INFLUENCE OF CLIMATE VARIABILITY ON SOUTH AFRICAN ELECTRICITY PRODUCTION

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ABSTRACT

Climate variability may play an important role in the South African electricity production. Several studies were conducted in the past to investigate the factors which modulate the national electricity production. This study investigates the influence of the Southern Oscillation Index (SOI) as a proxy of climate variability in South Africa, on national electricity production over a 27-year period from 1985-2011. Various linear statistical tools were used to study the electricity consumption trends in South Africa, the SOI trends and variability, the annual temperature distribution over the country, the SOI-electricity consumption correlation and periodicity in the national electricity production. The results have shown a statistically-significant relationship between the SOI and national electricity production. Further results showed the inverse relations between South African surface temperatures and electricity production, particularly in the coastal regions. A spectral analysis on the detrended electricity production data also revealed cycles which include the SOI signal of 3.85 years. The results in this study will assist in understanding the modulation of electricity production and also contribute to the prediction of the electricity production, particularly in the current changing climate environment.

Keywords: Climate variability, climate change, electricity production, Southern Oscillation Index

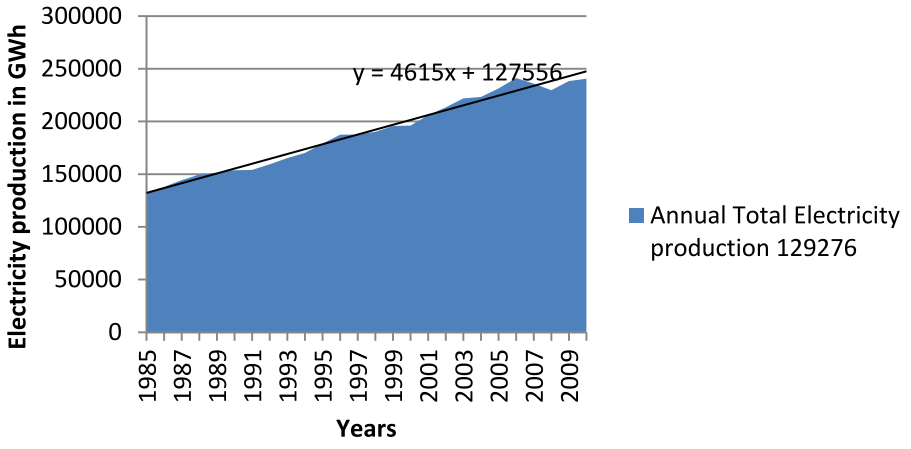
INTRODUCTION

Weather and climate variability influence many socio-economic sectors all over the globe. The energy sector is one of the most sensitive sectors to meteorological influences (Valor, Meneu, and Caselles, 2001:1413). The use of electrical energy in South Africa has grown over the past several decades and reached critical levels where demand has occasionally outstripped the supply. The critical nature of the energy sector has put pressure on decision-makers and planners in South Africa to understand the influences and improve modelling of electricity demand. This research study is focussed on the influence of meteorological parameters on electricity demand in South Africa, particularly at a climate scale.

Electricity demand in South Africa

The national demand for electricity has significantly increased in recent years leading widespread rolling blackouts and load-shedding as that witnessed in 2007 and 2008. These periods where demand exceeded supply were attributed in various media and government sources to general increase in the South African electricity demand, limited supply of coal and also skills shortages (DoE, 2008). During the period 1995-2003, South Africa has witnessed the rapid rise in the electrification of rural and urban areas. Figure.1 shows the steady increase of electricity production over South Africa at an approximate rate of 4615 GWh/year. This was in response to the government’s National Electrification Programme (NEP) to improve access to electricity by all nationals (Davidson and Mwakasonda, 2004:34). The 2001 target of 2.5 million households was exceeded with 3.4 million new connections achieved between 1994 and 2001 (NER, 2003). This significant increase in electricity demand has resulted in the construction of new multi-billion power-stations such as the Eskom's Medupe power station and electricity-saving campaigns. The near-capacity levels of electricity in 2008, led to the hiking of electricity prices in order for Eskom to embark on a massive programme to upgrade and expand the country's electricity infrastructure. These plans entailed a budget spending of R 385 billion over a 5 year period (Eskom, 2008).

