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The vulnerability of the South African electricity transmission network infrastructure to weather and climate: A review

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Abstract

Meteorological factors have an influence on global energy systems. This study reviewed some of the latest research contributions from other global studies on climate change impacts, energy transportation and international collaboration in the energy-meteorology sector. It is a summary of relevant South African research on energy demand, forecasting and vulnerability to extreme meteorological conditions. International weather-energy partnerships are growing fast, while the Global Framework for Climate Services has provided a global framework for scientific collaboration across sectors to assist with climate-related risk management and decision-making. The uptake of weather-energy partnerships in developing regions has remained slow, however, particularly in Africa, where basic requirements such as meteorological observations are still sought. This review found that studies on the impact that future projections of climate change and variability might have on the South African electricity transmission network were inadequate. A deeper understanding of such impacts on the electricity infrastructure would assist considerably with risk management and decision-making; consequently contributing to the sustainable provision of electricity in South Africa.

Keywords: *electricity supply; climate change; extreme weather events, electrical faults*

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1. Introduction

Weather refers to the atmospheric conditions over a short period (hours to days), while climate refers to atmospheric behaviour over longer periods, ranging from months to thousands or millions of years (Pyle and Zhang, 2015). Globally, power utilities have experienced power interruptions caused by severe weather and climate events (Yamba et al., 2011; McColl et.al., 2012; Ward, 2013). These weather and climate impacts are not limited to one power generation source type, but are common to almost all, including hydropower (Harrison and Whittington, 2002), wind power (Pryor and Barthelmie, 2010; Szeczuk and Prinsloo, 2010), biofuels (Lucena et al., 2009), solar energy (Fenger, 2007), oil and natural gas (Harsem and Heen, 2011), and thermal power (Kopytko and Perkins, 2011). The projected impacts of climate variability and change on electricity production and vulnerability have also been researched at institutions around the world, with a wide range of results that could assist weather- and climate-related risk management and the sustainable use of energy resources (Van Vliet, 2012). For instance, a study by Hamlet et al. (2010), based on climate projections, reported on the temperature impacts on energy supply in the Pacific Northwest and Washington State.

Extremes in weather parameters such as temperature, rainfall and wind impact on the generation, transmission and distribution of electricity. Electrical power supply is strongly intertwined with weather variability to such an extent that several power utilities already predict energy demand on an operational basis using weather parameters as predictors (Makridakis et al., 1998). For example, Ghosh (2008) used weather parameters to predict month peak demands of electricity in the northern region of India using a multiplicative seasonal autoregressive integrated moving average. Goia et al. (2010) explored the forecasting of short-term electricity loads using past heating demand data from a district heating system. An econometric multivariate regression model was used to investigate the impacts of the gradual warming associated with climate change on the need for heating and cooling in five European countries (Pilli-Sihvola et al., 2010). Sigauke and Chikobvu (2010) investigated the use of the non-parametric multivariate adaptive regression splines model in South Africa to forecast daily peak electricity loads using meteorological data inputs and found this method to be more effective than piecewise linear regression models. Majodina (2015) illustrated the linkage between the El Niño Southern Oscillation and electricity production in South Africa.

Ziramba (2008) examined the residential demand of electricity in South Africa through the use of an econometric model that factored in the gross domestic product per capita and the price of electricity during the period 1978–2005. Similar research studies have since been conducted in South Africa (Van Wyk, 2009; Inglesi, 2010). These studies were in response to the high electricity demand that had outstripped supply in South Africa since 2007, as found by Inglesi. Econometric models, which applied statistical techniques and are based on the economic theory, attempted to incorporate price elasticity into the modelling of electricity demand. Debba et al. (2010), on the other hand, successfully incorporated predictors, such as final consumption expenditure by households, population, mining index, manufacturing index, platinum production index, coal production index and gold ore treated, into a similar econometrics model for South Africa to forecast electricity demand for the period 2010–2035. The inclusion of meteorological parameters has therefore benefitted these models and created more representative forecasts of electricity demand.

