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A techno-economic study of energy efficiency technologies for supermarkets in South Africa

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Abstract

The food retail sector is energy intensive, consuming large amounts of electricity for refrigeration, air-conditioning and cooking. Retailers are aiming to reduce their electricity consumption in supermarkets and thus their carbon footprint using energy efficiency technologies. This paper reports on a techno-economic analysis of energy efficient technologies to recommend to the food retail sector for use in supermarkets. The targets and needs of food retail companies were surveyed and thereafter, the retailers were divided into three categories. Category 1 retailer had the highest targets for electricity and carbon reduction and was willing to take on more risk. Category 2 retailer had intermediate targets and would only use developed technologies, while category 3 retailer would only invest in developed technologies if they were proven to show significant long term saving with short pay back periods. The analysis showed that closed refrigerators had the highest electricity/carbon savings and the highest profit (NPV), followed by heat reclamation from refrigeration. Both these technologies were recommended for category 1 retailers. A combination of heat reclamation, energy efficient lights, fridge curtains, electronic controls for refrigerators and POS power management systems were recommended for category 3 retailers. A combination of the two recommendations was identified for category 2 retailers. Behavioural changes of all staff were identified as important for energy efficiency technologies to work at optimum levels.

Keywords: supermarkets; energy efficiency; lighting; refrigeration; water heating

1. Introduction

Electricity reduction in organizations in South Africa is beginning to emerge as an essential business activity for a multitude of reasons including the electricity price hikes of 25% year on year for the next three years (Nersa, 2009) and the possible adoption of a carbon price (Department of National Treasury, 2010); investor and customer demands due to climate change reasons, and incentives from government. Electricity security is a further concern as shortages are predicted to extend until 2015 when there will be increased capacity from two more power stations (Eskom, 2011). The local food retail sector, although not one of the most electricity intensive sectors in South Africa, is also aiming to reduce its electricity requirements using primarily energy efficiency technologies. By reducing electricity consumption, the three aspects of reduced costs, energy security and climate change can be addressed.

There is, however, a lack of information and demonstration projects which provide guidance in adoption of energy efficiency interventions. With no experience to learn from, retailers are largely looking to their international counterparts, who are more advanced in their implementation. Thus, there is a need for research to determine technologically appropriate measures for South Africa, specifically focusing on the feasibility of electricity reduction in different climatic regions of the country.

In this paper, the opportunities for electricity reduction, and hence, carbon mitigation, in the food retail sector in South Africa are investigated using a techno-economic approach, with a focus on the store level. Several commercially mature and undeveloped technologies are evaluated based on their level of efficiency and their financial rewards. It is envisaged that these results will provide the sector with an analysis that is specific to the South

African context, and that it will be used as a guideline to further explore the reductions within each organization.

2. Method

2.1. Determining motivations of South African food retailers for reducing their carbon footprints

To achieve this aim, several large food retail companies which make up 90% of the market (Weatherspoon, 2003) and consultants were surveyed to determine their views on, and requirements for electricity and carbon reduction in stores. On the basis of the survey outcomes, three types of hypothetical retailer categories were formulated such that different technologies could be recommended to meet the needs of different retailers. Although all the retailers stressed costs as the most important deciding factor, some retailers were able to take on more risk and were interested in meeting consumer demands to capture niche markets. Some companies had also included corporate sustainability reporting. The first category of retailer had the highest targets for electricity and carbon emission reductions and was willing to experiment with technologies to achieve this. The second category of retailer had lower reduction targets and would only use developed technologies. The third category of retailer had no targets for carbon reduction but would invest in proven energy efficient technologies to reduce electricity consumption, if they showed significant long term savings and short payback periods. Table 1 details the requirements for electricity savings and carbon reductions for each category.

2.2 Short-listing applicable energy efficient technologies

A wide variety of technologies was shortlisted to meet these targets. This shortlist was based on technology used in international and local supermarkets, application suitability, potential for electricity reduction, costs, visibility, availability, and technology maturity. The shortlist included:

a) Electronic ballasts,
b) Compact fluorescent lights (CFLs),
c) Power management systems,
d) Automated fridge curtains,
e) Upright fridges with doors (closed refrigerators),
f) Heat reclamation from refrigeration,
g) Electronic controls for refrigeration,
h) Heat pump geysers,
i) Evaporative coolers,
j) CO_2 fridges.