Fig 1 Annual Total Electricity production (1985-2011)



Climate Change and linkage with electricity production

The advent of global climate change with characteristic increases in frequency and intensity of severe weather events is presenting additional burden on the national electricity production, in terms of managing electricity demand peaks (IPCC, 2007). The South African Department of Science and Technology in response to the threat of climate change elaborated in the South Africa's Climate Change Technology Needs Assessment Synthesis Report, the potential technologies towards climate change adaptation and mitigation. In this report, the increasing use of air conditioners was projected as a response to hotter climate as a result of climate change. This report recommended the use of the continuously improving weather forecast products as a method towards climate change adaptation (DST, 2007). Numerous studies in the India, United States and Europe have found the linkages between electricity loadings and weather conditions. Specifically, many studies have shown that changing weather conditions, particularly temperatures represent a major source of variation in electricity peak demand forecasting (Ghosh, 2008:471; Goia, May andFusai, 2010:706; Hekkenberg, Benders, Moll and Schoot, 2009:1549; Makridakis, Wheelwright, and Hyndman, 1998:22; Munoz and Felicisimo, 2004:290 and Pilli-Sihvola, Aatola, Ollikainen and Tuomervita, 2010:2412, Valor et al., 2001:1418). Crowley and Joutz. (2005:25) established that general weather and specifically temperatures were important drivers for electricity consumption. The latter study also established that over 40% of end-user energy consumption was related to heating and cooling needs in the residential and commercial sectors. In support, Teisberg, Weiher and Khotanzad (2005:1769) also established that temperature was a key weather variable affecting the demand for electricity, particularly in regions where there was heavy use of air conditioning. Similar weather influences were also found in the second largest electricity producer in the world, China (Lin, 2003). In South Africa, Sigauke and Chikobvu (2010: 108) successfully demonstrated the important use of temperatures in the daily (or short-term) peak electricity load forecasting. The use of meteorological parameters in seasonal/ long term electricity demand forecast within South Africa was however relatively absent in the most recent and extensive studies of the econometrics model and the CSIR statistical approach.

The El Niño/La Niña-Southern Oscillation (ENSO) is defined as a quasi-periodic climate pattern that occurs across the tropical Pacific Ocean roughly every five years. It is characterized by variations in the temperature of the surface of the tropical eastern Pacific Ocean—warming or cooling known as *El Niño* and *La Niña* respectively—and air surface pressure in the tropical western Pacific—the *Southern Oscillation* (Trenberth, 1997:2775). ENSO variability causes extreme weather conditions (such as floods and droughts) in many regions of the world. In Southern Africa, a number of leading scientists have successfully linked the remote Southern Oscillation Index (SOI) index i.e. the index for ENSO, with the Southern African temperatures and rainfall (Harangozo and Harrison, 1983:413; Harrison, 1983:413; Schulze, 1983:84; Nicholson, 1986:474; Taljaard 1986: 2776; van Heerden, Terblanche and Schulze, 1988:583; Karoly, 1989:1243; Walker, 1990:3306; d'Abreton and Lindesay, 1993:54; Mason, 1995:129; Mason and Jury, 1997:47). SOI is a widely used index globally in weather and climate studies. It has minor geographical biases and erratic data that are common in local rainfall and temperature data.

This research study aims to investigate the existence of a linkage between the South African electricity production and the Southern Oscillation Index (as an approximation of South African weather and climate).

Objectives

The objectives of this research study are to:

i. Demonstrate the association of El Nino Southern Oscillation (ENSO) with electricity production in South Africa;
ii. Expand on the existing knowledge regarding remote geophysical factors which have an impact on the South African long-term electricity production.

The research paper is structured as follows. The next section identifies the leading theories in electricity demand forecasting in South Africa and proposes the factoring of meteorological parameters. The subsequent section describes the data used in the study and elaborates on the research methodology used. Section 4 introduces the key results in the relationship of the SOI and electricity production. The final section summarizes the most relevant conclusions drawn from the study and recommendations for future research.

