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Demand Side Management potentials for mitigating energy poverty in South Africa

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ABSTRACT

South Africa is severally posited to be Africa's most industrialized nation with an economy heavily reliant on energy. With depleted electricity reserve margin which led to massive load shedding and rationing of electricity in 2008, Eskom has stepped up the construction of additional power plants to cover for growing supply deficits. Emerging trends however favour Demand Side Management (DSM) initiatives as alternatives to building additional supply capacity due to environmental and economic constraints. This research evaluates the electricity per capita for 2007, 2011 and 2016 on provincial basis assuming 100% and 36.8% residential sector consumption of generated electricity to show declining electricity per capita values. A scenario simulation (for 100%, 50% and 30% household participation) of cloth washers and cloth dryers optimal dispatch is then modelled to show the enormous DSM potentials in terms of electricity cost reduction and supply flexibility. A modified genetic algorithm (MGA) is used in the dispatch of participating loads on the Medupi power plant which has been modelled to operate with carbon capture and sequestration (CCS) technology. DSM potentials of 6938.34 MW, 3469.18 MW and 2081.51 MW are computed for 100%, 50% and 30% household participation for cloth washers and cloth dryers.

1. Introduction

South Africa is one of Africa's most industrialized nation and also its highest net electricity producer (about 45%) (Eskom). Most of the electricity consumed by the nine provinces of South Africa is produced by Eskom from 27 major power stations with combined installed nominal capacity of over 42000 MW from various sources including; coal, hydro, liquid fuel, pumped storage, nuclear and wind (Where Eskom's electricity comes from, 2015). The significant growth witnessed in South Africa's electrification drive (rural and urban) which has seen electrification rate move rapidly from less than 33% (in 1990) to 58% (1996) and 90% (2016) has been largely due to various government policy and intervention (Marquard et al., 2007).

According to Marquard et al. (2007), electrification in South Africa which was around 35% of the total population before 1990 had doubled by 2000. The 1996 census conducted revealed that about 58% of the country's population had access to electricity. Continuing, Marquard et al. (2007) further posited that only about one in four non-urban black South African households were electrified compared to 97% electrification of non-urban white South African households before 1990. It could thus be surmised that the major obstacle to increased widening access to electricity was political, which kept electricity access prior to 1990 below 40%. These dismal statistics highlighting low electrification rates for pre-1990 years were further worrisome when compared to countries with similar income levels at the beginning of the electrification program (Argentina – 88%, Venezuela – 86%, Costa Rica – 85%, Thailand – 75% and Brazil – 65%). However, the abolishment of apartheid and subsequent entrenchment of democracy has led to a steady increase in electrification rates in the country. A further observation from the report (Marquard et al., 2007) was the fact that as at 1990, South Africa had an extremely energy intensive economy and possessed in Eskom a world class electricity supply industry with a huge electricity reserve margin.

Table 1 (Where Eskom's electricity comes from, 2015) gives a breakdown of the contribution share of each energy source to Eskom's overall capacity while Table 2 (Eskom power stations from 1926 to 2015, 2014) presents the time-line of the evolution of South Africa's power stations from 1926 to 2015 vis-a-vis their commissioning, decommissioning and recommissioning.

While government's initial efforts at boosting electricity generation

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Nomenclature

$AHHS_{j,k}$	year j, province k average household size
$C_{bias}{}^{cost}$	consumer cost biased function
CCS	carbon capture and sequestration
$DEC_{j,k}^{\eta=0.368}/DEC_{j,k}^{\eta=1}$	Daily Electricity Consumption per capita (individual) for year j assuming 36.8% and 100% respectively of electricity supplied province k is consumed by the residential sector
$HEC_{j,k}^{\eta=0.368}/HEC_{j,k}^{\eta=1}$	Hourly Electricity Consumption per capita (individual) for year j assuming 36.8% and 100% respectively of electricity supplied province k is consumed by the residential sector
$HWEC_{j,k}$	Normalized value for province k households with electricity connection for year j
$MEC_{j,k}^{\eta=0.368}/MEC_{j,k}^{\eta=1}$	Monthly Electricity Consumption per capita (individual) for year j assuming 36.8% and 100% respectively of electricity supplied province k is consumed by the residential sector
$OP_t{}^{cost}$	Time t operations cost
$P_{cost}{}^{DP}$	Daily cost of electricity to consumers using dynamic pricing
$P_{cost}{}^{FP}$	Daily cost of electricity to consumers using time of use pricing
$REC_{j,k}$	Residential Electricity Consumption for province k, year j
S_{cost}	Daily operational cost of generating electricity by the utility
$THH_{j,k}$	Total households for province k, year j
$U_{bias}{}^{cost}$	Utilization cost biased function
U_{cost}	Daily cost that penalizes generator utilization outside optimal operational limits
$YEC_{j,k}^{\eta=0.368}/YEC_{j,k}^{\eta=1}$	Yearly Electricity Consumption per capita (individual) for year j assuming 36.8% and 100% respectively of electricity supplied province k is consumed by the residential sector
DLC	Direct Load Control
DSM	Demand Side Management
MGA	Modified Genetic Algorithm
QoL	Quality of Life
TOU	Time Of Use

