefore do not add to the tenants' electricity bill.

The televisions do add to the tenants' carbon footprints, and therefore assumptions had to be made about the average power rating of the televisions, along with the number of hours they were switched on per week. This means that the electricity consumption answers for Amakhaya Ngoku must be treated with care when compared to those of Drommedaris and Sakabula.

D. Ocean View Flats (Poorly-located and does not contain SWHs)

Again, no hard data could be acquired for the electricity consumption of the Ocean View flats, and the survey answers had to be used instead. Ocean View tenants also buy prepaid electricity, and also qualify for 50 free kWh of electricity if they are low electricity consumers. Again, Ocean View's electricity consumption answers should be treated with care when being compared to those of Drommedaris and Sakabula.

3.7 Ethics

This research involved surveying low-income households, and because of this, it was important to show that the research would be conducted in an ethical manner, and to obtain ethical clearance in order to proceed with the research. The Ethics form is attached in the Appendices.

As there was no potential that the research could cause harm to a third party, and there was also no potential for conflicts of interest, the main cause of ethical concern is that the research makes use of human subjects and involves the participation of communities. The

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major cause for concern from this is that records of household's income and expenditure should be kept confidential.

In order for the hard data on Drommedaris and Sakabula prepaid electricity energy purchases to be matched up to the correct households' surveys, the surveys had to be recorded under the flat number. However, the following steps were taken to ensure confidentiality:

- The households were given the option to take the survey and were allowed to decline.
- The households were told that they could choose not to answer a certain question, but continue with the rest of the survey.
- All analysis and reporting on the expenditure of the different set of flats in the dissertation and in other reports will be averaged out into groups representing each set of flats of approximately 15 households each, and this was explained to the interviewed households.
- Only the author had access to the data that connects survey answers and prepaid electricity purchase data to flat numbers. Nobody else had access to this data, including the supervisors of this thesis.

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3.8 Testing the Methodology

The survey methodology was tested on a smaller scale project first, in order to gain experience in survey methodology, and to see where additional information is needed, and where the largest scope for error could occur.

3.8.1 Introduction

The smaller scale project compared the transport-related Carbon Footprint of University of Cape Town (UCT) students who live in residence with UCT students who commute from a digs/shared flat. UCT students who live in residences live close to UCT, and typically travel to UCT via shuttle (bus). UCT students who live in a shared flat typically live further from UCT and travel in their own private cars. This smaller project was used to help practise the carbon footprint modelling, and to aid in identifying data requirements before conducting the main dissertation survey.

3.8.2 Results

Table 3-1 gives a summary of the survey results:

Table 3-1 Comparing Transport Expenditure of UCT Students

	In Digs/shared flat (11 surveys)	In residence (9 surveys)
Average Household size	3.0	N/a
Average petrol expenditure (ZAR/person/month)	195	0
Average train travel (km/person/month)	87	16
Average bus/shuttle travel (km/person/month)	205	275
Average taxi travel (km/person/month)	15	31

Carbon footprint factors were sourced from Project 90X2030 (90 X 2030, 2011), and were used to compare the transport-related carbon footprints of the students. For an explanation of the underlying assumptions behind the carbon footprint factors, please refer to Chapter 4.3.2.

Figure 3-8 compares the transport-related carbon footprints of both sets of students. The results show that students living in digs/shared flats have a higher average transport-related carbon footprint than students living in university residences, mainly due to the use of private cars. This was an expected result.

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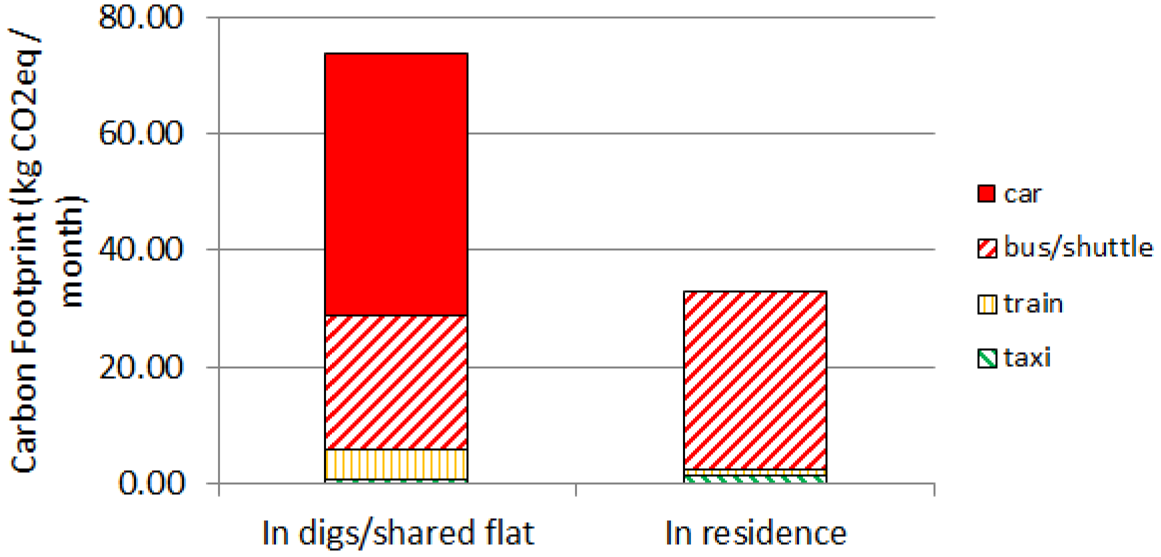

Figure 3-8 Comparing Transport-related Carbon Footprints of UCT Students

3.8.3 Discussion

The preliminary survey showed that students living in residence make greater use of the shuttle service and taxis, but that students living in digs/shared flats make greater use of private cars and trains and consequently have a higher transport-related carbon footprint. This was an expected result and shows the survey methodology to be a valuable method of gaining insight.

Carbon Footprint (2011) suggests that for a typical person in the developed world, transport should account for approximately 13% of their total carbon footprint. The average South African person has a carbon footprint of 8 700 kg $CO_{2\ eq}$ / annum (Millennium Development Goals, 2011), and the transport-related carbon footprint of the digs/shared flats students is approximately 10% of this figure. This demonstrates that the survey methodology can provide accurate figures, but that it is always important to look for evidence to back up the findings.

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3.8.4 Conclusion

Survey methodology is an effective way of exploratory research into comparing the carbon footprints of groups of people. The preliminary survey of UCT students was a useful exercise in gaining survey and carbon footprint modelling experience.

3.9 Summary of Methodology

The research aims to verify that gap income households with SWHs really do consume less electricity than similar households with electric geysers. The research also aims to prove that well-located gap income households do have a reduced transport related carbon footprint. Finally, the research aims to estimate and compare the carbon footprint of goods and services that these households may spend money on according to the rebound effect.

To do this, the research methodology conducts 15 household expenditure surveys for each of the four chosen groups of flats. The groups of flats have been chosen to compare households who have SWHs to those that use electric geysers, as well as to compare well-located households with poorly located ones.

The survey methodology was tested on a pilot case where the transport habits of university students living at home were compared with those of students living in residences. This pilot study gave encouraging results.

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4 RESULTS AND DISCUSSION – ELECTRICITY AND TRANSPORT

Chapter 4 first addresses how comparable the 4 chosen sets of flats are in terms of income, flat size and household size, and also attempts to uncover reasons why the electricity consumption and transport habits of the flats may differ apart from their location or use of solar water heaters. The survey results and electricity purchase data are then analysed to uncover the electricity consumption and transport expenditure of the 4 different sets of flats, and suitable carbon footprint factors are found to convert these results into carbon footprints.

4.1 Comparability of the Four Groups of Flats

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Before one can compare the groups of flats in terms of electricity and transport usage, one first has to ensure that the flats are very similar and comparable, except for those variables that are being studied: whether or not they have solar water heaters and whether or not they are well-located in terms of access to public transport, work, schools and shops. For the results to be meaningful, it is important to search for any other variables that might make a considerable difference to the flats' average electricity consumption or transport habits.

Questions 1, 2 and 6 in the household surveys were aimed at confirming that all 4 sets of flats were comparable, and some of the most important questions included:

- Do the households in each set of flats all have a similar average monthly household disposable income in the gap income bracket band, when rent is subtracted from total income?
- Do the households in each set of flats all have a similar average household size in terms of number of occupants? How much does household size affect the empirical electricity consumption data?
- Are all the flats a similar size and contain 2 bedrooms on average?
- Do all the flats have a similar range of appliances?
- Do all the flats only make use of space heaters during winter, if at all?
- Do all flats have a similar average expenditure on categories like food and groceries, rent and school fees?

Table 4-1 gives an overview of some of the most important similarities and differences between the four sets of flats.

Table 4-1 Overview of Survey Answers for Drommedaris, Sakabula, Amakhaya Ngoku and Ocean View

	Drommedaris (16 respondents)	**Sakabula (14 respondents)**	**Amakhaya Ngoku (5 respondents)**	**Ocean View (15 respondents)**
Type of Geyser	Solar water Heater, with electric geyser back-up	Only Electric geysers	Solar water Heater, with electric geyser back-up	Only Electric geysers
Average household size – total / adults	3.3 / 1.9	4.5 / 2.4	3.8 / 2.4	5.2 / 3.5
Average income (ZAR/month)	6 200	6 000	4 000	4 715
Average rent (ZAR/month)	2 120	2 050	400	335
Average expenditure on food and groceries (ZAR/month)	1 375	1 650	900	1 845
Average expenditure on electricity (ZAR/month)*	185	330	100*	315*
Average expenditure on transport (ZAR/month)	635	520	815	560
Average school fees (ZAR/month)	450	300	415	90
Average flat size	2 bedrooms	2 or 3 bedrooms	2 bedrooms	1 or 2 bedrooms

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Need for heaters for space heating	Most tenants 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	All groups of flats had a full list of appliances, including: • Television • Fridge • Oven/microwave and stove • Kettle • 4-6 overhead lightbulbs

The surveying at Amakhaya Ngoku in Masiphumelele yielded disappointing results. The management of the flats could only point out 9 households that were making an effort to pay the ZAR 400 rental regularly as an indication of which households had been able to find regular employment. Of these 9 households, only 5 were available to be surveyed. Because of the very small sample size, one household that had a comparatively high income and transport expenses was able to significantly alter the average income and transport expenditure of the group. If this single household is excluded, the average income becomes only ZAR 2 500 per month and the average transport expenditure becomes only ZAR 460. These figures may be more representative of households in Masiphumelele with regular work, but with a sample size of only 4 households one cannot assume this with high confidence. If the average income of working households in Amakhaya Ngoku in Masiphumelele is approximately ZAR 2 500 per month, then these households justifiably qualified for a full government housing subsidy, and cannot be considered as comparable to the households at Drommedaris and Sakabula.

The average rent in the council flats of Ocean View is also significantly less than that of Drommedaris and Sakabula, but the average household income is also significantly less in such a way that for all three cases, if rent is deducted from household income, the households are left with averages of ZAR 3 950 (Sakabula) to ZAR 4 380 (Ocean View) per month to spend on groceries, electricity, transport and other goods and services. These amounts are within 10% of each other.

A very obvious difference between Drommedaris and both Sakabula and Ocean View flats is that there are less people living in each household, both in terms of total inhabitants and

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number of adults. It will be important to bear this in mind when analysing the electricity consumption data.

In summary, Drommedaris, Sakabula and Ocean View household data should be viewed as comparable because in each case the number of surveyed households was approximately the same, and all households have similar disposable income when the rent is deducted from total household income. However it is very important to make note of the difference in average household size when analysing the results, and to remember that Ocean View's electricity expenditure is based on survey answers rather than actual prepaid purchase data.

Amakhaya Ngoku should be considered incomparable as only 5 suitable households were available to be surveyed, and typically the households were too poor to be considered comparable with the other 3 groups of flats. However, Amakhaya Ngoku may still provide interesting insight into electricity consumption, again remembering that its tenants' average electricity expenditure is based on survey answers.

