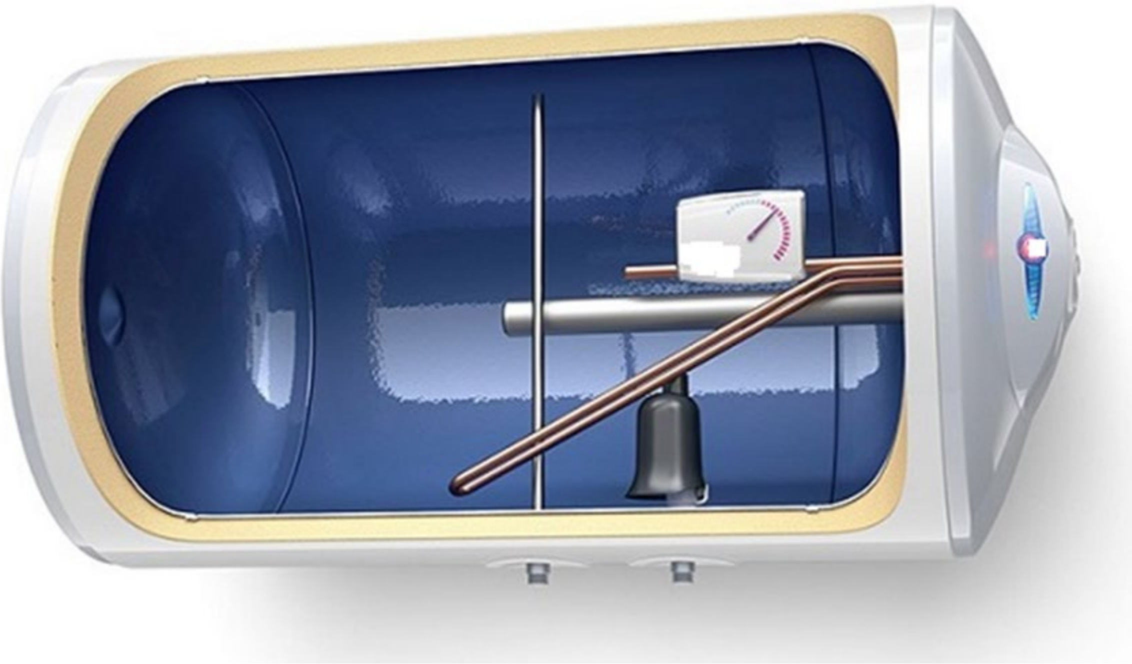

Residential Water Heating Demand Side Management (DSM) - South Africa

Executive Summary

Yu-Chieh J. Yen and Ken Nixon, University of the Witwatersrand

Stephane de la Rue du Can, Theo Covary and Jim Lutz, Lawrence Berkeley National Laboratory

Marcus Dekenah, Marcus Dekenah Consulting

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INTRODUCTION

The electricity crisis in South Africa has deteriorated significantly in recent years, characterized by frequent and extended rolling blackouts. These power outages have severe economic consequences, resulting in decreased growth and productivity. To address this crisis, Demand Side Management (DSM) emerges as a crucial strategy, with a particular focus on electric water heaters due to their significant energy consumption.

The residential sector, a major contributor to peak demand, heavily depends on electric water heaters (geysers). Recognizing this, the study aims to evaluate opportunities for DSM programmes targeting water heating to mitigate energy consumption and peak demand.

MARKET

Electric geysers dominate the household water heating market in South Africa, with between 450 000 and 550 000 units sold annually, primarily for newly built houses, renovations and replacement of failed units. Due to the straightforward technology and high import costs, almost all geysers in South Africa are locally manufactured. The market is dominated by two major companies, Kwikot and Ariston, collectively controlling 85% of the market. Kwikot, established in 1903 and acquired by Electrolux in 2017, remains the largest supplier, while Ariston has increased its market share.

A unique aspect of the South African market is that households have little day-to-day contact with their geysers, as they are typically stored in the attic. A common practice is installing geysers horizontally rather than vertically to accommodate the limited space available in the attic. Additionally, it is a legal requirement for financed houses to have building insurance covering geysers. Therefore, when a geyser fails, households contact their insurance company rather than a plumbing service. As a result, households have minimal involvement in the process beyond reporting the incident and granting access.