The number of units required for each option, which was required to compare across options, was based on an average store size of 1 500m^2. This information was provided by different retailers. For each option, the current numbers of fridges, lights, geysers, etc. were based on the existing infrastructure and equipment, such that these options would serve as retrofits. The difference in power output between the current equipment and the retrofits was compensated for. Information on costs, installation, maintenance, life span and electricity savings were also provided by suppliers and energy engineers. The average electricity end use used for all calculations was:

- Refrigeration – 45%
- Air conditioning -18%
- Water heating – 12%
- Lights – 8%
- Point of Sales (POS) – 1%
- Heating (ovens) – 16%

2.3 Selecting and calculating criteria for determination of energy efficient technologies

Criteria for the selection of energy efficient technologies included the following, each of which is discussed in more detail:

a) CO_2 reduction,
b) CAPEX,
c) economic profitability,
d) ease of implementation, and
e) awareness and visibility.

Economic profitability was the most important criterion to all retailers surveyed, and the remaining criteria were used as secondary criteria to further

Table 1: Characteristics of the different categories of retailers

	Category 1	*Category 2*	*Category 3*
Carbon reduction targets	30% of current levels by 2013	20% of current level by 2013	No target
Electricity savings	30%	30%	30%
Cost factor, initial costs vs. long term savings (economic profitability)	Important but willing to trial/ demonstrate technologies	Important – use only developed technologies with short pay back periods etc.	Very important – only factor considered, mature technologies only
Staff and customer awareness	Very important	Very important	Neutral

aid in the decision making process. These criteria were chosen according to a combination of retailer needs, data availability and data accessibility for the technology options chosen. Only criteria for which there was a significant difference in performance between technology options were considered.

a. CO_2 savings
The average electricity consumption and end use of a store was calculated using data made available from the large supermarket retail companies, from stores that are located in the Western Cape.

Prior to calculating the CO_2 emissions savings associated with each of the energy efficiency technologies, electricity savings is calculated as follows:

Electricity (kWh) savings per year = average store consumption per month x estimated % use of electricity by the technology1 x estimated energy savings x 12 months. (1)

e.g. total electricity consumed by the store per month = 150 000 kWh; water heating consumes 12% of total electricity; heat pumps save 70% of electricity for lighting;
then electricity savings per year (kWh)
= 150 000 x 12% x 70% x 12 months
= 151 200 kWh

Once the electricity savings has been calculated, the savings in CO_2 emissions is calculated as follows:

CO_2 (tons) savings per year = Electricity (kWh) savings/year x 0.001 ton CO_2eq^2 (2)

It is noted that the standard unit of measurement for energy consumption and efficiency typically used in commercial buildings (kWh/m^2) was not used here as the purpose was not to compare consumption against other buildings, but to meet reduction targets expressed as percentage.

b. CAPEX
Technology costs were obtained from suppliers and included installation (Table 3). These vary depending on supplier/ contractor and the volumes purchased. Initial investment was stressed as an important consideration. The initial investment included CAPEX, and installation costs.

c. Economic profitability
The profitability of technologies was described by all retailers to be very important, although some retailers placed lesser priority on it relative to other criteria and other retailers. To determine the economic profitability of each technology option, the Net Present Value (NPV) was the method of choice due to its advantages of using multiple discount rates and its applicability to long term projects.

The following formula was used for NPV:

$$\sum_{t=1}^{n} \frac{C_t}{(1+R)^t} \qquad (3)$$

where:
C_t = discounted cash flow (savings per year)
R = discount rate
savings per year = kWh savings per year x unit cost of electricity
and where the discount rate = interest rate or cost of capital = R
n = no. of periods
t = time

To evaluate all options on a consistent basis, the lifespan for all options was set at 15 years as this time frame was common for most technology options. For those options with shorter life spans, replacements were included in the calculation.