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4.2 Electricity

The electricity purchases were investigated and compared per flat. Because of this, it was important to investigate the affect the household size had on the flat's total electricity consumption.

4.2.1 Electricity Purchases

Table 4-2 shows the results for the electricity purchases and consumption of each of the four groups of flats. It must be remembered that for Amakhaya Ngoku and Ocean View, it was not possible to obtain recorded commercial data on electricity purchases, and the survey answers had to be used instead.

Table 4-2 Electricity Purchases of the Flats

	Drommedaris (16 flats)	Sakabula (14 flats)	Amakhaya Ngoku (5 flats)	Ocean View (15 flats)
Average household size – total / adults	3.3 / 1.9	4.5 / 2.4	3.8 / 2.4	5.2 / 3.5
Average income (ZAR/month)	6 200	6 000	4 000	4 715
Average Electricity Purchases Jan-Mar 2011 (ZAR/month)	185	330	*100*	*315*
Average Electricity Consumption Jan – Mar 2011 (kWh/month)	230	378	*195**	*385*

It is important to recall that for Amakhaya Ngoku, 50 free kWh had to be added to the amount of electricity actually purchased. Another key difference about Amakhaya Ngoku was that according to its tenants, the power used to run the televisions comes from external cables and is not included within their own personal electricity purchases, but should be calculated into the tenants' average electricity consumption. To do this, it was assumed that the average TV ran on 0.4kW power, and that the tenants watched 1.5 hours of TV on weekdays and 3 hours of TV on weekend days. This would account for an additional 23kWh of electricity consumption per month, and meant that the tenants of Amakhaya Ngoku had an electricity consumption average of approximately 15% below that of Drommedaris, despite having a significantly lower income.

An important question arising is whether the Drommedaris electricity expenditure is significantly less than that of Sakabula because of the installation of solar water heaters or because there are fewer inhabitants living in each flat. Table 4-3 shows that for Drommedaris, the households with few inhabitants have the same expenditure on electricity as the Drommedaris households with many inhabitants. On the other hand, at Sakabula and Ocean View, households with more inhabitants (almost double) appear to spend only slightly more (5%) on electricity compared to households with fewer inhabitants. This apparent difference is not unexpected. All the flats within a group are approximately the same size, and therefore should have similar lighting requirements to each other. Similarly,

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one oven will be used to cook meals no matter how many people are being fed. The main cause of larger electricity requirements for larger families should be that more people require hot water. For families with Solar Water Heaters, this should not lead to a larger electricity requirement as electricity is not needed to heat water in summer.

Table 4-3 Separating Flats by number of inhabitants

	Drommedaris		**Sakabula**		**Ocean View**	
	3 people or less (11 flats)	**4 people or more (5 flats)**	**5 people or less (8 flats)**	**6 people or more (6 flats)**	**5 people or less (9 flats)**	**6 people or more (6 flats)**
Household size – total / adults	2.7 / 1.8	4.6 / 2.2	3.0 / 2.1	6.5 / 2.8	3.8 / 2.6	7.3 / 5.0
Income (ZAR/month)	6 140	6 340	6 200	5 740	3 955	5 855
Electricity expenditure (ZAR/month)	184	187	324	339	***311****	***327****
Electricity Consumption (kWh/month)	229	232	369	390	373	409

The other significant finding from Table 4-3 is that the Sakabula households with 5 or less inhabitants still purchase significantly more electricity than the Drommedaris households with 4 or more inhabitants. This means that at a similar income and rent, and with fewer people per household, this group of Sakabula households are purchasing more electricity than the Drommedaris households. This suggests that the solar water heaters are the major cause of this reduced electricity expenditure, rather than household size.

From the survey responses, it would appear that even at a significantly lower income, the Ocean View tenants also consume significantly more electricity than the Drommedaris tenants. Unlike the transport survey results where respondents could accurately say where they regularly travel and by which mode of transport, the accuracy of survey responses about electricity expenditure needs to be questioned.

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The Ocean View survey was conducted in the summer month of January 2012, so that the survey responses could be as comparable to the January to March 2011 data from Drommedaris and Sakabula as possible. However, there is still scope for human error.

Table **4-4** compares the survey responses on electricity purchases from Drommedaris and Sakabula with the prepaid electricity purchase data.

Table 4-4 Comparing Survey Responses to Prepaid Purchase Data for Electricity Expenditure of Drommedaris and Sakabula

	Drommedaris		**Sakabula**	
	Prepaid Purchase Data Jan-Mar 2011 (ZAR / month)	**Survey Responses July 2011 (ZAR / month)**	**Prepaid Purchase Data Jan-Mar 2011 (ZAR / month)**	**Survey Responses September 2011 (ZAR / month)**
Average Monthly Electricity Purchases (ZAR / month)	185	235	330	400

In both cases the average survey response estimated higher electricity expenditure per month than that revealed by the actual prepaid electricity data (by 21% and 27% respectively). Unfortunately the surveys at Drommedaris and Sakabula were conducted in the winter months of July and September 2011 respectively, and it is difficult to account for how much of the increase is due to higher actual electricity purchases in winter over summer, and how much is due to human error. South African Electricity utility Eskom (2009) does explain that demand for electricity is higher in winter than in summer. Urban Earth (2012) points out that Eskom's 2012 summer peak electricity demand is approximately 30 000MW, and that Eskom is expecting a winter peak electricity demand of 37 500MW later in 2012. This suggests a 20% increase in electricity demand from summer to winter in South Africa. This would indicate that the electricity survey responses from Drommedaris and Sakabula could be quite accurate and that the Ocean View and Amakhaya Ngoku survey responses may be accurate as well, but it would still be wise to treat the electricity survey responses from Ocean View and Amakhaya Ngoku with caution.

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However, based on actual prepaid electricity data, 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 40%, or 150 kWh / month during the summer months of January to March.

It must be pointed out that these savings are probably not as large during the winter months. From January to March the solar irradiation levels average 6.95 kWh/m^2.day for a tilted flat plate collector (Synergyenviron, 2011). 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 therefore 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 more space heating and lighting requirements.

4.2.2 Electricity Error Analysis

To strengthen the above conclusion, it is useful to perform a statistical analysis to prove that the flats with solar water heaters have a mean electricity consumption that is statistically different from those flats without. To investigate this, the two-tailed, two sample of unequal variance T-test was performed between the different sets of data, as shown in Table 4-5.

Table 4-5 T-Test Error Analysis of Electricity Consumption Data

	Drommedaris	Sakabula	Amakhaya Ngoku	Ocean View
Drommedaris	1	0.0015	0.313	0.00055
Sakabula	0.0015	1	0.00096	0.853
Amakhaya Ngoku	0.313	0.00096	1	0.00047
Ocean View	0.00055	0.853	0.00047	1

It can be said with 99% confidence that the data from Drommedaris and the data from Sakabula was taken from two different populations with two different true mean household

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electricity consumptions. It can also be said with 99% confidence that the data from Drommedaris and the data from Ocean View are statistically significantly different.

To prove that the electricity consumption is not statistically different because of different household sizes, two-tailed, two sample of unequal variance T-tests were also performed to compare the Drommedaris flats with 4 or more people living in them with the Drommedaris flats with 3 or less people living in them, as well as the Sakabula and Ocean View flats with 5 or less people living in them. Table 4-6 shows that both the small and large households at Drommedaris have a statistically significant reduced electricity consumption compared to the smaller households at Sakabula and Ocean View.

Table 4-6 T-Test Error Analysis on Electricity Consumption by household Size

	Drommedaris 3 people or less (11 flats)	**Drommedaris 4 people or more (5 flats)**	**Sakabula 5 people or less (8 flats)**	**Ocean View 5 people or less (9 flats)**
Average Household Size – Total / Adults	2.7 / 1.8	4.6 / 2.2	2.7 / 1.8	3.8 / 2.6
Drommedaris 3 people or less (11 flats)	1	0.90	0.0047	0.0049
Drommedaris 4 people or more (5 flats)	0.90	1	0.0059	0.0059
Sakabula 5 people or less (8 flats)	0.0047	0.0059	1	0.93
Ocean View 5 people or less (9 flats)	0.0049	0.0059	0.93	1

Because each household has different electricity consumption habits, there was significant variance in the answers given for each of the 4 groups of flats. This means that the sample averages may not reflect the true averages of the whole population. A statistical analysis was performed to find the range of values that each group of flats' true average electricity consumption could be, assuming the survey households were only a small sample of a very large population.

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Table 4-7 Range of True Population Means for Electricity Consumption

	Confidence (%)	Lowest true mean electricity consumption (kWh/month)	Sample mean electricity consumption (kWh/month)	Highest true mean electricity consumption (kWh/month)
Drommedaris - 3 people or less (SWH)	95	186	228	270
Drommedaris - 4 people or more (SWH)	95	195	232	269
Sakabula (Electric geysers)	95	307	378	449
Amakhaya Ngoku (SWH)	95	145	195	248
Ocean View (Electric geysers)	95	319	387	456

Despite the wide ranges in what each true mean could be, assuming very large populations in each quadrant, it can still be said with 95% confidence that those flats that have solar water heaters consume less electricity than those with conventional electric geysers, and therefore there cannot be a 100% rebound towards buying more electricity as was the case with the studies of the lower income households at Kuyasa (Wesselink, 2010) and Zanemvula (Davis, 2010).

4.2.3 Estimating 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 kilowatt-hour 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 4-8.

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Table 4-8 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

(Eskom Integrated Report, 2010)

Notten (2010) has combined these figures to create a SimaPro database for the South African electricity mix. This simple life cycle assessment gives a carbon footprint of approximately 1.0 kg CO_{2eq} / kWh of South African electricity. This carbon footprint matches what Eskom publishes in its own annual report. (Eskom Integrated Report, 2010)

4.2.4 Electricity Carbon Footprint of the Flats

The carbon footprint factor for South African electricity is applied to the electricity consumption of the four groups of flats, assuming that the sample mean is close to the true population mean, in Table 4-9.

Table 4-9 Electricity Carbon Footprint of the Flats

	Drommedaris (16 flats)	Sakabula (14 flats)	Amakhaya Ngoku (5 flats)	Ocean View (15 flats)
Average Electricity Carbon Footprint (kg CO_{2eq} /month)	230	378	195	384

Drommedaris has a reduced electrical carbon footprint of 150 kg $CO_{2\ eq}$ / month compared to Sakabula and Ocean View for the summer months.

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Using the method of Guma *et al* (2008), and assuming that the SWH delivers 200 litres of hot water per day to a family of 4 people, and that the average Cape Town solar irradiation from January to March is 6.95 kWh/m^2.day for a tilted flat plate collector (Synergyenviron, 2011), it is possible to estimate that a SWH could theoretically reduce the carbon footprint of a household by approximately 180 kg $CO_{2\ eq}$/ month.

This means that for this study, and assuming that the method of Guma *et al* (2008) is applicable, the direct rebound effect could tentatively be estimated as:

(180-150) / 180 % = ± 20%.

Surprisingly, this figure corresponds well with the lower range of literature values described in Chapter 2.3.1 of the literature review. It was expected that because the households in this study are still relatively poor, there would have been a higher direct rebound towards buying more electricity. Because South Africa's electricity is so carbon-intensive, this finding is very encouraging for the promotion of solar water heaters.

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4.3 Transport

The transport habits and expenditure were investigated and compared per person.

4.3.1 Transport Expenditure and Habits of the Flats

Question 4 of the household expenditure surveys aimed to discover what modes of transport were used by the households, how often they travelled and what distance, and also the expense incurred because of their transportation habits.

Table 4-10 Transport Habits and Expenditure of the FlatsTable 4-10 provides a summary of the results.

It should be noted that it was decided to remove Amakhaya Ngoku from the transport analysis. The fact that only 9 households are attempting to pay the rent regularly indicates that the majority of households in this housing scheme are unemployed and trapped in a location where finding nearby employment is extremely difficult and to travel to other areas of Cape Town is too expensive. Masiphumelele highlights those cases where a settlement is poorly located in that the size of its population overwhelms the amount of work available in the area, and therefore must be considered socially unsustainable, and incomparable to the other three groups of flats.