CURRENT REGULATION

All electric geysers in South Africa must comply with the South African National Standard (SANS) 151:2022 Edition 8.03, which requires that geysers must meet or not exceed a minimum standing loss over a 24-hour period, which serves as the minimum energy performance standard (MEPS). The MEPS was revised in 2016 from a level E (up to 2.54kWh) to a level B (less than 1.40kWh), resulting in significant electricity savings estimated at 3.8 TWh by 2030.

Furthermore, South Africa implemented a mandatory building code in 2011 (SANS 10400 XA, updated in 2021 to XA2), which mandates that at least 50% of the annual average hot water requirement of all new buildings must be provided by means other than electrical resistance heating. This includes options such as solar heating, heat pumps, heat recovery systems, and renewable combustible fuel, promoting energy efficiency (EE) and reducing reliance on electric water heating.

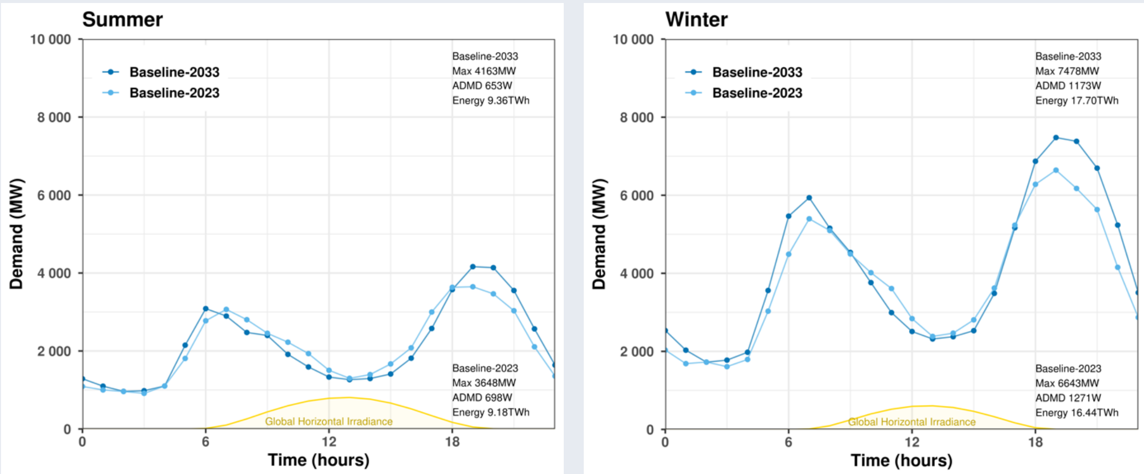
METHODOLOGY AND BASELINE

A tool was developed to simulate water heating power load profiles for multiple electric resistance geysers using a bottom-up approach and a Monte Carlo method. The results from the simulation tool take the form of a baseline load profile for summer and winter weekdays for the year 2023 with a 10-year forecast into 2033. For this study, several EE and demand response (DR) interventions are identified and simulated to compare the impacts of electricity demand on the national grid.

BASELINE

A baseline analysis was conducted to establish the national water heating energy demand in South Africa for the current year, 2023, and projected over a 10-year forecast scenario to 2033. The analysis accounts for the number of households with access to electricity and water, estimating 5.2 million connected geyser units in 2023 and projecting 6.4 million units by 2033. Load profiles developed for each season show a forecasted increase in maximum demand, with winter demand projected to rise to 7 478 MW compared to an estimated 6 643 MW in 2023, nearly reaching a level requiring an additional stage of load shedding (Figure ES 1). However, the forecast also indicates a notable reduction in daytime load by 2033, attributed to an increase in residential rooftop PV installations indirectly servicing geyser load during solar production hours. This increase in PV penetration, driven by the ongoing supply shortages and load shedding, is forecast to reach 30% by 2033 in the baseline scenario due to increasing current trends of adoption.

FIGURE ES 1. Representative load profiles for estimated 5.2M (2023) and 6.4M (2033) geyser units nationally with set points at 65°C for (a) summer and (b) winter.



(a) Baseline summer

(b) Baseline winter

The baseline analysis shows a reduction in After Diversity Maximum Demand (ADMD) from 1 271 W in 2023 to 1 173 W in 2033 in winter and from 698 W in 2023 to 653 W in 2033 in summer. This is attributed to the increased number of geysers with insulation ratings of level B instead of level E. The total annual energy consumption due to water heating load is increased from 25.6 TWh to 27.1 TWh from 2023 to 2033. This is a relatively small increase of 1.5TWh for a 10-year duration and a 1.2M increase in population can be attributed to the combination of increased level B insulated geysers and increased rooftop PV penetration.