PROPOSED MODEL OR CONCEPTUAL METHOD

The dominant literature in seasonal or long term energy demand forecasting in South Africa revolves around the following two main theories:

i. Econometrics model – this is the statistical model led by Van Wyk (2009) and Inglesi (2010:203) This model is based on the economic theory and has incorporated price elasticity into the modelling of electricity demand (Belli, Anderson, Barnum, Dixon and Tan 2001:27). The two identified drivers or predictors in this model were income and price of electricity.

ii. CSIR electricity demand model – this is a statistical regression model which has analysed electricity demand into specific and key sectors viz. Agriculture, Domestic electricity, Commerce and Manufacturing, Mining, Transport. The individual sector models were combined to forecast the total national electricity demand. The identified drivers or predictors in these various sectors included Mining index, Platinum production index, Final Consumption Expenditure of Households (FCEH), population, Manufacturing index, treated gold ore and coal production index.

This research study proposes a model where the SOI is factored into a statistical regression model to analyse electricity demand, once a significant correlation is established between SOI and electricity production data.

RESEARCH METHODOLOGY

The Southern Oscillation Index (SOI) is a standardized index based on the observed sea level pressure differences between Tahiti and Darwin, Australia. The SOI is one measure of the large-scale fluctuations in air pressure occurring between the western and eastern tropical Pacific (i.e. the state of the Southern Oscillation) during El Niño and La Niña episodes. In general, smoothed time series of the SOI correspond very well with changes in ocean temperatures across the eastern tropical Pacific. The SOI was used in this study as an approximation of South African weather and climate variability. This approximation was selected due to the following reasons:

i. Existing global, peer reviewed scientific literature affirming the significant correlation between the SOI and Southern African rainfall and temperature records;
ii. The modern and regular use in South Africa of SOI in seasonal rainfall and temperature forecasts;
iii. The erratic nature and strongly irregular spatial distribution of rainfall in South Africa;
iv. The rapid temperature changes attributable to varying altitude (high $\frac{dT}{dz}$);
v. The freely available high quality-controlled monthly SOI data.

The SOI data used in this research study was obtained freely from reliable global sources via the internet. The data sources include StatSA (http://www.statssa.gov.za/timeseriesdata/main_timeseriesdata.asp), the U.S.'s National Center for Atmospheric Research -Global Climate and Dynamics Division (http://www.cgd.ucar.edu/cas/catalog/climind/soi.html) and also the South African Weather Service. On the other hand, data on total national electricity consumption in GWh for South Africa from 1985 to 2011 were obtained from Statistics South Africa (StatsSA) from Statistical release P4141 – Generation and Consumption of electricity (http://www.statssa.gov.za/timeseriesdata/main_timeseriesdata.asp). This StatsSA data is reported as the total electricity available for distribution in South Africa which includes losses. Values are reported per month, and for the purpose of these study, the monthly data was aggregated into a calendar year, i.e. January to December. In addition, surface mean temperature data for ten weather stations were obtained from the South African Weather Service for the corresponding period. Monthly means were used and aggregated into a year in order to determine relations with electricity production.

The data used in this study is summarized in Table 1.

Correlation analysis was also used in this study to evaluate the strength of the linear relations between variables. The strength of linear association between two numerical variables is determined by the correlation coefficient, **r**, whose range is -1 to +1. The sign (positive or negative) of the correlation denotes the sign of the slope of a straight line. The sample correlation (**r**) is derived from the coefficient of determination (**R²**)

$$R^2 = \frac{Regression\ sum\ of\ Squares}{Total\ Sum\ of\ Squares} = \frac{SSR}{SST} \quad (3.1)$$

The correlation coefficient $r = \sqrt{R^2}$ (3.2)

Numerous statistical significance test were used to determine meaningful associations between variables in order to infer relations and create an understanding of the underlying physical processes involved.

In addition, spectral analysis (using the Fast Fourier Transform), was performed in the Electricity production data to investigate cycles in order to understand the underlying dynamics and associations with weather and climate. Spectral analysis is used to describe the tendency of a series to show oscillations of a given frequency. The time series of a variable is represented as a sum of sine squares of different periods. This procedure uses the Fast Fourier Transform (FFT) which works on equally spaced values and plots the squared amplitude of the sinusoids. Spectral analysis is a modification of Fourier analysis so as to make it suitable for stochastic process. Periods or cycles in the electricity production may be due to non-linearity or interactions between high frequencies. Therefore caution should be taken when applying spectral analysis method in identifying cycles or periods. A possibility of adding artificial periods to the data set may be encountered with filtering. The periodigram represented hidden cycles in a series. In this study, spectral analysis was performed on the monthly electricity production data, utilizing a Matlab script to identify periodicities. A detrending mechanism was also used before the spectral analysis to reduce the risk of contaminating the results with the expected trend.