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Table 4-10 Transport Habits and Expenditure of the Flats

	Drommedaris – well-located (16 flats)	Sakabula – well-located (14 flats)	Ocean View – poorly-located (15 flats)
Average Expenditure on transport (ZAR/household/month)	635	520	560
Average Expenditure on transport per person (ZAR/capita/month)	190	115	110
Total one-way work/school/grocery related trips per month	1441	1352	2112
% trips car use	24.6%	18.7%	9.3%
% trips taxi use	22.3%	14.0%	32.4%
% trips bus use	8.7%	3.1%	10.9%
% trips train use	0%	31.6%	0%
% trips train/taxi mix	9.4%	0%	1.4%
% trips bus/taxi mix	2.9%	0%	0%
% walk/bicycle	32.1%	32.7%	46.0%

Figure 4-1 allows the percentage use of each transport mode to be compared to each other.

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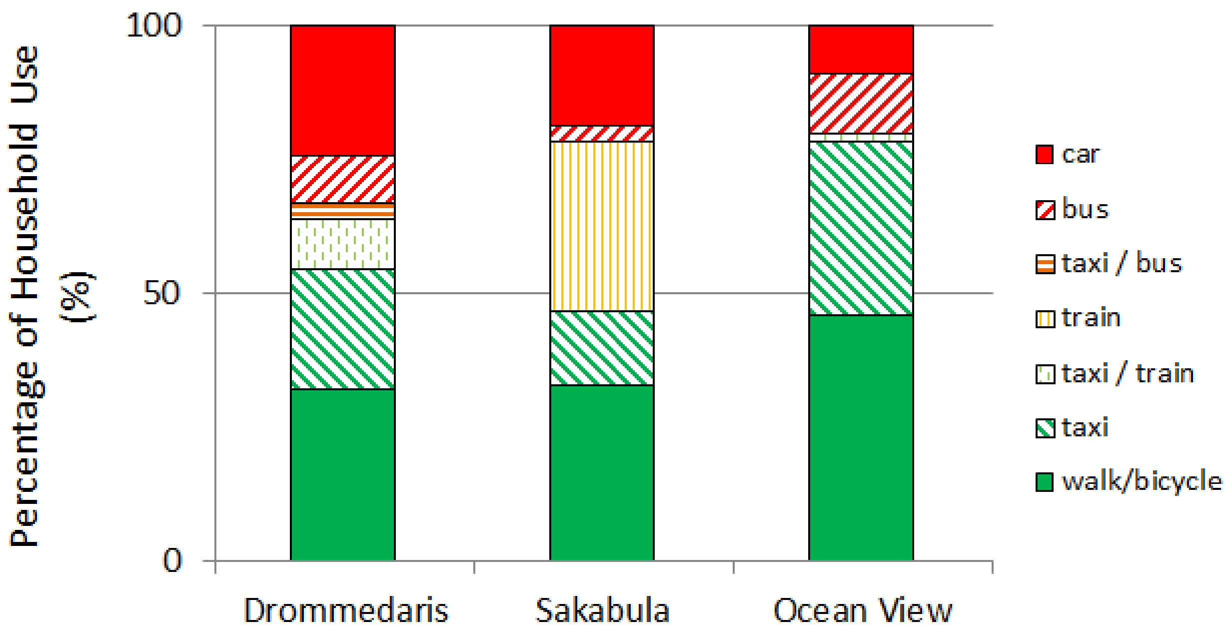

Figure 4-1 Household use of each Transport Mode by Percentage

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It can be seen that people in Ocean View walk (or use bicycles) more than the other two groups of flats. At the Ocean View flats, there was a primary school and a high school located nearby and almost all school children were able to walk to school. At Drommedaris and Sakabula there were also schools within walking distance, which explains the high percentage of walking (or cycling) there, but in each case several of the children went to other schools further away. It could be posed that at Ocean View the schools within walking distance were the only cheap and convenient schools in the area.

Sakabula is the only group of flats within walking distance of a train station, which sees many people being able to use the trains without having to take a taxi to reach the station first. For Drommedaris, the closest train station is in Maitland about 4 km away, and people who use the trains have to catch a taxi first. For Ocean View, one would have to travel approximately 10 km to Fish Hoek in order to catch a train. For this reason, trains are not used as much by the Drommedaris tenants as by those of Sakabula, and trains are hardly used at all by people in Ocean View. This results in a higher use of taxis and buses at Ocean View, and a higher use of taxis, buses and private cars at Drommedaris.

Travelling by train is relatively cheap with monthly tickets costing either ZAR 99 or ZAR 199. Resorting to other options like private car use, buses or taxis is usually more expensive, which explains at least in part why the average transport cost for Drommedaris is more than for Sakabula. The average expenditure per trip (excluding walking / cycling) is ZAR 10.35 for Drommedaris, ZAR 8.00 for Sakabula and ZAR 7.37 for Ocean View.

Ocean View tenants have to travel approximately 10 km to Fish Hoek or 7 km to Noordhoek for grocery shopping and do this about 4 times a month by taxi, costing the household an extra ZAR 48 per month, whereas most households at Drommedaris and Sakabula can either shop on the way home from work, or are within walking distance of shops.

Figure 4-2 shows the average expenditure per person on each mode of transport from each group of flats, and in a surprising result; instead of the isolated Ocean View tenants having the highest average transport expenditure per person, they have the lowest. It is actually the Drommedaris tenants that spend the most on transport per person and even per household. It appears that Drommedaris tenants spend more on private car transport than Ocean View tenants, as well as more on taxi transport than Sakabula tenants. This higher expenditure on transport by the Drommedaris tenants may suggest an indirect rebound effect, with the money saved on electricity via the solar water heaters being spent on transport instead. On the other hand, even though Drommedaris is centrally located in the city, it does lack access to relatively cheaper rail transport.

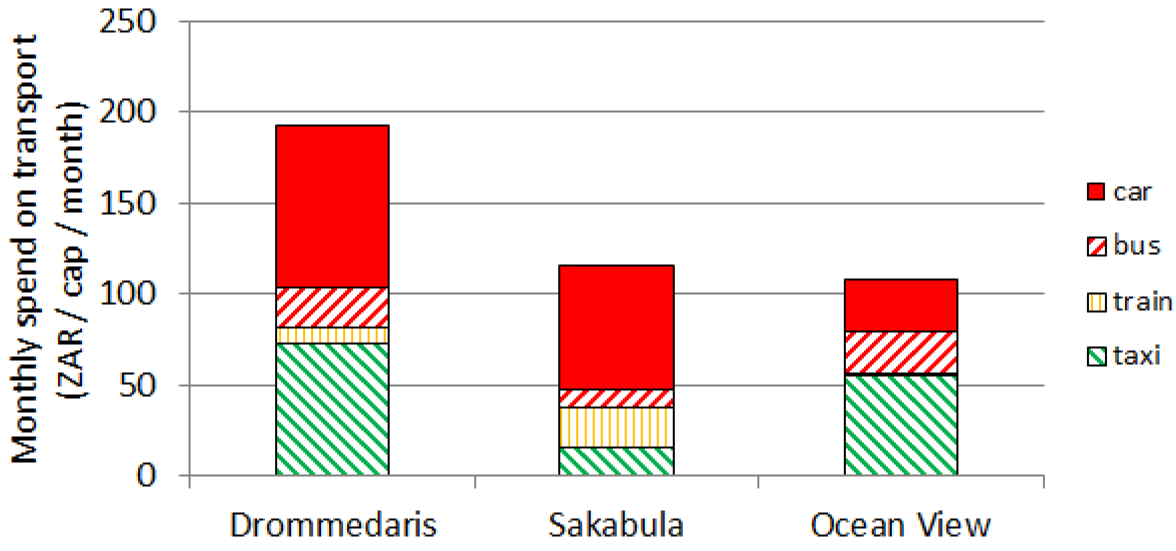

Figure 4-2 Average expenditure on each mode of transport per person

4.3.2 Estimating the Carbon Footprint of South African Transport

To evaluate the carbon footprint of the transport habits of each block of flats, the following transport related carbon footprints were taken from the Project 90X2030 website (90 X 2030, 2011):

Table 4-11 Transport carbon footprint factors

Mode of Transport	**Carbon footprint (kg $CO_{2\ eq}$ / passenger / km)**
Minibus Taxi	0.0433
Short distance Bus	0.1115
Train	0.0611

For evaluating the carbon footprint of private or company car use, a carbon footprint figure of 2.3 kg $CO_{2\ eq}$ / litre for petrol and 2.7 kg $CO_{2\ eq}$ / litre for diesel was taken from Project 90X2030 (90 X 2030, 2011), who took the figures from DEFRA (2009). The price of petrol and diesel were adjusted several times during the study, and so an average price of ZAR 10 / litre was assumed.

It should be noted that petrol and diesel are manufactured in two distinctly different ways in South Africa. The first method of production is via ordinary crude oil refineries in South Africa, and these refineries are located along the coast in Durban and in Cape Town, so that crude oil can be shipped to them easily. Petrol and diesel are also produced by a second method inland and at the coast in Mossel Bay, where coal (inland) or natural gas (in Mossel Bay) are gasified and the synthesis gas then reacted into petrol and diesel (along with other petrochemical products). Sasol published an LCA paper (looking into the benefits of Carbon sequestration) that admits that the carbon footprint of coal-to-liquids petrol and diesel is approximately 2.5 times that of ordinary petrol and diesel refined from crude oil (Goede et al, 2006). However, it is noted that petrol bought in Cape Town is produced at the Chevron crude oil refinery in Milnerton and will have a carbon footprint close to the 2.3 kg $CO_{2\ eq}$ / litre for petrol used by DEFRA (2009).

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For train travel, Project 90X2030 (90 X 2030, 2011) combined the total electricity and diesel consumption by national trains available from the 2007/08 Department for Transport (DfT) National Modelling Framework Environment Module, along with DfT transport statistics on the total number of passenger kilometres for 2007/08. These calculations yielded a carbon footprint of South African train travel of 0.0611 kg $CO_{2\ eq}$ / passenger / km.

For minibus taxis, Project 90X2030 (90 X 2030, 2011) assumed that the average fuel consumption of a minibus taxi is 13.8 litre / 100km and that the average occupancy was 7 passengers (not including the driver). These assumptions were combined, with the petrol carbon footprint, to calculate a figure of 0.0433 kg $CO_{2\ eq}$ / passenger / km. This gives the surprising result that minibus taxis have a lower carbon footprint per kilometre than trains, however it should be remembered that trains run on electricity, which is mainly derived from coal in South Africa, and is therefore very carbon-intensive.

For local bus travel, Project 90X2030 (90 X 2030, 2011) calculated the factor of 0.1115 kg $CO_{2\ eq}$ / passenger / km by accessing publically available data from major bus operators including Stagecoach, First Group, Arriva, National Express, Go-Ahead and from Transport for London. This was supplemented by national statistics for average bus occupancy.

4.3.3 Transport Carbon Footprint of the Flats

By combining the carbon footprint factors with survey information on how often and how far the households regularly used various types of public transport, along with how much the average petrol consumption was, it was possible to estimate the carbon footprint of each household's transport habits. Table 4-12 provides a summary of the results.

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Table 4-12 Transport Carbon Footprint of the Flats

	Drommedaris (16 flats)	Sakabula (14 flats)	Ocean View (15 flats)
Average Expenditure on transport (ZAR/household/month)	635	520	560
Average Expenditure on transport per person (ZAR/capita/month)	190	115	110
Total one-way work/school/grocery related trips per month	1 441	1 352	2 112
Average Transport carbon footprint per household (kg $CO_{2\ eq}$ / household / month)	96	106	56
Average Transport carbon footprint per person (kg $CO_{2\ eq}$ / person / month)	29	24	11
Car – Percent carbon footprint (%)	76.6	55.9	29.8
Taxi - Percent carbon footprint (%)	7.6	3.1	31.1
Bus - Percent carbon footprint (%)	10.4	2.7	34.7
Train - Percent carbon footprint (%)	5.4	22.2	4.4

Figure 4-3 displays the modes of transport that contribute to each group of flats average transport-related carbon footprint per person. It is very surprising that Ocean View has the lowest average carbon footprint, as it was expected that Ocean View tenants would have to travel further on average due to their poor location. It appears that it is the other flats' tenants' use of private cars that makes their transport more carbon-intensive.