TECHNOLOGY OPTIONS

In this section, the study provides a concise overview of the initial technologies and measures considered to reduce energy demand for water heating. Ten potential water heater technologies are listed and briefly described, outlining their key concepts and potential impact on EE (Table ES 1). These technologies range from thermostat adjustment and insulation enhancement to advanced solutions such as heat pump water heaters and solar water heating systems. Here, different policy tools are needed for successful implementation, where regulations are more effective and equitable for standardised products and installation practises, whilst incentives are better suited to a technology switch which require a sizable capital investment from the homeowner. By considering these interventions, the study aims to assess their effectiveness in reducing energy demand and improving overall EE in water heating systems. Six of those interventions were selected and their impact on load demand was assessed in Section 5. This study, undertaken in partnership with the Department of Mineral Resources and Energy (DMRE), prioritises regulatory interventions given the ministry's role and mandate.

TABLE ES 1. Water Heating Technology Assessment

Options	Short Description
Tank and Piping Insulation	Insulating the pipes (2m) and fittings close to the geyser will reduce heat loss whenever there is hot water in the tank, not just when hot water is being used.
Geyser Element Wattage Rating Reduced	Installing lower wattage elements reduces the instantaneous aggregated electricity demand of geysers at all times including peak times. The time to reheat water will take longer at individual geysers. This measure will not reduce total demand but shift load.
Electricity Tariff Time of Use (TOU)	TOU tariff is a pricing structure for electricity consumption where the rate varies depending on the time of day, typically divided into peak, off-peak, and shoulder periods. This tariff is designed to encourage consumers to shift their electricity usage away from peak times when demand and costs are highest, to help to balance the load on the electrical grid. TOU is most effective when control devices adjust the temperature and energy demand to the prevailing tariff.
Smart Controls	Smart control technologies refer to systems and devices that enable automated and intelligent control over electrical equipment by utilizing sensors, communication networks, and data processing capabilities to monitor, analyse, and manage the geyser more efficiently. These technologies help optimize energy demand without compromising user service comfort. These can be controlled centrally or by the user.

Heat Pump Water Heaters (HPWH)	HPWH are typically 200-300% efficient, compared to no better than 100% efficiency of resistance electrical heating. HPWH use an electrically powered compressor to operate a refrigeration cycle to extract heat from ambient air. Upfront costs are a barrier.
High pressure solar thermal water (HP SWH)	HP SWH comprises a solar collector, a storage tank, and a network of pipes to transfer heated water to the existing hot water pipes. HPSWH can reduce annual energy use by 63%. However, upfront cost remains a barrier and there is always a risk that the backup element will switch on in peak demand hours.
Low pressure solar water heaters (LP SWH)	In LP SWH the water in the tank is under low pressure and is equal to the gravity of the water. The water heats up directly in the collector tubes. LP SWH are commonly installed in low-income households to offer access to hot water where it was previously unavailable. These systems do not have a backup electrical element, but they are affordable.
Direct Photovoltaic Water Heating Systems	Electricity generated by PV can be conducted directly to heating elements in geysers. The direct current power from the PV panels is converted to heat, thus the installation does not include an inverter. The system can be integrated with existing geysers, with the option to retain the alternative current (AC) element as backup or replace it with a direct current (DC) element. Effective control of the elements is crucial to prioritize PV electricity and minimize grid electricity consumption.
Indirect Photovoltaic and Timer Switch	Residential rooftop PV systems, when equipped with inverters and batteries, can help offset energy usage by geysers. Typically, geysers are connected as non-essential loads in these systems, meaning they do not draw power directly from the battery but are indirectly supplied with excess PV electricity. Batteries are usually sized to supply essential loads like lighting, entertainment, IT, and security, while coordination between the inverter and geyser controls is necessary to ensure surplus PV electricity is used to heat water effectively.
Low-Flow Showerheads and Taps	Low flow showerheads are engineered to minimize water flow while maintaining a satisfactory shower experience. By reducing the volume of water per minute, these showerheads decrease the amount of hot water consumed, subsequently lowering the overall energy required for water heating. This feature can result in notable energy savings.