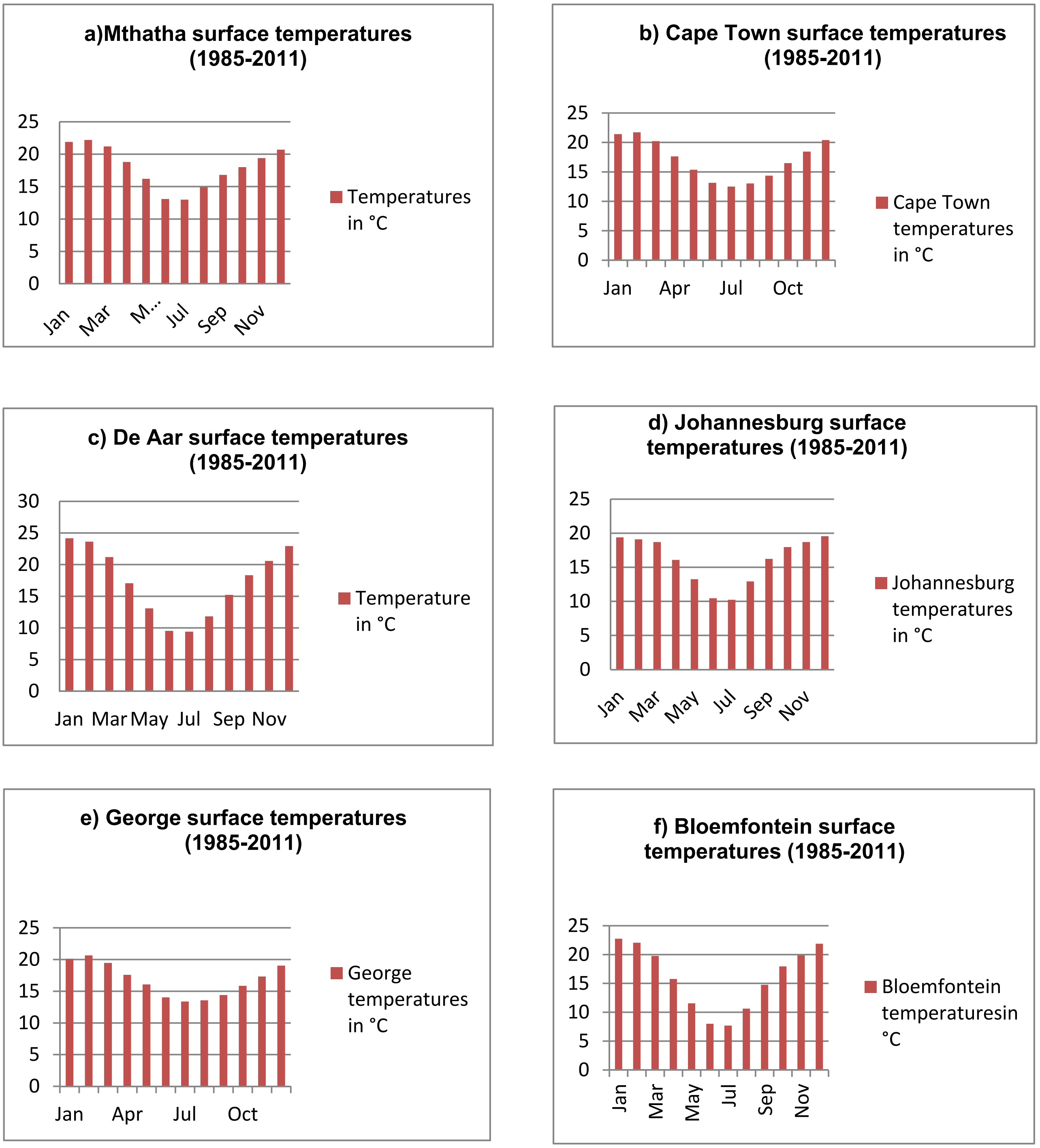
Table 1. Table 1 summarizes the data used in this research study