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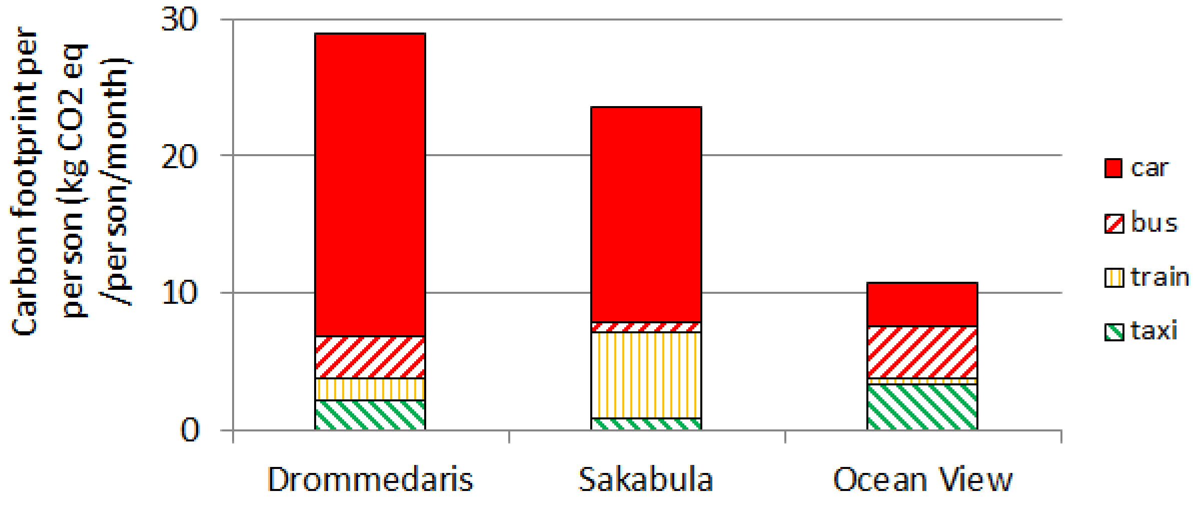

Figure 4-3 Average Transport-related Carbon Footprint per Person

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The average transport-related carbon footprints of Drommedaris, Sakabula and Ocean View are 0.35, 0.28 and 0.13 $tCO_{2\,eq}$ / cap / annum respectively. WWF (2010) suggests that by 2050, developed countries' emissions should be reduced by 80% compared to 1990 levels in order to prevent global warming from exceeding a 2°C increase. This will correspond to developed countries having average emissions of 2.8 $tCO_{2\,eq}$ / cap / annum. The transport-related carbon footprints of Drommedaris, Sakabula and Ocean View correspond to 12%, 10% and 5% of this target respectively.

It is possible to estimate the transport related energy consumption average per person for each of the three groups of flats. To do this it was assumed that trains run on electricity where 1.0 kg $CO_{2\,eq}$ corresponds to 1 kWh of energy, buses run on diesel where 0.266 kg $CO_{2\,eq}$ (DEFRA, 2009) corresponds to 1 kWh of energy and cars and taxis run on petrol where 0.255 kg $CO_{2\,eq}$ (DEFRA, 2009) corresponds to 1 kWh of energy. It can then be estimated that on average, Drommedaris, Sakabula and Ocean View tenants account for 4.7, 3.2 and 1.7 GJ / cap / annum of transport-related energy consumption respectively. All three figures are lower than the average of almost all of the cities that feature in Figure 2-4 (where transport-related energy consumption was compared with urban density).

4.3.4 *Transport Error Analysis*

All of the different modes of transport available meant that the transport expenditure and carbon footprints varied greatly between households within the groups. Table 4-13 give the two tailed - two sample of unequal variance T-Test results for the transport expenditure per person between the different groups of flats.

Table 4-13 T-Test Error Analysis of Transport Expenditure per Person

	Drommedaris	Sakabula	Ocean View
Drommedaris	1	0.056	0.015
Sakabula	0.056	1	0.51
Ocean View	0.015	0.51	1

It can be said with 98% confidence that the transport expenditure per person at Drommedaris is statistically significantly higher than that of Ocean View. The two tailed - two samples of unequal variance T-Tests were also performed on the transport-related carbon footprints per person between each group of flats, as displayed in Table 4-14.

Table 4-14 T-Test Error Analysis of Transport-related Carbon Footprints per person

	Drommedaris	Sakabula	Ocean View
Drommedaris	1	0.69	0.02
Sakabula	0.69	1	0.03
Ocean View	0.02	0.03	1

It can be said with 95% confidence that the average carbon footprint per person at Ocean View is statistically significantly lower than that of both Drommedaris and Sakabula.

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4.3.5 Transport Discussion

The main reasons for the choice of Ocean View as a poorly-located area was that it was situated very far from any of Cape Town's recognised business areas such as the Central Business District, Voortrekker Road, the Industrial Circles or Bellville; further that it was 10 km from the nearest train station, and that it would still take a very long train ride to get to the above-mentioned business areas. It is also approximately 7 km from the closest supermarkets. Upon closer inspection, there are several reasons why Ocean View's tenants may have reduced transport-related carbon footprints.

- There is both a primary school and a high school within walking distance of the flats at Ocean View, and because there are so few other affordable schools in the area, most school children went to these schools. This may have social implications if the quality of schooling is not adequate, and there are no other options for schooling in the area.
- There were more incidences of unemployed adults living with their employed friends. These people would not have to use transport regularly.
- Almost all of the interviewed subjects that were working had managed to find or create work in the Southern Peninsula in places like Noordhoek, Fish Hoek, Simons Town and the nearby small factories at Fish Eagle Park. This may have a lot to do with how the majority of the interviewed households had grown up in Ocean View, and therefore may have grown up with a feeling of the work available in the area and the required skills. This is in contrast to Masiphumelele where the majority of households are new to the area and may not have been able to adapt.
- Minibus Taxis are available to transport people, and typically charge ZAR 6 per trip to places like Fish Hoek. These taxis have the lowest carbon footprint per kilometre compared to private car use, trains and buses.

This does not mean that Ocean View does not still have many problems such as high unemployment, gangsterism and crime. The social sustainability of the area could be called into question when compared to the areas surrounding Drommedaris and Sakabula, but the gap between the population size and the available work opportunities is not as pronounced as at Amakhaya Ngoku in Masiphumelele.

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4.4 Electricity and Transport Summary

The results presented in this chapter, and primarily the prepaid electricity purchase data for Drommedaris and Sakabula, suggest that for households accommodated in social housing, earning an average of ZAR 6 000 per month, electricity consumption is reduced by approximately 150 kWh / month in the summer months when SWHs are installed. It is estimated that the direct rebound effect of purchasing more electricity is small, approximately 20 %, which is very different to the very low income cases of Kuyasa and Zanemvula that were mentioned in chapter 2. These electricity savings will probably not be as high in winter, when Cape Town's solar irradiation levels average 4.46 kWh / m^2.day. This is significantly less than that of the summer months, averaging 6.95 kWh / m^2.day. It should also be recalled from the literature review in chapter 2 that heat pumps are a viable alternative to solar water heaters, and should also result in significant electricity savings.

In a surprising result, the poorly located flats at Ocean View had a lower transport-related carbon footprint (11 kg $CO_{2\ eq}$ / person / month) than the well-located flats at Drommedaris or Sakabula (29 and 24 kg $CO_{2\ eq}$ / person / month respectively). A positive result is that the average transport-related energy consumption for all three groups of flats is very low when compared to the average of almost all of the cities that feature in Figure 2-4 (where transport-related energy consumption was compared with urban density).

It was expected that Ocean View households would have the highest transport-related carbon footprint rather than the lowest. This surprising result could be explained by some of the following observations:

- Having convenient access to public transport may encourage one to use the transport more.
- Even if a tenant's home is well-located, this does not mean that their place of work is also well-located, and therefore it may still feel more convenient to use private transport if one can afford it.
- The tenants of Drommedaris had only recently moved there, and had qualified to stay there based on their current employment, which may have been closer to where they had lived previously. In contrast, Ocean View tenants had mostly been living in

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Ocean View since childhood, and had adapted to the work opportunities available there.

- Ocean View had more cases of unemployed adults, who would not have to use transport regularly, and would therefore reduce the average transport-related carbon footprint.
- Ocean View tenants only had one set of schools within walking distance, and no other affordable and convenient schools were nearby.

In essence, it appears that households living in a poorly-located area are limited to specific schools and work opportunities, and while this may reduce their transport-related carbon footprint, it may also reduce their opportunities to improve their income and circumstances. It could be argued that some of the biggest impacts of living in poorly-located areas lie within the sphere of social sustainability. However, this conclusion would need to be verified by a trained social scientist.

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5 RESULTS AND DISCUSSION – INVESTIGATING THE INDIRECT REBOUND EFFECT

Chapter 5 compares two methods to estimate the carbon footprint of the indirect rebound effect, where money saved via the installation of solar water heaters is spent on other goods and services, besides electricity or transport.

The first method is to use the answers to question 5 of the Household Expenditure survey to estimate what percentage of saved money would be spent on various expenditure categories, and then to source carbon footprint factors for each category, and then combine these into a weighted average.

The second method is to make use of the Statistics South Africa publication "Income and Expenditure of Households 2005/2006". This publication provides the income and expenditure survey results for 24 000 households in South Africa, and one section describes the expenditure habits of South Africans according to their income deciles. The second method takes data on the increased marginal spending on each category of expenditure as a household increases in wealth from the 8th to the 9th income decile, and combines the estimates carbon footprint factors for each category.

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5.1 Survey Method

5.1.1 Survey Data on Indirect Rebound Effect

Question 5 of the Household Expenditure Survey asked the flat tenants for information on what major categories of goods and services they would buy if they had slightly more money than they currently do, or what would be the first item / services they would cut back on if they had to save more. This was an attempt to uncover where marginal spending via the indirect rebound effect may be spent, and to estimate the environmental impacts of the indirect rebound effect through carbon footprint factors.

Table 5-1 Survey Insight into the Indirect Rebound Effect

Indirect Rebound Category	NUMBER OF SURVEY MENTIONS			Total
	Drommedaris	Sakabula	Ocean View	
Education	1	2	0	3
Luxuries	4	3	0	7
Take Outs / junk food	3	1	0	4
Entertainment/alcohol/cigarettes	6	0	3	9
Clothes	3	4	0	7
Appliances / furniture	1	1	0	2
Basic groceries	7	9	9	25
Transport	1	2	1	4
Meat	2	2	0	4
Electricity	8	3	8	19
TOTAL	**36**	**27**	**21**	**84**

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 of chapter 4, which indicates that the Drommedaris tenants save almost 40% on electricity compared to Sakabula tenants, suggesting that there is only approximately a 20% direct rebound towards buying more electricity.

Very few people said they would allocate more money towards transport, and those that did mainly mentioned buying slightly more petrol. This is surprising as Drommedaris tenants clearly already have a higher average transport expenditure per person.

The next section will attempt to source or estimate approximate carbon footprint factors for the remaining rebound categories, and combine these carbon footprint factors into a weighted average carbon footprint factor.

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5.1.2 Estimating Carbon Footprint Factors of Indirect Rebound Effect Categories

This section explains some of the sources used to find carbon footprint factors, and the strategy of combining them into an expenditure category.

Take Outs / junk food: It was assumed that the two most common types of junk food were pizza or a burger and fries. The carbon footprints for both meals were sourced from Eat Low Carbon (2011).