SCENARIO ASSUMPTIONS

A selected number of interventions aimed at reducing energy demand for water heating were simulated with forecasted adoption rates over a 10-year period. Table ES 2 describes the main assumptions for each of the technologies selected.

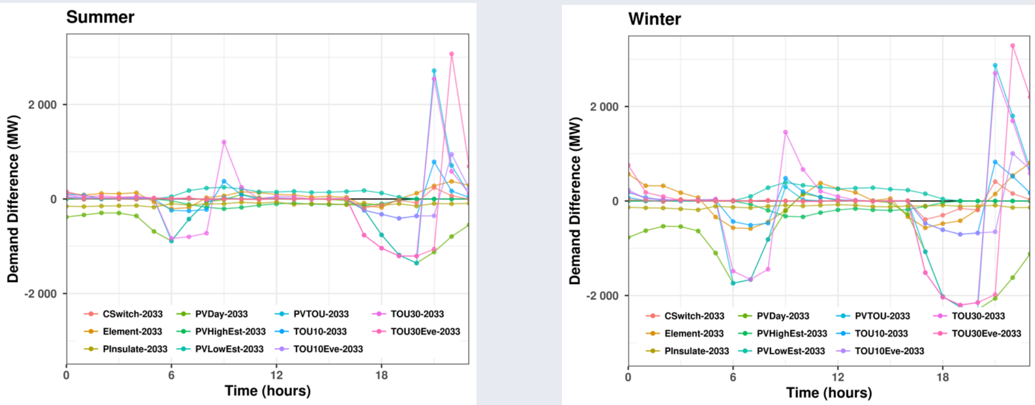
TABLE ES 2. Main Intervention Scenario Assumptions

Piping Insulation	Pipe insulation is simulated by reducing the pipe losses to half. For the ten-year forecast, the simulation considers full adoption by 2033 with 100% penetration
Reducing Heating Element rating	200-litre and 150-litre geyser elements are reduced by 1kW (4 to 3kW, and 3 to 2kW). For the ten-year forecast, it is simulated that this intervention is fully adopted by 2033.
Controlled Switching	For the evening peak period (17:00-21:00), one quarter of the 30% switched geysers are sequentially turned off each hour and returned the next hour, i.e. the first quarter turn off at 17:00 and return at 18:00, the second quarter turn off at 18:00 and return at 19:00 etc.
TOU – 3	A 30% penetration of external switches are set to keep elements off during morning peak (06:00-09:00) and evening peak (17:00-21:00).
PVDay	Geyser load demand is coupled with a PV rooftop installation and is switched off all the time except from 10:00-15:00.

RESULTS

Results are presented through 24-hour load profiles with hourly averaged power demand values, comparing against baseline scenarios for 2023 and 2033. Difference curves are developed to indicate changes in demand from the 2033 baseline, with zero values indicating no change, negative values indicating reduced demand, and positive values indicating increased demand. A combined demand difference profile for all interventions against the 2033 baseline is presented in Figure ES 2 (a) and (b) for summer and winter.

FIGURE ES 2. Combined demand differences for all interventions against 2033 baseline.



(a) Demand difference for all interventions (summer).

(b) Demand difference for all interventions (winter).

All interventions demonstrate a reduction in overall demand (below the zero mark). The interventions that have a large impact on reducing demand during peak times have the consequence of high restorative loading effects, except PVDay. However, the restoration load occurs after 9 pm, corresponding to reduced demand on the overall system, and can be compensated by the operating reserve.

The overall summary of results for each intervention are presented in Table ES 3 with the user comfort, the difference of maximum demand, ADMD and annual energy compared to 2033 baseline. The user comfort level metric indicates the percentage of geysers with hot water below 40°C at the outlet, providing insight into potential issues with hot water service. Table ES 4 provides a summarized analysis of these results.