Data source and variable	Period
South African Weather Service (SAWS), Monthly Temperature data from 10 SAWS weather stations (Bloemfontein, Cape Town, De Aar, Durban, East London, George, Johannesburg, Mthatha, Port Elizabeth, Polokwane	1985-2011 (27 years)
United States' National Center for Atmospheric Research -Global Climate and Dynamics Division, Southern Oscillation Index (SOI), monthly	1985-2011 (27 years)
StatsSA, Electricity consumption data (monthly)	1985-2011 (27 years)

RESULTS

The main results of the study are as follows:

- The annual temperature variability patterns throughout the country were homogenous with distinct temperature maxima in the months of November, December and January (summer). The temperature minima were observed in each of the 10 selected stations during May, June and July (winter) in Fig 2 below.



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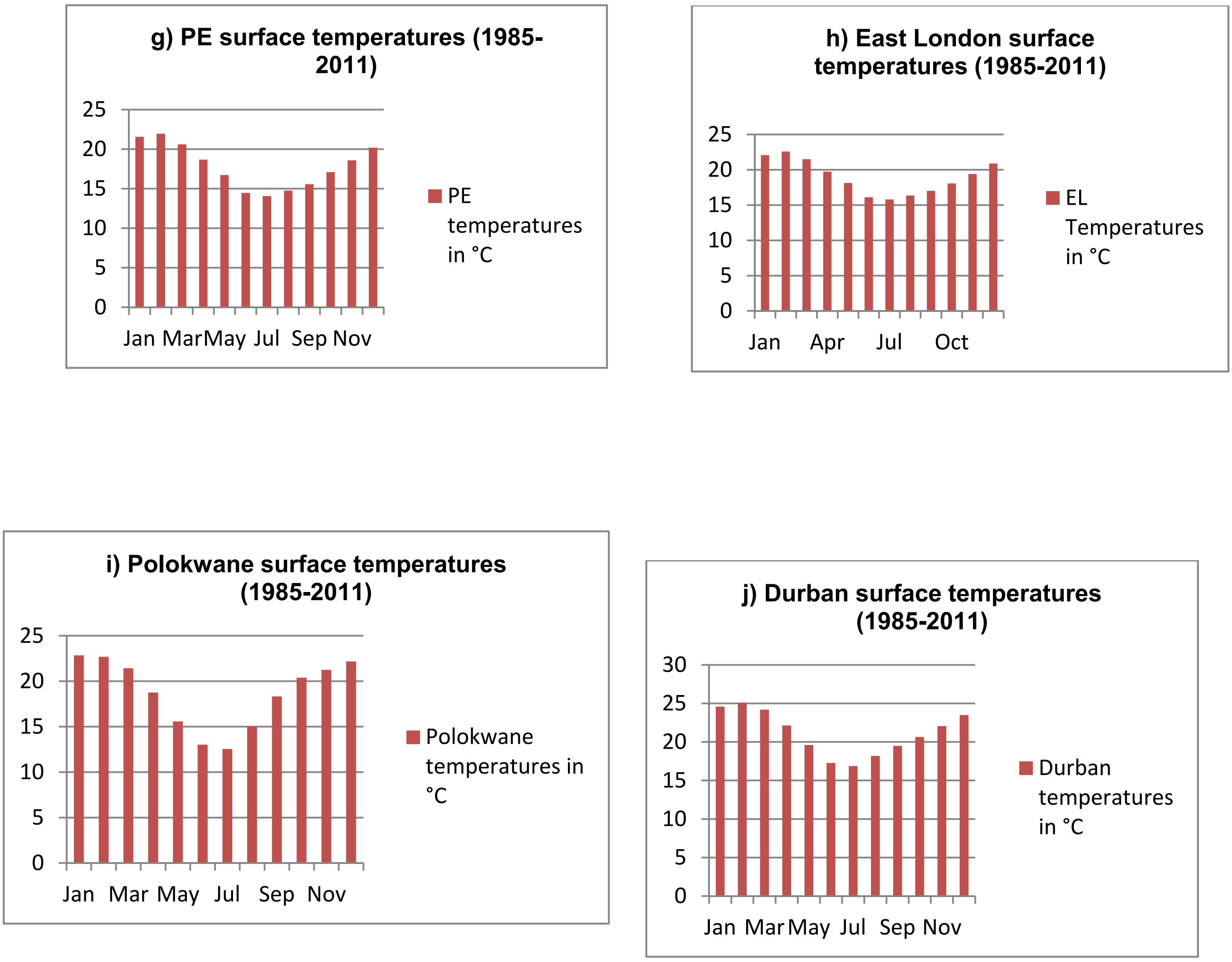