Table 5-2 Estimating the Carbon Footprint Factor of Take Outs / Junk Food

Meal	Carbon footprint (g $CO_{2\ eq}$)	Estimated Average Price (ZAR)	Carbon footprint per Rand spent (kg $CO_{2\ eq}$/ZAR)
Burger and Fries	2 948	30	0.098
Pizza	913	50	0.018
Average			**0.058**

Clothes: Carnegie Mellon University Green Design Institute (2008) hosts a free economic input and output lifecycle assessment tool. This tool uses USA data from 2002. Data was collected on 3 different types of clothing.

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Table 5-3 Estimating the Carbon Footprint Factor of Clothes

Item	Carbon footprint (kg $CO_{2\ eq}$/\$1000)	Exchange Rate (ZAR/USA$)	Carbon footprint per Rand spent (kg $CO_{2\ eq}$/ZAR)
Men's and boys' cut and sew apparel manufacturing	487	8.14	0.06
Women's and girls' cut and sew apparel manufacturing	566	8.14	0.07
Footwear manufacturing	846	8.14	0.104
Average			**0.078**

Basic Groceries

The guardian (2010) gave a carbon footprint factor stating that spending a British Pound on a typical supermarket trolley of food would incur a carbon footprint of 930 g $CO_{2\ eq}$. Assuming an exchange rate of ZAR 12.60 / GBR, this would be the equivalent of 0.074 kg $CO_{2\ eq}$/ZAR.

To verify this number, it was compared to selected food data taken from Carnegie Mellon University Green Design Institute (2008). This tool gives a carbon footprint factor of 0.12 kg $CO_{2\ eq}$/ZAR for money spent on breakfast cereals, fruit and vegetables or soft drinks and ice. This suggests that 0.074 kg $CO_{2\ eq}$/ZAR for groceries in general may be an underestimate.

Other

In a similar method to the carbon footprint factors described above, carbon footprint factors were also estimated for the following expenditure categories:

- Meat
- Entertainment, Alcohol and cigarettes

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- Furniture and Appliances
- Education
- Luxuries

Most of the data was sourced from Carnegie Mellon University Green Design Institute (2008), and the calculations can be viewed in the Appendices at the end of the dissertation. It should be recalled that coal-fired power plants do not contribute as much to the USA and UK electricity mixes as they do to the South African electricity mix. This means that goods and services in South Africa probably have higher carbon-intensities than those estimated from USA and UK data (for the purpose of this dissertation) because they are manufactured using South African electricity. The inaccuracies of these carbon footprint factors may not be consistent as they are gathered mainly from the US and UK, which do not have the same electricity mix as each other. Unfortunately, very little South African-specific carbon footprint data is readily available. Foreign carbon footprint factors could be improved by substituting in South African electricity data and transport distances, but this is beyond the scope of this dissertation.

5.1.3 Calculating the Weighted Average Carbon Footprint Factor of the Indirect Rebound Effect

The major assumption is that saved money would be spent in average proportions matching how often each expenditure category was mentioned in the surveys. This means that because basic groceries were mentioned most often, the highest amount of saved money would be spent on groceries. Table 5-4 demonstrates how this assumption can allow one to estimate a weighted average for the carbon footprint factor of the indirect rebound effect.

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Table 5-4 Estimating the Carbon Footprint of the Indirect Rebound Effect via Survey Answers

Item/Service	Number of mentions via surveys	Percentage of marginal spending (excluding electricity and transport) (%)	Carbon Footprint Factor (kg $CO_{2\ eq}$ / ZAR)
Education	3	4.9	0.046
Luxuries	7	11.5	0.066
Take Outs/junk food	4	6.6	0.058
Entertainment/alcohol/cigarettes	9	14.8	0.043
Clothes	7	11.5	0.078
Appliances/furniture	2	3.3	0.068
Basic groceries	25	41.0	0.074
Meat	4	6.6	0.503
Total	**61**	**100**	
Weighted Average			**0.094**

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It should be recalled that a kWh of electricity has a carbon footprint of approximately 1 kg $CO_{2\ eq}$ and if the kWh of electricity sells for about ZAR 0.80 on a prepaid scheme as is the case at Drommedaris and Sakabula, then the electricity has a carbon footprint factor of approximately 1.25 kg $CO_{2\ eq}$ / ZAR.

In addition, if the carbon footprint of transport of the 3 flats is combined with the expenditure on transport, one can estimate an overall carbon footprint factor of 0.154 kg $CO_{2\ eq}$ / ZAR for transport.

The weighted average carbon footprint factor of all the other categories of expenditure that the tenants mentioned as likely indirect rebound categories is 0.094 kg $CO_{2\ eq}$ / ZAR. This means that spending money on almost any category of spending is preferable to electricity and transport. The one exception is spending saved money on meat, which was estimated to have a carbon footprint factor of 0.53 kg $CO_{2\ eq}$ / ZAR, meaning that spending money on meat has a worse environmental impact than spending the same amount of money on transport.

Meat also significantly increased the weighted average carbon footprint, which would have been calculated as 0.066 kg $CO_{2\ eq}$ / ZAR without the inclusion of a specific category focussing on meat. It could be argued that this weighted carbon footprint factor is more accurate, as some meat will be accounted for in the carbon footprint factor for basic groceries.

5.2 Estimating the Weighted Average Carbon Footprint Factor of the Indirect Rebound Effect via *Statistics South Africa* Data

Because so many different categories were mentioned in the Household Expenditure Surveys, another valid assumption could be that the indirect rebound effect may follow the average expenditure profiles of South Africans in the gap income bracket. The best source of data for this information is the Statistics South Africa publication “Income and Expenditure of Households 2005/2006”. This publication provides the income and expenditure survey results for 24 000 households in South Africa, and one section describes the expenditure habits of South Africans according to their income deciles.

Households earning an average of ZAR 6 000 / month would be placed between income deciles 8 and 9 in South Africa. It is assumed that by saving money on electricity though the use of solar water heaters, the tenants would follow the patterns of additional spending as average South Africans do while increasing in wealth from income decile 8 to income decile 9.

The carbon footprint factors were compiled in a similar method to section 5.1, mainly by combining greenhouse gas emissions data from Carnegie Mellon University Green Design Institute (2008).

The calculation is demonstrated in Table 5-5 below. In this method, it can be seen that far less of the additional expenditure is spent on basic groceries (food and non-alcoholic

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beverages) than estimated from the response of the tenants via the surveys, and this is one of the reasons why the weighted average carbon footprint is less than that calculated in chapter 5.1.

It is interesting to note that according to Statistics South Africa data, 29.6% of the additional expenditure is spent on transport, and a lot of this money is spent on petrol and private car maintenance. It appears that as a household moves from income decile 8 to income decile 9, owning a car may start to become affordable when it was not before. This means that money saved via the installation of solar water heaters could be spent on transport, and this appears to be happening from the expenditure habits of Drommedaris tenants compared to those of Sakabula and Ocean View in Chapter 4.

The Statistics South Africa 2005/2006 data supports the survey finding that money saved via solar water heaters or reduced transport would mostly be spent on goods and services with a significantly lower carbon footprint.

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Table 5-5 Estimating the Carbon Footprint of the Indirect Rebound Effect via Statistics South Africa Data

Item/Service	**SA Income decile 8 Expenditure (ZAR/annum)**	**SA Income decile 9 Expenditure (ZAR/annum)**	**Percent of additional spending (%)**	**Approximate carbon footprint (kg CO2eq./ZAR)**
Unclassified expenses	174	310	0.3	?
Miscellaneous goods and services (mainly insurance)	7851	16659	16.6	0.020
Communication	2048	3875	3.4	0.026
Education	2142	2935	1.5	0.046
Restaurants and hotels	1102	2304	2.3	0.070
Alcoholic beverages and tobacco	773	1117	0.6	0.036
Clothing and footwear	3419	4793	2.6	0.078
Food and non-alcoholic beverages (25% marginal is meat)	9225	11990	5.2	0.181
Health	863	1717	1.6	0.034
Recreation and culture	2114	4603	4.7	0.057
Transport	9015	24690	29.6	0.154
Furnishings, household equipment and routine maintenance of the dwelling	4008	6398	4.5	0.068
Housing, water, electricity, gas and other fuels (mainly rental)	12321	26634	27.0	0.05
Total	55055	108025	100	
Weighted Average, excluding electricity and transport				**0.054**

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5.3 Overall Comparison of Electricity, Transport and Indirect Rebound Carbon Footprint of the Three Flats

It provides useful insight to compare the flats on the basis of the highest average amount of money spent on electricity and transport. It was expected that Ocean View would incur the highest total combined cost of electricity and transport, and this was the case, with Ocean View households having an average combined electricity and transport expenditure of ZAR 875 per month.

Figure 5-1 shows the expenditure on electricity and transport of the 3 sets of flats. It can also be seen that it is assumed that the other flats will eventually spend the saved money on other goods and services via the indirect rebound effect.

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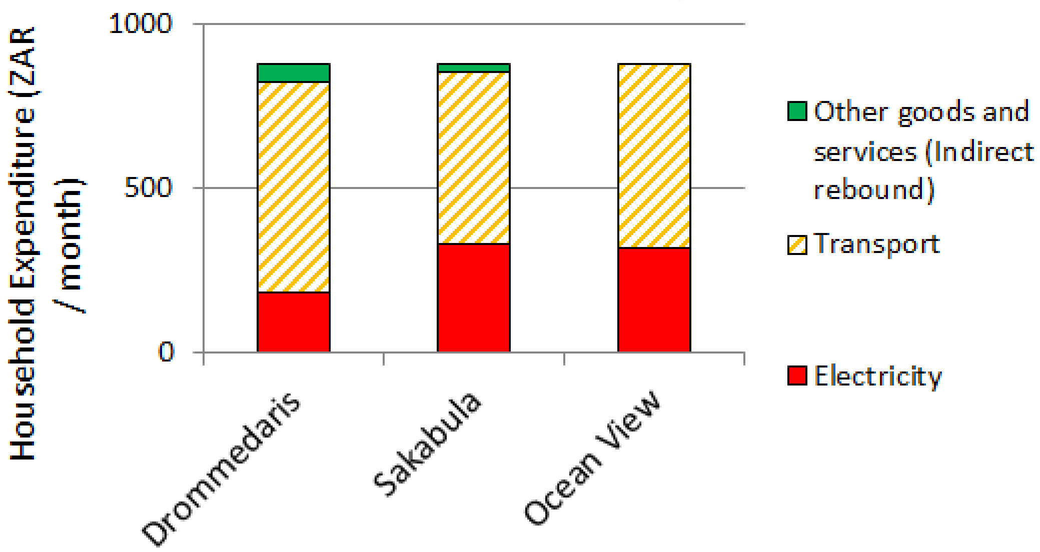

Figure 5-1 Comparing Electricity and Transport Expenditure of the Flats

An indirect carbon footprint factor of 0.066 kg CO2 eq / ZAR was applied to the amount of money spent on other goods and services. This corresponds with the finding from the surveys that neglected the specific category on meat, assuming that the general groceries carbon footprint factor adequately included the carbon footprint factor of meat.

Figure 5-2 compares the electricity and transport carbon footprint of the 3 groups of flats on the basis of the ZAR 875 / month average expenditure that the Ocean View tenants pay for electricity and transport.