TABLE ES 3. Energy Demand and Consumption Impacts of Each Intervention

Simulated Scenario		User Comfort [%]	Hourly Averaged Max Demand [MW]		After Diversity Max Demand (ADMD) [W]		Energy Consumption [TWh]
Scenario	Description	S/W	Summer	Winter	Summer	Winter	Annual
PInsulate-2033	Insulate pipes up to 1-m from tank at 100% penetration	100/100	-99	-113	-15	-17	-1.1
Element-2033	Reduce element ratings at 100% penetration	99/92	96	-275	15	-43	0.2
CSwitch-2033	30% penetration of controlled switches	100/99	-30	-157	-4	-24	-0.1
TOU-3	30% switch, elements off morning and evening peak	99/94	1,931	1,921	303	302	-1.2
PVDay	30% PV, switch on during day	87/76	-1,187	-2,242	-186	-351	-5.7

TABLE ES 4. Analysis of Each Intervention Result

Piping Insulation	The comparison of the 2033 intervention with 100% adoption against the 2033 baseline shows a uniform reduction of demand for all 24 hours. With the full adoption of this intervention, benefits and savings are passively observed on the system. This results in a reduced maximum demand, ADMD and energy consumption of 1.1 TWh in 2033 with no service impact to consumers, whilst they benefit from reduced losses.

Reducing Heating Element Rating	The simulated results show that the fully-adopted intervention has the potential to passively reduce morning and evening peaks and elongate the peak period resulting in a small increase in energy consumption of 0.2 TWh. The impact of the intervention on summer months on user comfort is minimal, with 99% of geysers supplying water temperatures above 40C for all draw events. However, the reduction of element ratings has a much greater impact on winter hot water usage, resulting in 92% of geysers supplying hot water at user comfort levels.
Controlled Switching	The simulated results show a slight reduction in demand during the switching period with a slightly elevated demand after the switching period. Interestingly, energy is reduced in this scenario by 0.1TWh. User comfort is minimally affected, with 99% of geysers at water temperatures above 40ºC in winter.
TOU – 3	The simulated results show a significant peak demand reduction with the consequence of a high restorative load when elements are turned back on. This can introduce a loss of diversity to the system. Results show significant energy savings of 1.1TWh. The energy reductions observed can be due to the shifted load in the morning peak, where the PV systems are absorbing a portion of the restorative load from 10am onwards. PV system has been forecasted to increase to 30% penetration by 2030 in the baseline scenario. The user comfort is relatively unaffected during summer months with 99% of geysers supplying water temperatures above 40ºC for all draw events. The user comfort levels drop to range between 94% in winter, with the possible manual override for specific geysers for households that experience a lack of hot water service.
PVDay	This intervention shows the highest peak demand reduction and the highest energy savings. The results can reduce overall demand to levels below 2023 demand. There is a slight peak observed at 10:00, when elements can draw from the grid, and it indicates that not all geyser load is supplied by the rooftop PV generation. Individual households can adjust this time to suit the specific rooftop solar installation to defer more load onto the rooftop PV generation. The overall power demand and energy consumption is greatly reduced, but at the trade-off of overall user comfort, with summer levels at 87% and winter levels at 76%. While this switching scheme has great potential to vastly reduce water heating demand from the grid, the switching will need to be customised to specific households or allow manual overrides.

DISCUSSION AND RECOMMENDATIONS

This study explores strategic approaches for DSM of electric water heaters to reduce overall demand and energy consumption from the electrical power grid. Two main categories of interventions are summarised in Table ES 5.

TABLE ES 5. Policy Recommendations

Regulations	Insulation of Pipes: Estimations suggest a potential reduction of 100 MW throughout the day and 1 TWh annually by 2033. Enforcing existing regulations through insurance replacement and incentives is recommended.
	Reduction of Element Rating: This intervention, achieved through new manufactured geysers and replacements, can passively reduce maximum demand during peak times without significantly affecting user comfort levels. It also has little to no impact on manufacturing and is deemed a low cost intervention.
Financial Incentives	Controlled Switch: A coordinated switching scheme can effectively lower the high restorative load from synchronised geysers, particularly beneficial for municipalities.
	TOU Tariffs and External Switch: Deferring water heating loads with external switches is effective in reducing maximum demand during peak times, though challenges may remain with restorative loads.
	Indirect water heating load reduction through rooftop PV augmented with external switch: With an anticipated increase in rooftop PV, this scenario offers a potentially advantageous alternative to HPSWH. The increase in rooftop PV allows water heating load, and potentially residential loads, to be offset from the grid during solar production hours. A forecast of 30% PV penetration by 2033 can potentially reduce daytime water heating demand below 2023 levels, with some impact on user comfort levels. Manual override options may enhance consumer acceptance, especially if extreme switching schemes are incentivized through higher electricity bills.