Figure 2 a-j depicting the temperature minima during winter months and maxima in the summer months.

The correlation between the surface temperatures and electricity production generally show a negative relationship between the two variables but strongest negative and significant correlations in the Eastern Cape Province (George, Port Elizabeth and East London -in bold). Weaker negative correlations were also found in other coastal cities (in italics) viz. Cape Town and Durban. The correlation results suggested the strongest influence of temperatures on electricity production in the coastal cities of South Africa. The correlation results are summarized in the Table 2 below:

Table 2 showing correlations of surface temperatures and electricity production at the 10 selected South African weather stations

City name	Correlation coefficient
Mthatha	*-0.24*
Cape Town	*-0.34*
De Aar	-0.13
Johannesburg	+0.04

City name	Correlation coefficient
George	-0.47
Port Elizabeth	-0.41
Bloemfontein	-0.06
East London	-0.44
Polokwane	-0.04
Durban	*-0.34*

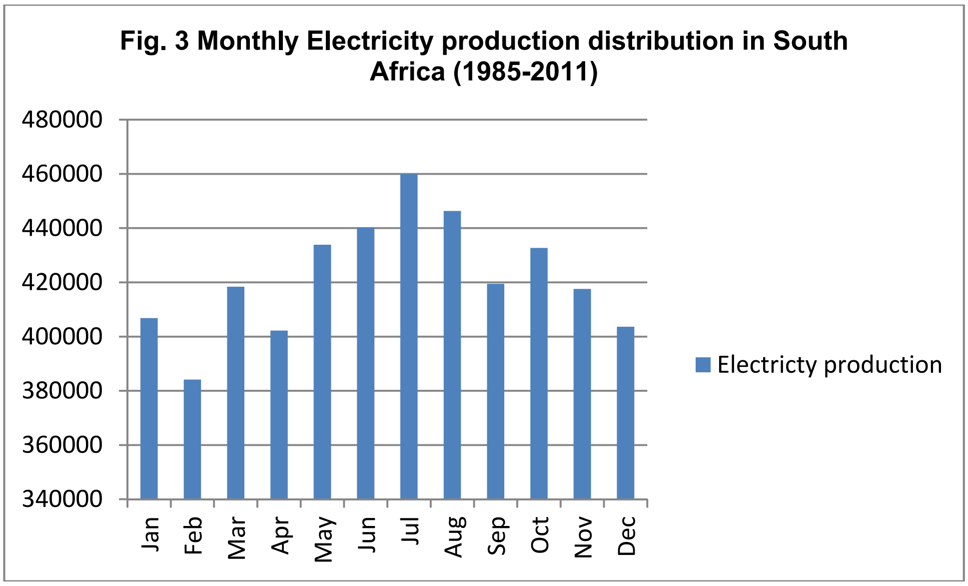

Figure 3: Montly electricity production distribution in South Africa (1985-2011)

- The country's electricity production peaked during winter months and levelled off in the warmer summer months (Fig. 3) suggesting an inverse relationship with the surface temperatures in Fig. 2.
- An increasing trend of electricity production in South Africa throughout the study period of 1985-2011 was found at an approximate rate of 4616GWh/ year. This trend is in line with the increasing local demand and also the government's mass electrification programme which began in 1991. A disruption of this trend was identified in recent years and coincided with the rolling blackouts of 2008.
- A significant, positive but mild relationship (r = +0.38) was observed between the monthly SOI and South African electricity production values leading to the acceptance of the null hypothesis which was posited in this study i.e. "The Southern Oscillation Index (SOI) has a significant association with long term South African electricity demand"
- Spectral analysis of South African Electricity production showed the highest peak at 6.75 years, followed by 13.5 years and 3.85 years, with the latter period being associated in previous studies with the ENSO signal or SOI. This is a further support to the null hypothesis and has indicated that SOI is one of the important contributing factors to electricity production in South Africa (Fig 3).