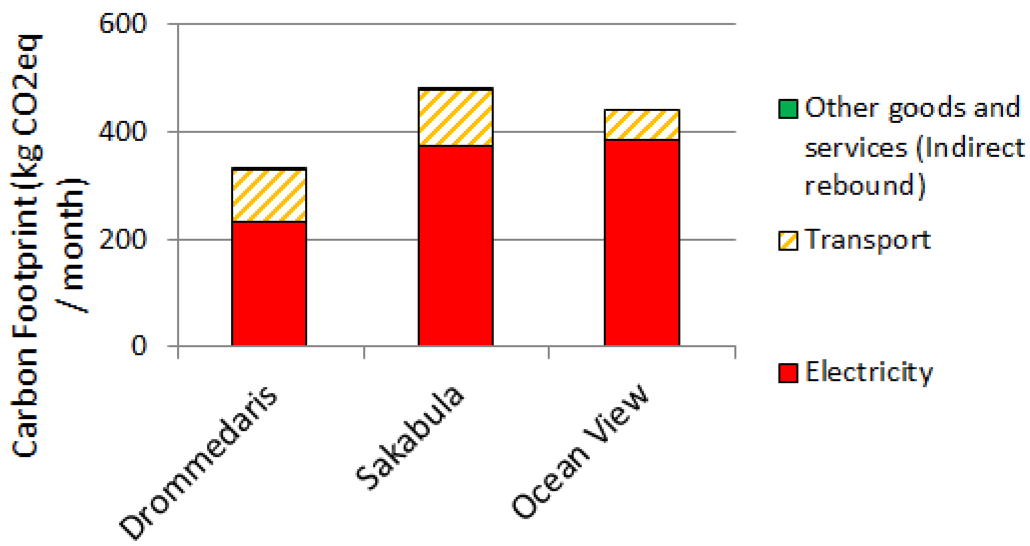

Figure 5-2 Comparing Electricity and Transport carbon footprint of the 3 flats, taking the Indirect Rebound effect into Account

It can be seen that the reduced electricity carbon footprint via the solar water heaters results in the overall carbon footprint for Drommedaris being significantly lower than that of the other two blocks of flats. It can also be seen that the additional carbon footprints brought about by the indirect rebound effect are very small in comparison to South African electricity consumption and transport.

The indirect rebound effect only accounted for an extra carbon footprint of approximately 3.6 kg $CO_{2\ eq}$ / month for the Drommedaris households and 1.7 kg $CO_{2\ eq}$ / month for the Sakabula households. This is encouraging, as it indicates that solar water heaters reduce the overall carbon footprint of a gap-income household, even when all direct and indirect rebound effects are considered.

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6 CONCLUSIONS AND RECOMMENDATIONS

To close off the dissertation, this final chapter reviews the research objectives as presented in Chapter 1, in light of the findings of the research. The key research questions developed in Chapter 3 are revisited to establish whether or not the research results presented in Chapters 4 and 5 are able to sufficiently answer them.

This chapter begins by revisiting the motivation for carrying out the research in Section 6.1. The major findings of the dissertation are summarised in relation to its objectives, in Section 6.2. The key research questions are answered in Section 6.3, and recommendations are made in Section 6.4.

6.1 Research Motivation

There is a large number of people moving into Cape Town and requiring formal housing. For those households that fall into the gap income bracket, recent social housing schemes like Drommedaris and Steenvilla have been built to provide rental accommodation, and an optimistic assumption is that more social housing schemes will be built in the near future.

Governments and social housing companies can make important decisions to reduce the tenant's lock-in to high electricity and transport consumption, and two strategies that have received attention are the installation of solar water heaters to reduce electricity consumption, and high-density well-located housing schemes within an overall strategy of city densification to reduce the consumption of transport fuels.

The research undertaken by this dissertation aimed to confirm that these two strategies successfully reduce electricity and transport fuel consumption in spite of the direct rebound effect. The research also aimed to uncover the carbon footprint of those goods and services that are bought with the money saved on electricity and transport via the indirect rebound effect, so that the full carbon footprint reduction brought about by the above-mentioned strategies can be understood.

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6.2 Objectives and Major Findings

The study was aimed at addressing the following objectives:

- To determine the extent to which solar water heaters and housing scheme location choice and density would lower the future carbon footprint of new and upgraded households in the gap income bracket.

- To consider direct and indirect rebound effects, and to investigate whether or not they significantly reduce the environmental benefits of placing housing schemes in high density, well-located areas, and if they reduce the environmental benefits of installing solar water heaters.

The major findings of the research are presented in the next 3 sub-sections.

6.2.1 Solar Water Heaters and Electricity Carbon Footprint

The prepaid electricity purchase data from Drommedaris and Sakabula confirms that tenants with solar water heaters consume less electricity than those with electric geysers. Drommedaris households had a lower average number of inhabitants, but it was possible to isolate those households with 4 or more people living in them, and to show that these households consumed less electricity as well. Although the electricity consumption of the households within a group varied widely, the T-Test analysis still showed that the average electricity consumption of Drommedaris and Sakabula can be stated to be different with 99% confidence.

The results suggest that for households accommodated in social housing, earning an average of ZAR 6 000 per month, electricity consumption is reduced by approximately 150 kWh/month in the summer months when SWHs are installed. These savings will probably not be as high in winter however, as Cape Town's winter solar irradiation levels average 4.46 kWh/m^2/day, which is less than the average summer solar irradiation levels of 6.95 kWh/m^2/day.

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Assuming that the solar water heaters are provided to the social housing schemes for free, through climate change funding or other funding, such that the tenants do not have the cost of the SWHs added to the rent, the SWHs theoretically save each household approximately ZAR 130 per month in summer. This money will eventually be spent on other goods and services. It should be noted that if the solar water heaters were funded by a specific climate change project, then the carbon footprint reductions belong to this project, and not to the tenants themselves. It should also be noted that the literature review in chapter 2 has suggested that heat pumps would make a viable alternative to SWHs, and should therefore also result in significant electricity savings.

6.2.2 Good location and Transport Carbon Footprint

A surprising result occurred where the tenants of the poorly-located group of flats at Ocean View were found to spend less on transport then the tenants of well-located Drommedaris. In fact, a two tailed two sample of unequal variance T-Test demonstrated that the finding that Ocean View households spent less on transport per person than Drommedaris households to be statistically significant. A positive result is that the average transport-related energy consumption for all three groups of flats is very low when compared to the average of almost all developed cities.

Several observations can help to explain why Ocean View households spend less on transport than the other groups of flats. Almost all of the school-children were able to walk to school. Many households had unemployed adults living with their employed friends or family, and these unemployed people did not make regular use of transport. Far fewer Ocean View households used private cars, and most used minibus taxis which are significantly cheaper.

Another surprising result was that the average carbon footprint of the Ocean View tenants' transport habits was significantly less rather than more than that of either of the well-located groups of flats' tenants. Again, it was possible to use a two tailed two sample of unequal variance T-Test to confirm with 95% confidence that the finding that the transport-related carbon footprint per person of Ocean View's tenants is less than that of both Drommedaris and Sakabula is statistically significant.

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Many of those people who were working regularly in Ocean View had managed to find or create employment within the Southern Peninsula, and used low carbon-intensity minibus taxis to travel.

Because of these results, it cannot be confirmed that placing social housing schemes in high-density, well-located areas reduces the transport expenditure or carbon-footprint of their households.

In retrospect, it is important to remember that even if a person lives in a high-density, well-located area, that person may work or attend school in a poorly-located area far from public transport. This might make it more convenient for that person to use his/her own car to commute. In addition, it must be recalled that most Ocean View tenants had been living in the area for a very long time and had been able to adapt to the work opportunities in the area, while the tenants of Drommedaris had only recently moved, and most were still working at the same jobs as before, and some of these jobs were relatively far away.

In short, it may be very difficult to clearly see the benefits of living in well-located areas until the entire city is densified. In future studies, it may provide more insight to compare the transport expenditure of people in the gap income bracket who live in high-density towns with those that live in low-density towns, or to compare the transport expenditure of people in the gap income bracket who are known to live close to their place of employment with those that are known to live far from their work.

It must also be pointed out that the ill effects of living in poorly-located areas may not only lead to environmental sustainability issues, but social sustainability issues as well. One certainly got the feeling that the township of Masiphumelele is poorly-located in that there are not enough work opportunities to match the size of the population. In Ocean View one can get a similar, if less drastic impression, because of the high unemployment rates. It could be posed that the work that is available in the area does not match the range of opportunities available in well-located areas and that people may be doing work that does not suit them. Similarly, most children in Ocean View attend the only cheap and convenient school in the area, but it could be posed that they would benefit from a choice of schools that would arise from living in a well-located area. A future study where a trained social scientist investigated the social sustainability implications of living in well-located and poorly-located areas should be recommended.

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6.2.3 The direct and indirect rebound effects

For households earning an average of ZAR 6 000 per month, the direct rebound effect towards buying more electricity after the installation of a solar water heater was found to be small. Drommedaris has a reduced electrical carbon footprint of 150 kg $CO_{2\ eq}$ / month compared to Sakabula and Ocean View for the summer months. It was estimated that a solar water heater in Cape Town delivering 200 litres of hot water per day to a family of 4 people could theoretically reduce the carbon footprint of the household by approximately 180 kg $CO_{2\ eq}$ / month in summer, and this means the direct rebound effect is only in the order of 20%.

It was not possible to estimate the direct rebound effect with regards to transport expenditure.

From the Drommedaris data, there appears to be an indirect rebound effect towards a higher transport expenditure when solar water heaters allow for a reduction in electricity expenditure, but there is no way to rigorously test for this. From the survey responses it appeared that people would not spend much of their marginal income on transport, but the Statistics South Africa 2005/2006 data suggests that transport accounts for the largest percentage of marginal spending as households move from income decile 8 to income decile 9, and that the majority of this extra money is spent on private cars. This suggests that there is a household income between income decile 8 and income decile 9 where private cars become affordable, and solar water heaters could help a household be able to reach this point. Private car use was indeed the major reason why Drommedaris households had a higher transport expenditure per person than the other groups of flats.

Survey data and Statistics South Africa data both suggest that saved money is spent on a wide range of other goods and services. Both sets of data were used to estimate the average carbon footprint of spending via the indirect rebound effect. Both methods confirm that the average carbon intensity of the goods and services (at ~ 0.054 to 0.066 kg CO_{2eq}/ZAR) is significantly lower than that of South African electricity (at ~ 1.25 kg CO_{2eq}/ZAR) or transport (at ~ 0.154 kg CO_{2eq}/ZAR).

6.3 Answering the Key Research Questions

As indicated in Chapter 3.1, this dissertation aimed to answer three key questions. This section describes whether the questions were convincingly answered, and what the answers are.

1. *By how much would installing solar water heaters in social housing schemes reduce emissions from household energy use?*

    - *What is the electricity consumption of ordinary low-income houses compared to ones that have solar water heaters?*

The results presented in this report, and especially the prepaid electricity purchase data from Drommedaris and Sakabula, confirm that solar water heaters do reduce electricity consumption, and that this finding is statistically significant. Solar water heaters reduce the electricity consumption of a social housing scheme by approximately 150 kWh / month / household during the summer months.

2. *By how much would building social housing schemes in well-located areas closer to the city centre reduce people's transport emissions? Would it also result in the inhabitants saving money on public transport?*

    - *Where do low-income earners who live in poorly-located areas on the outskirts of the city work? How do they travel?*
    - *Where do people, of the same income, but who live in well-located areas closer to the CBD work? What, if any, are the benefits in travel distance to work?*
    - *What are the benefits in terms of money saved due to not having to travel as far?*

This research question was not convincingly answered. The tenants of poorly-located Ocean View turned out to have the lowest transport expenditure per person and the lowest

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transport-related carbon footprint per person, and this was shown to be statistically significant. It could be posed that the true disadvantage of living in poorly-located areas lies in social sustainability, with many people making low use of transport because they were unemployed and could not afford to use transport to seek employment elsewhere.

3. *If people save money on transport and electricity, what major products and services do they spend this extra money on instead? What is the comparative environmental impact of these products and services?*

It could be demonstrated that money is saved on electricity through the installation of solar water heaters. However, it could not be proved that living in a well –located area reduces a household's transport expenditure.

Contrary to the survey responses on how tenants would spend extra money, the expenditure of Drommedaris tenants, along with Statistics South Africa 2005/2006 data suggest that a large portion of saved money is spent on transport, especially as the household approaches an income where owning a private car becomes affordable. Survey data agrees with Statistics South Africa data that saved money is also spent on a wide range of goods and services. Both methods confirm that the average carbon intensity of the goods and services (at ~0.054 to 0.066 kg CO_{2eq} / ZAR) is significantly lower than that of South African electricity (at ~ 1.25 kg CO_{2eq} / ZAR).