and access led to a surplus in electricity supply in 1990 which resulted in the mothballing of the Komati, Camden and Grootvlei power stations, inconsistencies in government policies and an initial delay in the construction of additional power stations to compensate for increasing population and industrialization activities, have seen Eskom in recent times implementing load shedding (Kohler, 2014; Loadshedding) to offset supply deficits and prevent grid collapse.

Government has consistently evolved policies to guarantee energy security and sufficiency right from the National Electrification Forum of 1991–1993. Furthermore, the South Africa Government electrification thrust is service delivery based rather than on providing energy for productive services. With an increasing population and rising demand of energy for both residential and non-residential (commercial, transportation, industrial etc.) activities, building additional power plants to boost supply though logical is becoming increasingly expensive as recognised in the United Kingdom by Bradley et al. (2013), Ofgem (2015). In addition, global concerns relating to the negative contribution of fossil based electricity generation to the environment puts further constraints on the design and construction of these additional power plants. Further compounding South Africa's energy (electricity) sector drive issues is the fact that a number of South Africa's coal-powered plants will be decommissioned within the next decade. This presents a problem of energy security as planned replacements may not be able to completely cover the expected shortfalls due to delays in completion or other competing factors.

South Africa in keying into global trends has been increasing its energy base share of renewable energy. Interests has varied from solar (solar water heating) (Eskom) to wind (Eskom) to concentrating solar power (CSP) (Eskom) etc. However, despite the modest contribution of renewable energy sources (RES) to South Africa's generation mix, their availability is both stochastic (with respect to location) and probabilistic (with respect to supply) which means that exactly quantifying their real time capacity via prediction does create some disparity between predicted and actual values. This is however at variance with generation from conventional sources like coal and diesel generator power plants whose capacities are known values and provide exact figures during system operations (SO) and planning.

Table 1
Breakdown of energy category contribution to Eskom's capacity (Where Eskom's electricity comes from, 2015).

Source/Category	Number	Capacity (MW)	% of Eskom's total capacity
Coal power	13	34,952	84.85
Liquid fuel	4	2409	5.85
Nuclear power	1	1830	4.44
Pumped storage	2	1400	3.40
Hydro power	6	600	1.46
Wind power	1	3	0.01

Demand Side Management (DSM) has in recent times been gaining traction as a viable means of curtailing or modifying consumer's consumption pattern by shifting demand/supply imbalance control from the supply side to the demand (consumer) side. A reason for this is based on the fact that significant savings can be achieved from the consumer side that could eliminate the need for grid extension or additional generating capacity (Mishra et al., 2013; Pierce and Paulos, 2012). In the United Kingdom for example, the Energy Efficiency Commitment Phases 1 and 2 (EEC1) and (EEC2) programs which ran from 2002 to 2005 and 2005 to 2008 achieved energy savings of 86.8 TWh and 187 TWh respectively. Similarly, a carbon reduction of about 293MtCO_2 was achieved via the Carbon Emissions Reduction Target (CERT) and Community Energy Saving Programme (CESP) between 2008 and 2012 (Warren, 2014). In similar vein, Eskom in 2008 began a campaign to exchange incandescent bulbs in homes for more energy efficient CFL bulbs with about 65 million of such energy efficient CFL bulbs installed in South African homes to date. The result has been considerable energy savings and reduced electricity bills, job creation and a culture of greater energy efficiency among South Africans. It is estimated that about 11.8 TWh of DSM programs are currently in place in South Africa with expected cumulative savings of 466 MW by 2017/2018 from the additional Residential Mass Roll-out lighting LED program which commenced 2015/2016 (Eskom).

In a recent report SA must reduce power by up to 15: Peters (2013), it was posited that for South Africans to enjoy uninterrupted power supply, there had to be about a 10% reduction in energy consumption (from the residential sector). It can therefore be evidenced and further inferred from the report that energy efficient habits (DSM) can guarantee a balance between electricity demand and supply for residential homes. However, statistics emanating from CSIR (2016) indicate that national electricity demand using the less energy scenario modelling would increase (year-on-year) by 2.3% in 2016 and 2017, 2.5% in 2018, 2.7% in 2019 and 2.8% in 2020. To compensate for increasing electricity demand and diversify the generation mix, DOE (2016) posits that renewable energy planned capacity expansion is 2915 MW for 2016, 3799 MW for 2017, 4864 MW for 2018, 6879 MW for 2019 and