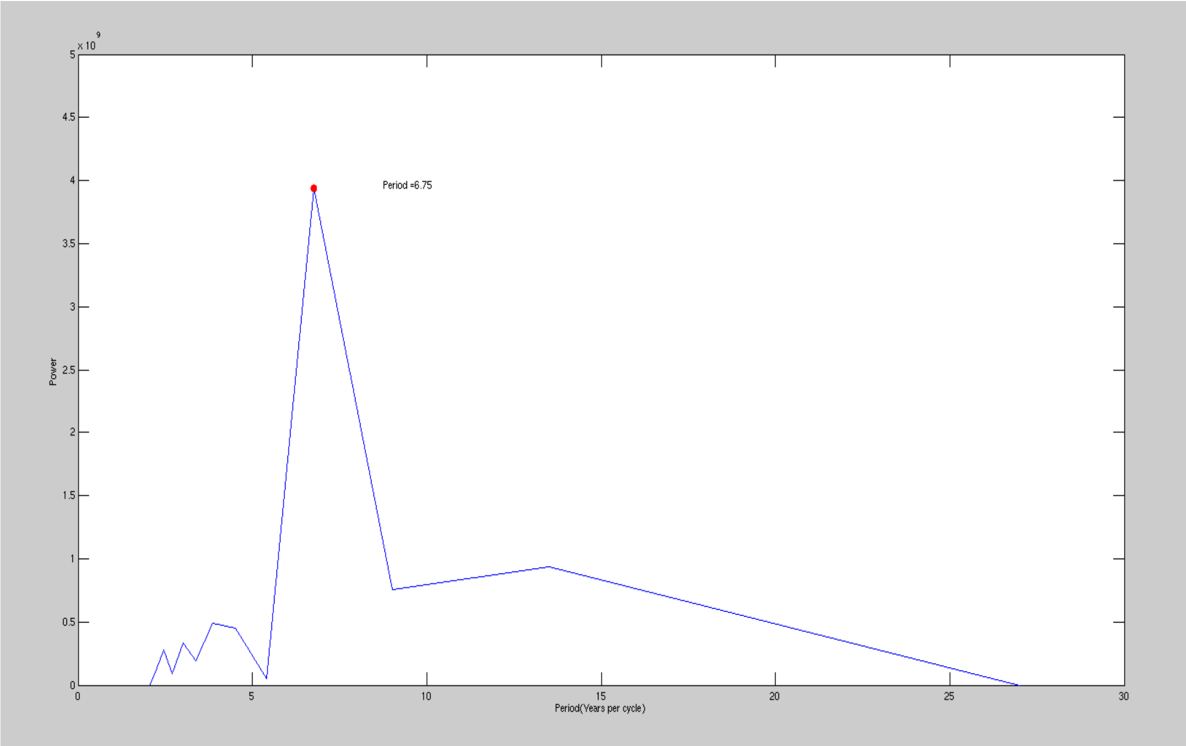

Figure 4. Periodicity of electricity production in South Africa (1985-2011)

CONCLUSIONS AND RECOMMENDATIONS

This research study exposed the important role which the SOI played in electricity production in South Africa. The correlation found between the SOI and Electricity production although statistically significant was mild (r=0.38) and only explained a relatively small fraction of the variance (approximately 16%). This implied the potential existence of non-linear relations between the variables and which necessitate the use of more complex statistical tools such as Principal Component Analysis, Multiple regression models, Auto-regression etc. This study could therefore be pursued further using these analyses and could introduce other related variables such as Quasi-Biannual Oscillation (QBO), Solar cycle etc. which were suggested by the spectral analysis results on the electricity production data. The future study could furthermore expand to neighbouring Southern African countries which are also affected by the same ENSO signal. Finally, it is also recommended that the future study investigates the impact of climate change on electricity distribution and transmission faults. This is particularly important as we face the advent of climate change which is characterised by increasing frequency and magnitude of severe weather events and climate episodes.

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