In summary, South African electricity is so carbon intensive per ZAR spent that even if the social housing tenants spend the money saved on electricity by solar water heater installation on other carbon-intensive products such as petrol (gasoline) or meat, their overall carbon footprint would still be reduced. Interestingly, one exception to this conclusion could be a case where the indirect rebound is spent on education, training or other means to eventually increase the income bracket of the household, as this increased income should result in increased household consumption.

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6.4 Recommendations

Based on the major findings and conclusions described above, the following recommendations can be offered to policy makers and researchers.

6.4.1 Recommendations for Policy Makers

1. All social housing schemes should make use of solar water heaters. The literature review suggested that heat pumps can also be considered as a feasible energy-saving alternative to conventional electric geysers. These electricity saving measures should always result in an improved quality of life and/or reduced electricity consumption. While money saved by the tenants will be spent on other goods and services with environmental impacts attached to them, South African electricity is so cheap and carbon-intensive that almost any other category of spending has a significantly lower carbon footprint.
2. The new national building regulations and standards should be incrementally made stricter in favour of enforcing solar water heaters and other methods of reducing coal-fired electricity use.
3. Policy attempts to focus on city densification in South Africa should be encouraged. Literature has shown that cities with a high population density have reduced transport related carbon emissions compared to low density cities. Based on this study, it could be posed that cities with high population densities may have social sustainability benefits as well.
4. The new approach to social housing which prescribes a minimum density and a good location should be continued. The average transport-related energy consumption for Drommedaris may be higher than that of Sakabula and Ocean View, but it is still very low when compared to the average of almost all developed cities. Social housing schemes should always be built in areas that are well-located, where the availability of employment, shops and schools matches the needs of the new tenants. The area should also be well served by public transport.

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6.4.2 Recommendations for Further Research

In addition to the recommendations made above, the following recommendations are offered regarding the need for further research:

1. A study should be conducted to compare the prepaid electricity data of a social housing scheme containing solar water heaters with a similar block of flats containing only electric geysers for a full calendar year to confirm the results of this dissertation, and to investigate how the electricity savings via SWHs are reduced in the winter months.
2. The transport expenditure and carbon footprint benefits of living in well-located areas in high density cities still needs to be better understood, because the strategy undertaken by this study proved ineffective. Alternative study strategies that could be considered are:
    a. To compare the transport expenditure and carbon footprint of social housing scheme tenants living in a sprawling city to that of similar tenants living in a high density city or town.
    b. To compare the transport expenditure and carbon footprint of social housing scheme tenants who are known to live close to work with that of similar tenants who are known to live far from work. The survey strategy would have to be aimed at capturing additional transport for leisure and other means besides work, school and shopping.
3. It appears that some of the biggest impacts of living in poorly-located areas lie in the sphere of social sustainability, with higher unemployment and a reduced range of work and education opportunities. A study should be conducted where a trained social scientist investigates the social implications of living in poorly-located areas, and such a study should be combined with studies such as this one investigating the environmental implications.
4. Evidence from the Drommedaris expenditure habits, as well as Statistics South Africa data, suggests that the income bracket where owning a private car becomes an affordable option is located inside the “gap” income bracket. Literature has shown that the carbon intensity of private car usage is higher than that of public transport, and that Cape Town is already too car-dependent and suffers from high traffic congestion and smog as a result. A study should be carried out to estimate

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what household income is required before owning a private car becomes affordable, and to determine what measures, services or schemes could be implemented to reduce the benefits of owning a car and to encourage the continued use of public transport.

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APPENDICES

APPENDIX A – Ethics Forms

MAIN SURVEY ETHICS FORM

University of Cape Town

EBE Faculty: Assessment of Ethics in Research Projects

Any person planning to undertake research in the Faculty of Engineering and the Built Environment at the University of Cape Town is required to complete this form before collecting or analysing data. When completed it should be submitted to the supervisor (where applicable) and from there to the Head of Department.
If any of the questions below have been answered YES, and the applicant is NOT a fourth year student, the Head should forward this form for approval by the Faculty EIR committee: submit to Ms Zulpha Geyer - Zulpha.Geyer@uct.ac.za, Chemical Engineering Building, Upper Campus, UCT, (Ph 021 650 4791).
NB: Students must include a copy of the completed form with the thesis when it is submitted for examination.

Name of Principal Researcher/Student: JASPER DICK Department: CHEMICAL ENGINEERING

Preferred email address of applicant: JASPER.DICK@UCT.AC.ZA

If a Student: Degree: MSC (CHEMICAL ENGINEERING) Supervisor: A/PROF H. VON BLOTTNITZ

If a Research Contract indicate source of funding/sponsorship: AFRICAN CENTRE FOR CITIES

Research Project Title: QUANTIFYING THE EFFECT OF DENSIFICATION AND ENERGY EFFICIENCY / RENEWABLE ENERGY INTERVENTIONS ON THE ENVIRONMENTAL IMPACT OF CAPE TOWN'S LOW-INCOME HOUSING SCHEMES

Overview of ethics issues in your research project:

Question 1: Is there a possibility that your research could cause harm to a third party (i.e. a person not involved in your project)?	YES	NO
Question 2: Is your research making use of human subjects as sources of data? If your answer is YES, please complete Addendum 2.	YES	NO
Question 3: Does your research involve the participation of or provision of services to communities? If your answer is YES, please complete Addendum 3.	YES	NO
Question 4: If your research is sponsored, is there any potential for conflicts of interest? If your answer is YES, please complete Addendum 4.	YES	NO

If you have answered YES to any of the above questions, please append a copy of your research proposal, as well as any interview schedules or questionnaires (Addendum 1) and please complete further addenda as appropriate.

I hereby undertake to carry out my research in such a way that

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

Signed by	Full name and signature	Date
Principal Researcher/Student JASPER DICK		17/06/2011

This application is approved by:

Supervisor (if applicable): HARRO VON BLOTTNITZ		17/06/2011
HOD (or delegated nominee): Final authority for all assessments with NO to all questions and for all undergraduate research.		
Chair : Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the above questions.		28/06/2011

ADDENDUM 1:
Please append a copy of the research proposal here, as well as any interview schedules or questionnaires:

ADDENDUM 2: To be completed if you answered YES to Question 2:

It is assumed that you have read the UCT Code for Research involving Human Subjects (available at http://web.uct.ac.za/depts/educate/download/uctcodeforresearchinvolvinghumansubjects.pdf) in order to be able to answer the questions in this addendum.

2.1 Does the research discriminate against participation by individuals, or differentiate between participants, on the grounds of gender, race or ethnic group, age range, religion, income, handicap, illness or any similar classification?	YES	NO
2.2 Does the research require the participation of socially or physically vulnerable people (children, aged, disabled, etc) or legally restricted groups?	YES	NO
2.3 Will you not be able to secure the informed consent of all participants in the research? (In the case of children, will you not be able to obtain the consent of their guardians or parents?)	YES	NO
2.4 Will any confidential data be collected or will identifiable records of individuals be kept?	YES	NO
2.5 In reporting on this research is there any possibility that you will not be able to keep the identities of the individuals involved anonymous?	YES	NO
2.6 Are there any foreseeable risks of physical, psychological or social harm to participants that might occur in the course of the research?	YES	NO
2.7 Does the research include making payments or giving gifts to any participants?	YES	NO

If you have answered YES to any of these questions, please describe below how you plan to address these issues:

I WILL NEED TO STORE SURVEY ANSWERS UNDER THE HOUSEHOLD'S FLAT NUMBER SO THAT IT CAN BE MATCHED UP WITH PRE-PAID ELECTRICITY DATA.

HOWEVER, ALL ANALYSIS AND REPORTING IN THE THESIS AND OTHER PUBLICATIONS WILL BE AT A GROUP LEVEL OF 20 TO 30 HOUSEHOLDS PER GROUP.

ADDENDUM 3: To be completed if you answered YES to Question 3:

3.1 Is the community expected to make decisions for, during or based on the research?	YES	NO
3.2 At the end of the research will any economic or social process be terminated or left unsupported, or equipment or facilities used in the research be recovered from the participants or community?	YES	NO
3.3 Will any service be provided at a level below the generally accepted standards?	YES	NO

If you have answered YES to any of these questions, please describe below how you plan to address these issues:

ADDENDUM 4: To be completed if you answered YES to Question 4

4.1 Is there any existing or potential conflict of interest between a research sponsor, academic supervisor, other researchers or participants?	YES	NO
4.2 Will information that reveals the identity of participants be supplied to a research sponsor, other than with the permission of the individuals?	YES	NO
4.3 Does the proposed research potentially conflict with the research of any other individual or group within the University?	YES	NO

If you have answered YES to any of these questions, please describe below how you plan to address these issues:

TESTING THE METHODOLOGY

ETHICS FORM

University of Cape Town

EBE Faculty: Assessment of Ethics in Research Projects

Any person planning to undertake research in the Faculty of Engineering and the Built Environment at the University of Cape Town is required to complete this form before collecting or analysing data. When completed it should be submitted to the supervisor (where applicable) and from there to the Head of Department.
If any of the questions below have been answered YES, and the applicant is NOT a fourth year student, the Head should forward this form for approval by the Faculty EIR committee: submit to Ms Zulpha Geyer - Zulpha.Geyer@uct.ac.za; Chemical Engineering Building, Upper Campus, UCT, (Ph 021 650 4791).
NB: Students must include a copy of the completed form with the thesis when it is submitted for examination.

Name of Principal Researcher/Student: JASPER DICK Department: CHEMICAL ENGINEERING

Preferred email address of applicant: JASPER.DICK@UCT.AC.ZA

If a Student: Degree: MSC. IN CHEMICAL ENGINEERING Supervisor: A/PROF H. VON BLOTTNITZ

If a Research Contract indicate source of funding/sponsorship:

Research Project Title: CARBON FOOTPRINT DETAILS OF UCT STUDENTS

Overview of ethics issues in your research project:

Question 1: Is there a possibility that your research could cause harm to a third party (i.e. a person not involved in your project)?	YES	NO
Question 2: Is your research making use of human subjects as sources of data? If your answer is YES, please complete Addendum 2.	YES	NO
Question 3: Does your research involve the participation of or provision of services to communities? If your answer is YES, please complete Addendum 3.	YES	NO
Question 4: If your research is sponsored, is there any potential for conflicts of interest? If your answer is YES, please complete Addendum 4.	YES	NO

If you have answered YES to any of the above questions, please append a copy of your research proposal, as well as any interview schedules or questionnaires (Addendum 1) and please complete further addenda as appropriate.

I hereby undertake to carry out my research in such a way that

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

Signed by:	Full name and signature	Date
Principal Researcher/Student:	JASPER DICK	03/08/2010

This application is approved by:

Supervisor (if applicable):	H von Blottnitz	03/08/2010
HOD (or delegated nominee): Final authority for all assessments with NO to all questions and for all undergraduate research.		
Chair : Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the above questions.		17/8/2010

ie not required here!

ADDENDUM 1:
Please append a copy of the research proposal here, as well as any interview schedules or questionnaires:

ADDENDUM 2: To be completed if you answered YES to Question 2:

It is assumed that you have read the UCT Code for Research involving Human Subjects (available at http://web.uct.ac.za/depts/educate/download/uctcodeforresearchinvolvinghumansubjects.pdf) in order to be able to answer the questions in this addendum.

2.1 Does the research discriminate against participation by individuals, or differentiate between participants, on the grounds of gender, race or ethnic group, age range, religion, income, handicap, illness or any similar classification?	YES	NO
2.2 Does the research require the participation of socially or physically vulnerable people (children, aged, disabled, etc) or legally restricted groups?	YES	NO
2.3 Will you not be able to secure the informed consent of all participants in the research? (In the case of children, will you not be able to obtain the consent of their guardians or parents?)	YES	NO
2.4 Will any confidential data be collected or will identifiable records of individuals be kept?	YES	NO
2.5 In reporting on this research is there any possibility that you will not be able to keep the identities of the individuals involved anonymous?	YES	NO
2.6 Are there any foreseeable risks of physical, psychological or social harm to participants that might occur in the course of the research?	YES	NO
2.7 Does the research include making payments or giving gifts to any participants?	YES	NO

If you have answered YES to any of these questions, please describe below how you plan to address these issues:

PERSONAL EXPENDITURE HABITS, BUT NO IDENTIFIABLE RECORDS KEPT.