The cash flow was based on electricity savings per year for each technology option, as calculated using equation (1). A unit cost of electricity of 92c/kWh was used for 2011, R1.15 for 2012 and R1.45 for 2013 in line with the NERSA's electricity pricing (NERSA, 2009). Thereafter electricity prices increased by 10% every year (based on historical price increases). The discount rate was pegged to interest rate forecasts provided by Standard Corporate Merchant Bank in South Africa (Darmalingam, 2011). These interest rate forecasts are adjusted for risk premium and inflation and they are commonly used as a discount rate (Darmalingam, 2011).

d. Ease of implementation
The ease of implementation of each technology was noted according to the length of time required for installation, downtime, loss of sales, and if a technician was required to retrofit

e. Awareness and visibility
The visibility of each technology was also noted as to who it would be visible to, i.e. the customer, staff only or technician only.

3. Results

Table 2 shows that the biggest electricity savers are heat reclamation, CFLs, heat pump geysers and evaporative coolers. However, due to the biggest use of electricity being refrigeration (45%), followed by air conditioning (18%), ovens (12%), hot water (12%) and lights (8%), the retrofits that were associated with these end uses produced the highest savings in electricity and thus carbon emissions.

Table 3 shows the CAPEX and economic profitability (NPV) for these energy efficiency technologies.

Table 2: CO_2 savings per year for each technology option

Retrofit Option	*Units*	*Life time (years)*	*Electricity savings (%)*	*Electricity savings / year (kWh)*	*CO_2 saving / year (tons)*
Fridges with doors (closed)	10	15	35	295 000	295
Evaporative cooling A/C	11	15	70	270 000	270
CO_2 fridges	1	25	30	253 000	2533
Heat reclamation from refrigeration	2	15	100	225 000	225
Heat pump geyser (150L)	2	15	70	151 000	151
Electronic controls and monitoring (refrigeration)	1	15	15	126 000	126
Fridge curtains (1.8m)	20	5	20	84 000	84
Electronic ballast & T8 (28W) light	50	7	22	31 000	31
Power management soft-ware for POS	10	15	50	9000	9
CFL (28W)	5	3	85	8000	8

The biggest cost savings were through refrigeration, water heating and air conditioning related technologies, as expected due to the ratio of electricity they consume. Fridges with doors saved the most amount of money in the long term and did not have a significant initial investment, compared to energy efficient air conditioning, electronic controls or CO_2 refrigeration. Changing the lighting and installing power management systems, which are frequently regarded as low cost measures, did not show significant savings. However, the results also revealed that there was no relationship between initial investment costs and the long term financial rewards, thus supporting the case for strategic analysis and reviews instead of adopting random technologies.

CO_2 refrigeration is interesting as at first glance the NPV showed a loss which is contradictory to international case studies that show large savings. However, when the project lifetime was increased to 25 years (the expected lifespan), a profit of more than R3.5 million was projected.

The effect of increasing electricity tariffs in the next three years on the financial savings each year is also shown in Table 4. These price hikes have been taken into account for the long term NPV calculations.

Results for the other two criteria – ease of implementation and awareness and visibility as well as the status quo on the usage of these technologies are summarized in Table 5.

4. Discussion

The survey of the food retailers and consultants who participated revealed the various reasons that retailers in South Africa are reducing their electricity consumption and carbon footprints. These reasons are no different to retailers in the rest of the

Table 3: Costs and NPV for technology options considered

Retrofit Option lifetime	*Units*	*Capex/unit (R)c/osts (R)*	*Total initial)otal Mainac (R)*	*Maint. costs lifetime (R*	*Total maint. /year (R)*	*Product years) Product l (R)*	*Savings (R)*	*NPV (15*
Fridges with doors (closed)	10	10 000	100 000	0	0	15	271 000	4 720 000
Evaporative cooling A/C	11	25 000	275 000	500	5 500	15	248 000	2 520 000
CO_2 fridges	1	5 000 000	5 000 000	8 000	200 000	25	233 000	- 870 000
Heat reclamation from refrigeration	2	20 000	40 000	0	0	15	207 000	3 600 000
Heat pump geyser (150L)	2	9 000	18 0006	500	1 000	15	145 000	2 500 000
Electronic controls and monitoring (refrigeration)	1	60 000	60 000	0	0	15	116 000	2 000 000
Fridge curtains (1.8m)	20	1 500	30 000	0	0	5	78 500	13 000 000
Electronic ballast & T8 (28W) light	50	240	11 200	0	0	7	29 000	495 000
Power management software for POS	10	160	1 600	30	300	15	9 000	140 000
CFL (28 W)	5	35	-257	0	0	3	7 000	126 000