The purpose of the present study was to review the latest global research developments on climate change impacts, energy transportation and international collaboration in the energy-meteorology discipline. The study also aimed to contrast the meteorological-energy research conducted in other parts of the world with that which has been conducted in South Africa.

2. Impacts of climate variability and change on electricity supply

The advent of climate change is a concern for many key socio-economic sectors throughout the world (Alcamo et al., 2007). Schaeffer et al. (2012) highlighted research gaps in understanding how climate change could affect the electricity sector, including the challenges posed by uncertainties when using climate change projections to investigate the impact of the intensity of extreme weather events on the energy sector. The study emphasised the need to conduct climate impact assessments on energy planning and operations using different scenarios. The gaps identified in the conduct of climate assessments for specific energy segments included regional impacts and climate impacts on energy variations across regions (e.g. tropical vs temperate energy consumption in a warmer environment). Cooling requires more electricity, which in turn can lead to energy bottlenecks in the warmer tropics where air-conditioning could become a factor – a topic for further research. Schaeffer et al. noted that there was limited knowledge on the impacts of a projected increase in extreme weather events on electricity transmission. These extremes could include winds, ice loads, lightning strikes, conductor vibrations, and heavy rains leading to landslides and flooding.

Investigating the impact of climate change on nuclear power generation in Europe, Linnerud et al.

(2011) found that rising temperatures have a general negative effect on the efficiency of thermal power stations. For example, a rise in temperature of 1°C in Europe would reduce nuclear power supply by 0.5%. During periods of drought associated with high temperatures, nuclear output could be reduced by 2%. The study found that higher temperatures reduced efficiency and loads of nuclear power plants. More frequent shutdowns of nuclear power could result from higher temperatures because of cooling problems and pressure exceedances, leading to energy insecurities, given the relatively large energy outputs of nuclear power stations.

In a review of contemporary research on the impact of climate change on the electricity markets through both demand and supply (Mideska and Kallbekken, 2010), the uncertainty characterising this research area was further revealed. The consensus from the research was that rising temperatures could lead to increased electricity demand for cooling, reduced demand for heating, and reduced electricity production from thermal power plants. Power generation from non-thermal power plants showed great diversity because of geographical variability, given different patterns of rainfall and temperature. Mideska and Kallbekken highlighted four significant research gaps: (a) regional studies of demand impacts for Africa, Asia, the Caribbean and Latin America; (b) the effects of extreme weather events on electricity generation, transmission and demand; (c) changes to the adoption rate of air-conditioning; and (d) the understanding of the sensitivity of thermal power supply to changes in air and water temperatures.

Similarly, Franco and Sanstad (2008) investigated, using global climate models (GCMs), the impact of climate change on electricity demand in California, United States of America. It was found that the rise in temperatures from global warming would result in a rise in peak time demand, leading to an increase in the cost of power generation. In a review of downscaling from GCM research, Fowler et al. (2007) pointed to the need and feasibility of applications of downscaling research to aid decision-making during planning and management of resources that are vulnerable to climate change, such as water and electricity.

In a study of the potential influence of climate change and variability on hydropower electricity generation in the Zambezi River basin, Yamba et al. (2011) used GCMs to project future monthly rainfall. The water demand was projected using estimated population growth figures in each sub-basin. A water balance model was used, incorporating the projected rainfall data and water demand input to determine projected run-offs. Strong relations were found between hydropower potential and projected rainfall. The study provided further insight on other factors, such as projected dry years, floods and increasing water demand. It also forecast a general trend of decreasing hydroelectric power potential in the Zambezi River basin, linked to climate change and increasing water demands. A modelling study by Spalding-Fecher et al. (2017) showed that, although the electricity demand and supply in twelve countries in the Southern Africa Power Pool would increase by multiples of eight to fourteen between 2010 and 2070, there would be a notable reduction in the share of South Africa. A study conducted in Kenya on the impacts of climate change on energy generation from the Seven Forks hydroelectric project concluded that temperatures were increasing on an annual basis at a rate of +0.02 °C, while rainfall was declining by 3.9 mm annually, resulting in continued reduced electricity generation from Seven Forks (Bunyasi, 2012).