ADDENDUM 3: To be completed if you answered YES to Question 3:

3.1 Is the community expected to make decisions for, during or based on the research?.	YES	NO
3.2 At the end of the research will any economic or social process be terminated or left unsupported, or equipment or facilities used in the research be recovered from the participants or community?	YES	NO
3.3 Will any service be provided at a level below the generally accepted standards?	YES	NO

If you have answered YES to any of these questions, please describe below how you plan to address these issues:

ADDENDUM 4: To be completed if you answered YES to Question 4

4.1 Is there any existing or potential conflict of interest between a research sponsor, academic supervisor, other researchers or participants?	YES	NO
4.2 Will information that reveals the identity of participants be supplied to a research sponsor, other than with the permission of the individuals?	YES	NO
4.3 Does the proposed research potentially conflict with the research of any other individual or group within the University?	YES	NO

If you have answered YES to any of these questions, please describe below how you plan to address these issues:

APPENDIX B – Summary of Survey Responses

Drommedaris

FLAT	Household size			
	Adults	School-children	Pre-School Children	Total
1	2	1	3	6
2	2	1	1	4
3	2	1	0	3
4	2	0	1	3
5	3	0	1	4
6	2	1	0	3
7	2	0	1	3
8	2	0	0	2
9	2	0	0	2
10	2	1	0	3
11	2	1	0	3
12	1	2	0	3
13	2	2	0	4
14	2	1	0	3
15	1	0	1	2
16	2	2	1	5

FLAT	Transport			
	Workers commuting	Children commuting	expenditure	footprint
1	1	1	0.0	0.0
2	1	1	610.0	89.2
3	2	1	908.0	28.5
4	2	1	800.0	184.0
5	2	0	1272.0	279.6
6	2	1	600.0	138.0
7	1	0	500.0	115.0
8	2	0	702.0	82.3
9	2	0	400.0	12.1
10	1	1	378.0	12.7
11	1	1	1200.0	276.0
12	1	2	1446.0	59.8
13	2	1	150.0	4.5
14	2	1	304.0	46.8
15	1	1	400.0	92.0
16	2	2	462.0	108.3

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FLAT	Electricity		
	Survey expenditure	Prepaid Data expenditure	footprint
1	200.0	186.7	232.2
2	300.0	210.0	261.2
3	200.0	80.0	99.5
4	200.0	203.3	252.9
5	450.0	230.0	286.1
6	360.0	260.0	323.4
7	120.0	93.3	116.1
8	200.0	156.7	194.9
9	250.0	206.7	257.1
10	200.0	233.3	290.3
11	400.0	226.7	282.0
12	250.0	210.0	261.2
13	150.0	150.0	186.6
14	200.0	200.0	248.8
15	150.0	150.0	186.6
16	120.0	156.7	194.9

FLAT	Income	Other Expenditure		
		Food	Rent	School Fees
1	5859	1700	1795	220
2	7500	1400	2250	1250
3	6616	1500	2250	220
4	6365	2000	2250	600
5	6212	1500	2250	0
6	6287	2500	2250	0
7	6262	700	2250	0
8	6575	1200	1795	0
9	5064	450	1600	0
10	5880	792	2025	164
11	5700	1250	1950	400
12	7500	1600	2250	2100
13	6030	1500	2250	400
14	5654	1600	2250	600
15	5609	1500	2250	600
16	6100	800	2250	660

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Sakabula

FLAT	Household size			
	Adults	School-children	Pre-School Children	Total
1	2	3	0	5
2	4	1	1	6
3	2	4	1	7
4	3	0	0	3
5	2	1	0	3
6	2	3	1	6
7	2	0	0	2
8	4	3	1	8
9	3	2	1	6
10	2	3	1	6
11	1	2	0	3
12	3	0	0	3
13	2	1	0	3
14	2	0	0	2

FLAT	Transport			
	Workers commuting	Children commuting	expenditure	footprint
1	2	3	730	169
2	2	1	830	98
3	2	5	1100	268
4	2	0	720	155
5	1	1	590	136
6	1	1	100	29
7	2	0	600	123
8	0	1	150	62
9	0	2	1000	230
10	1	2	600	11
11	1	1	198	83
12	1	0	252	14
13	1	1	0	0
14	2	0	400	103

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FLAT	Electricity		
	Survey expenditure	Prepaid Data expenditure	footprint
1	400	400	460
2	300	175	201
3	450	530	613
4	400	291	319
5	500	180	207
6	300	111	127
7	300	373	429
8	300	379	436
9	650	422	485
10	500	417	479
11	300	230	264
12	400	377	424
13	300	320	368
14	500	420	480

FLAT	Income	Other Expenditure		
		Food	Rent	School Fees
1	8820	2000	2605	735
2	5830	1500	2000	200
3	5100	1500	2605	653
4	6000	1200	2030	0
5	5435	2500	2034	210
6	4942	1000	1850	600
7	8348	100	2034	413
8	6620	3000	2600	270
9	4933	1350	1933	0
10	7000	3000	1900	650
11	5000	800	1541	487
12	5500	2000	1937	0
13	5000	1200	1600	0
14	5500	2000	2000	0

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Amakhaya Ngoku

FLAT	Household size			
	Adults	School-children	Pre-School Children	Total
1	3	1	0	4
2	3	0	1	4
3	1	1	1	3
4	3	1	1	5
5	2	1	0	3

FLAT	Transport			
	Workers commuting	Children commuting	expenditure	footprint
1	1	1	600	17
2	2	0	2240	515
3	1	1	424	21
4	2	1	440	39
5	1	1	380	110

FLAT	Electricity		
	Survey expenditure	Prepaid Data expenditure	footprint
1	175	Na	291
2	50	Na	135
3	110	Na	210
4	80	Na	173
5	80	Na	173

FLAT	Income	Other Expenditure		
		Food	Rent	School Fees
1	3500	800	400	1100
2	10000	600	400	0
3	2000	1400	400	450
4	2000	800	400	400
5	2500	1200	400	120

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Ocean View

FLAT	Household size			
	Adults	School-children	Pre-School Children	Total
1	5	2	0	7
2	2	1	0	3
3	2	3	0	5
4	4	0	0	4
5	6	2	1	9
6	2	1	0	3
7	1	2	0	3
8	3	2	0	5
9	3	2	0	5
10	5	1	0	6
11	4	3	0	7
12	3	0	0	3
13	3	0	0	3
14	4	3	0	7
15	6	0	2	8

FLAT	Transport			
	Workers commuting	Children commuting	expenditure	footprint
1	2	2	420	46
2	2	1	820	138
3	1	3	300	12
4	1	0	48	3
5	5	2	1128	80
6	2	1	528	99
7	1	2	149	14
8	2	2	336	24
9	1	2	480	24
10	1	1	368	85
11	3	3	1752	67
12	1	0	228	16
13	2	0	426	25
14	3	3	1248	199
15	2	0	174	7

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FLAT	Electricity		
	Survey expenditure	Prepaid Data expenditure	footprint
1	560	Na	672
2	400	Na	480
3	300	Na	360
4	300	Na	360
5	300	Na	360
6	200	Na	240
7	200	Na	240
8	300	Na	360
9	500	Na	600
10	400	Na	480
11	100	Na	170
12	300	Na	360
13	300	Na	360
14	400	Na	480
15	200	Na	290

FLAT	Income	Other Expenditure		
		Food	Rent	School Fees
1	7000	4000	395	67
2	6000	2800	450	33
3	1800	1800	340	117
4	2200	1000	300	0
5	5000	2000	490	88
6	7000	1600	280	33
7	1200	1600	60	83
8	6000	1600	270	83
9	4000	1200	350	42
10	4900	2000	350	30
11	8000	1600	350	83
12	3000	1500	320	0
13	4400	1500	350	0
14	7000	2000	390	550
15	3240	1500	300	0

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APPENDIX C – Estimating the Carbon Footprint of Indirect Rebound Effect Categories

Meat

Data was sourced from Carnegie Mellon University Green Design Institute (2008).

Item	Carbon footprint (kg $CO_{2\ eq}$/$1000)	Exchange Rate (ZAR/USA$)	Carbon footprint per Rand spent (kg $CO_{2\ eq}$/ZAR)
Animal (except poultry) slaughtering and processing	4 090	8.14	0.503

Entertainment/alcohol/cigarettes

For alcohol, Eat Low Carbon (2011) tells that a beer (assumed to average ZAR 10) has a carbon footprint of 0.328 kg $CO_{2\ eq}$ and that a glass of wine (assumed to be a quarter of a ZAR 20 bottle) has a carbon footprint of 0.167 kg $CO_{2\ eq}$. These two main types of alcoholic beverage are combined to give an estimated carbon footprint factor of 0.033 kg $CO_{2\ eq}$ / ZAR for alcohol.

For cigarettes, data was sourced from Carnegie Mellon University Green Design Institute (2008).

Item	Carbon footprint (kg $CO_{2\ eq}$/$1000)	Exchange Rate (ZAR/USA$)	Carbon footprint per Rand spent (kg $CO_{2\ eq}$/ZAR)
Tobacco Industry	309	8.14	0.038

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For entertainment, data was sourced from Carnegie Mellon University Green Design Institute (2008) for 4 different types of entertainment.

Item	**Carbon footprint (kg $CO_{2\ eq}$/$1000)**	**Exchange Rate (ZAR/USA$)**	**Carbon footprint per Rand spent (kg $CO_{2\ eq}$/ZAR)**
Amusement parks and arcades	394	8.14	0.048
Spectator sports	223	8.14	0.027
Fitness and recreational sports centres	566	8.14	0.07
Other amusement, gambling, and recreation industries	671	8.14	0.08
Average			**0.057**

The average carbon footprint factor for entertainment, alcohol and cigarettes is **0.043 kg $CO_{2\ eq}$ / ZAR.**

Furniture/Appliances

For furniture, data was sourced from Carnegie Mellon University Green Design Institute (2008) for 2 different types of furniture.

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Item	Carbon footprint (kg $CO_{2\ eq}$/$1000)	Exchange Rate (ZAR/USA$)	Carbon footprint per Rand spent (kg $CO_{2\ eq}$/ZAR)
Upholstered household furniture manufacturing	574	8.14	0.071
Metal and other household non-upholstered furniture	810	8.14	0.100
Average			**0.085**

For appliances, data was sourced from Carnegie Mellon University Green Design Institute (2008) for 2 different types of appliances.

Item	Carbon footprint (kg $CO_{2\ eq}$/$1000)	Exchange Rate (ZAR/USA$)	Carbon footprint per Rand spent (kg $CO_{2\ eq}$/ZAR)
Electronic computer manufacturing	284	8.14	0.035
Audio and video equipment manufacturing	549	8.14	0.067
Average			**0.051**

The average carbon footprint factor for furniture and appliances is **0.068 kg $CO_{2\ eq}$ / ZAR.**

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Education

Data was sourced from Carnegie Mellon University Green Design Institute (2008).

Item	Carbon footprint (kg $CO_{2\ eq}$/\$1000)	Exchange Rate (ZAR/USA\$)	Carbon footprint per Rand spent (kg $CO_{2\ eq}$/ZAR)
Elementary and secondary schools	374	8.14	0.046

Luxuries

Luxuries that were mentioned were typically chocolates, toys, personal care services, gym and other sports or airtime. The table below shows how data was sourced from Carnegie Mellon University Green Design Institute (2008) to approximate the carbon footprint of these categories of spending.

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Item	**Carbon footprint (kg $CO_{2\ eq}$/$1000)**	**Exchange Rate (ZAR/USA$)**	**Carbon footprint per Rand spent (kg $CO_{2\ eq}$/ZAR)**
Confectionery manufacturing from cacao beans	1 050	8.14	0.129
Doll, toy, and game manufacturing	581	8.14	0.071
Telecommunications		8.14	0.026
Fitness and recreational sports centres	566	8.14	0.07
Personal care services	284	8.14	0.035
Average			**0.066**

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