Table 4: The effect of increasing electricity tariffs on savings for each technology

Retrofit option	*Electricity savings /year (kWh)*	*Savings/ year (2010/11) (R)*	*Savings/ year (2011/12) (R)*	*Savings/ year (2012/13) (R)*
Fridges with doors (closed)	295 000	271 000	340 000	423 000
Evaporative cooling A/C	270 000	248 000	310 000	388 000
CO_2 fridges	253 000	233 000	290 000	363 000
Heat reclamation from refrigeration	225 000	207 000	258 000	323 000
Heat pump geyser (150L)	151 000	145 000	180 000	226 000
Electronic controls and monitoring (refrigeration)	126 000	117 000	145 000	182 000
Fridge curtains (1.8m)	84 000	78 000	97 000	121 000
Electronic ballast & T8 (28W) light	31 000	29 000	36 000	45 000
Power management software for POS	9 000	9 000	11 000	13 000
CFL (28W)	8 000	7 000	9 000	11 000

Table 5: Awareness and ease of implementation of each technology

Retrofit option	*Ease of implementation*	*Visibility/awareness*	*Status quo*
Fridges with doors (closed)	New units required and possible change of floor design	Very visible	Few units in most stores
Evaporative cooling A/C	Easy to install, little downtime, but technician required	Hidden	Trialed
CO2 fridges	Complete retrofit, long downtime	Hidden	Trialed
Heat reclamation from refrigeration	Easy to install, no/little downtime, but technician required	Hidden	Trialed
Heat pump geyser (150L)	Easy to install, no/little downtime, but technician required	Hidden	Trialed
Electronic controls and monitoring (refrigeration)	Easy to install, no/little downtime, but technician required	Visible to staff only	Trialed
Electronic ballast & T8 (28W) light	Directly interchangeable with magnetic ballasts	Very visible	Roll out in most stores
Fridge curtains (1.8m)	Units need to be factory fitted	Visible to staff only	Trialed
Power management software for POS	Install programme, no down time	Visible to staff only	Not used
CFL (28W)	Directly interchangeable with incandescent bulbs	Very visible	Roll out in most stores

world (Zipplies, 2010). Although all the retailers recognized the importance of energy saving and climate change, and in particular their part in carbon mitigation, some were leaders while some preferred to delay adopting interventions for reducing their emissions. This delay was ascribed to several reasons including experiential learning, favourable market mechanisms or until it was mandatory. Retailers were also cognizant of the costs associated with these reductions, especially since the food retail sector has small profit margins of between 1 and 2% (Bradshaw, 2011), however, the "leaders" were more willing to accept longer payback timeframes for projects, as long as these projects showed large financial rewards in the future.

Although the carbon reduction targets for each category of retailer were different, the electricity reduction targets were the same for all retailers surveyed (30% by 2013). The biggest reductions in carbon/electricity were from closed refrigerators, evaporative cooling, CO_2 refrigeration and heat reclamation from refrigeration. Using a combination of technologies, the electricity reduction targets can be achieved. The 30% electricity target for all retailers requires a saving of 561 600 kWh/annum (total average annual consumption per store = 1.87 million kWh). Using closed fridges saves 300 000 kWh/ annum (table 2) and heat reclamation from fridges to heat water has a high carbon savings of 225 000 kWh/ annum (Table 2).

Closed refrigerators have also showed the highest profitability, almost R5 million over 25 years. Additional benefits are that they are easy to install and allow the store to maintain a comfortable temperature for customers. Closed refrigerators are also at the front end of the store, and customers interact with them directly. Therefore, this option is highly recommended. However, it is well known that there is a perception by marketing divisions of retail organizations that closed fridges hamper sales due to their effect on decision making as a result of the inconvenience associated with opening fridges for every item (Smith, 2010). Thus retailers are not keen to install closed fridges throughout the stores. Therefore, closed refrigerators are only recommended for a category 1 retailer.