In a study by Fauchereau et al. (2003) on regional climate model (RCM) projections of climate change in southern Africa, the HadAM3 RCM and A2 special reports on emission scenarios RCMs were compared in their downscaling capability. Projected changes in summer season rainfall totals, rain days and average air temperatures were analysed. Broad and consistent changes were found for most of the region. Time and location difference were, however, noted in the magnitude of change, which could be attributed to different representations in the internal physics and local hydrological cycles in the RCMs. Fauchereau et al. (2003) also analysed rainfall variability over southern Africa and investigated future rainfall projections using a GCM, and showed that southern Africa had experienced significant rainfall variability in the past. Historical rainfall anomalies did not show any statistically significant trends, however; inter-annual rainfall variability was found to have increased since the late 1960s, while droughts were found to be more intense and widespread. Teleconnection patterns associated with summer rainfall variability were found to have changed from regional-scale before the 1970s, to near global-scale thereafter. An increased correlation with the El Niño Southern Oscillation phenomenon was also observed since the 1970s. It is interesting to note that the French ARPEGE-Climat GCM indicated that these changes in teleconnections are related to long-term cycles in sea-surface temperature patterns, which is a known signal of global warming (Déqué et al. 1994).

South Africa's climate change research is relatively advanced, compared with other developing countries and consensus has been reached amongst scientists projecting likely future climate patterns. Hewitson and Crane (2006) described the use of empirical downscaling techniques as a new approach as expressed on self-organising maps. For this purpose, the National Centre for Environmental Prediction six-hourly data were used for the period 1972-2002, while self-organising maps were used to characterise the state of the atmosphere. Future climate states were obtained from three GCMs, namely the HadAM3, ECHAM4.5 and CSIRO Mk2 GCMs (Hewitson et al. 2004). Precipitation results from all three GCMs were consistent and showed increased summer rainfall over the South African interior and eastern parts of the country, and dry patterns over the Western Cape (austral winter rainfall region). More recently, the development of representative concentration pathways has provided important new tools in climate research, vital for impact analysis into socio-economic sectors such as electricity (Van Vuuren et al., 2011). These projected weather patterns, including possible extreme weather events, might have implications for the electricity infrastructure and generation, and therefore must be factored into researched that addresses sustainable electricity production in South Africa.

In this section, it has been established that electricity supply, both globally and regionally, is susceptible to climate variability and change. Studies have shown long-term atmospheric behaviour or climate impact on electricity supply (Sinden, 2007). The research gaps included climate impact assessments for specific energy segments, the impact of the projected increases in weather extremes on electricity transmission, climate impact on energy generation, the long-term change in temperatures on energy consumption, and the potential use of climate models in climate research into the electricity sector.

3. Energy transport and electricity faults

Troccoli et al. (2014) recognised that transmission of electricity in Australia often extended over distances in the order of thousands of kilometres. Similarly, the transmission and distribution networks of Eskom (South Africa's electricity utility) are in excess of 300 000 km (Minaar et al., 2012). These networks, which are responsible for the transportation of electricity and extend across different climate zones, are exposed to a variety of meteorological conditions. The high voltage in transmission (approximately 11 000 V and usually in three-phase transmission) is ideal for carrying electricity efficiently over long distances (Koen and Gaunt, 2003). Before use, the high voltage in distribution is transformed down to lower and safer voltage levels in substations, which makes the electricity suitable for consumption by commercial and household users (Al-Shaher et al., 2009). According to Aivalioti (2015), the bulk of the transmission networks consist of overhead lines rather than underground cables, because of the ease of installation, maintenance and cost-effectiveness. Electricity substations are also generally designed for the outside environment.

In an investigation of weather-related electrical faults, McColl et al. (2012) found the electrical network (overhead lines, underground cables, transformers and substations) in the United Kingdom to be susceptible to various types of extreme weather variables: winds and gales;, snow, sleet, blizzards, and lightning. Campbell (2012) estimated the annual costs of weather-related electrical faults in the United States of America at USD 20–55 billion. That study also found an increasing trend in US power outages linked to weather-related faults. Similar interruptions to electricity transmission and distribution were found in Italy (Pirovano et al., 2014), where the vulnerability of the network was linked to thunderstorms, salt deposits and heavy snowfalls, prompting the enhancement of weather forecasting systems to allow the optimal deployment of remedial solutions.