The heat reclamation system would replace an electrical geyser completely and be more efficient and cost effective than a SWH or heat pump, as it utilizes waste heat. The heat can also be diverted for use in under floor heating and maintaining thermally comfortable temperatures in the stores, thereby reducing the load on the HVAC system. Furthermore, the heat reclamation system does not require any additional servicing as there are no moving parts, and can be maintained as part of the refrigeration units at the back end of the store. A combination of heat reclamation and closed refrigerators meets the electricity targets for the store.

For category 3 retailers, a combination of heat reclamation (225 tons/year CO_2), electronic controls for refrigeration (126 tons/year CO_2), fridge curtains (84 tons/year CO_2), energy efficient lights (40 tons/year CO_2), and POS power management systems (9 tons/year CO_2) are recommended to meet electricity and carbon targets. All of these technologies are low cost adding up to R140 000 for installation per store, which is the same combined cost as installing a heat reclamation system and closed refrigerators that is recommended for category 1 retailer. Additionally, the NPV for the combination of technologies for category 3 retailer amounts to R8 million, slightly less than the technologies recommended for category 1 retailer (R 8.3 million). These technologies are easy to install and require little maintenance. These technologies also complement each other with the heat reclamation system saving the majority of electricity and lights being able to meet visibility requirements for all categories. The added advantage is that all of these technologies are mature technologies and their efficiencies and experiences have been well documented. As mentioned, most stores have already installed CFLs, but magnetic ballasts are not very prominent at present, and their use could be extended.

It is important not to overestimate the potential success of energy efficiency, especially if the high energy consumption is due to low levels of behavioural discipline (Schelly *et al*., 2011) and/or poor insulation. This behavioural discipline stems from poor management and lack of commitment to electricity reduction, and if these attitudes persist when energy efficient technologies are installed, these technologies will lose efficiency over time due to poor maintenance of equipment. Usually simple and regular cleaning methods by staff as well an annual service by qualified technicians is enough to ensure proper operation of most equipment e.g. fridges and air-conditioners (Schlemmer, 2010). Other behavioural changes that will reduce electricity consumption include, amongst others, switching off equipment that is not in use, maintaining appropriate temperatures for cooling and heating equipment for different times of day and year, and not overloading fridges and freezers thereby blocking off air vents. Research shows that the implementation of energy efficient technologies may sometimes have the reverse reaction in behaviour resulting in people consuming more. This is known as the "Rebound Effect". Therefore, energy efficiency technologies go hand in hand with increased staff awareness, training and buy-in, introducing this into key performance areas for employees and including it in sustainability reporting for organizations. Although this study attempted to include criteria such as "Ease of implementation" that assist in the uptake of these selected technologies, this is a technology centric study, and a multi-faceted approach which includes the behaviour of retailers and their staff should also be undertaken.

5. Conclusion

This research forms a preliminary investigation into the techno-economic feasibility of electricity and carbon reduction in supermarkets in South Africa. Closed refrigerators showed the highest electricity/carbon savings and the highest profit (NPV), followed by heat reclamation. Both these technologies were recommended for category 1 retailers who have the largest targets for both electricity and carbon reduction and are willing to trial technologies. A combination of heat reclamation, energy efficiency lights, fridge curtains, electronic controls for refrigerators, and power management systems for point of sales (POS) systems were recommended for category 3 retailers. Category 2 retailers have intermediate targets and can adopt a combination of the two recommendations to meet targets. Further research is needed to determine the feasibility of technologies within specific organizations and specific locations. Behavioural changes are also imperative if energy efficient technologies are required to work at optimal levels to reduce the targeted electricity and carbon reductions.

Notes

1. The number of units per end use was included in calculations
2. The emissions factor varies between years. This factor includes losses in transmission (5.58%) and distribution (1.74%) specific for the Western Cape (Eskom,

2010; Letete et al., 2010)

3. Emissions from leakages not included
4. Includes Eskom rebate for lights at 34c/kWh saved (Eskom, 2010b)
5. Includes Eskom rebate for lights at 34c/kWh saved (Eskom, 2010b)
6. Includes rebate of R3600 per heat pump

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