Ward (2013) defined a 'fault' as any unplanned event that results in the circuit or component of the equipment in a network to be switched out of service, either automatically by an electrical protection system or manually in response to an alert on the system. Faults on an electrical network can be caused by a myriad of factors that may include tsunamis, earthquakes, hardware failure, vandalism, theft, veld fires, geomagnetic storms, birds and weather events. In fact, in both Europe and North America, weather events were found to be the major cause of faults linked to loss of supply to consumers (Campbell, 2012). Hines et al. (2009) found that approximately half of the faults in the electrical network in North America were linked to unfavourable weather events. Similar percentages for faults were also reported by Ward (2013) for Great Britain, and a slightly higher figure of 56% was found by Martikainen et al. (2007) for Finland. The significant contribution of weather events to faults on the electricity distribution network was also reported by Brown (2002) and by Amin (2015).

Oseni (2012) characterised the provision of electricity over Africa as being low in supply and generation; and dominated by frequent outages owing to lack of financial resources, old infrastructure, poor maintenance and lack of business continuity management. Brown and Lawson (1988) attributed electrical faults on the Namibian electricity transmission network to interference by several species of birds. Similar electrical faults caused by birds were identified by Rooyen and Ledger (1999) in several southern and eastern African countries including Botswana, Kenya, Lesotho, Malawi, Mozambique, Swaziland and Zimbabwe. These were attributed to the lack of bird-friendly electricity network designs. Kaseke and Hoskins (2013) attributed the electricity faults in Sub-Saharan Africa to droughts, oil price shocks, system disruptions caused by social conflicts, and low investment in generation.

Similarly, in South Africa, Minaar et al. (2012) characterised the fault types on the Eskom transmission network and investigated relations between these faults and local climate and key design parameters of the overhead power lines. This research found four main causes of transmission faults: bird streamers, lightning, fire, and pollution. Included was the characterisation of the faults according to the winter and summer rainfall regions in which they were occurring and through the use of performance statistics of the transmission network.

In summary, the long transmission lines that are responsible for transportation of high voltage electricity globally are vulnerable to weather and climate extremes. The electrical faults resulting from severe weather and climate are, however, not adequately researched, particularly on the African continent. Although similarities were found in key causes of transmission faults amongst African countries, the South African transmission network seems to be particularly vulnerable to lightning. An understanding of the impact of these faults is essential for a soundly managed and sustainable electricity supply in South Africa.

4. International collaboration in the energy-meteorology discipline

Zillman (2014) identified five international initiatives which could hold a potential for related service delivery enhancements in the energy sector as a consequence of the important influence of weather and climate:

- the Intergovernmental Panel on Climate Change (IPCC);
- the Global Earth Observation System of Systems (GEOSS);
- the Madrid Action Plan on social and economic benefits of weather, climate and water services;
- the Third World Climate Conference (WCC-3) and Global Framework for Climate Services (GFCS); and
- the World Meteorological Organization (WMO) Strategy for Service Delivery.

The IPCC assessment process provided the most authoritative source of information on aspects of science and implications of anthropogenic climate change. The 2014 IPCC Fifth Assessment Report suggested major implications for the global energy sector, requiring extensive collaboration between the climate and energy communities (IPCC, 2014). The intergovernmental Group on Earth Observations, with its ten-year GEOSS implementation plan to provide *in situ* and space-based observations for effective application in nine key societal benefit areas, including weather, climate and energy, made recommendations for the energy sector (Koike et al., 2010). These included support of environmentally responsible and equitable energy management; better matching of energy supply and demand; and management of risks to energy infrastructure. Through the 2007 Madrid Conference on Secure and Sustainable Living, the WMO is currently developing specific proposals concerned with the development of new-energy-needs-specific observing; data collection and model development of new wind, solar, wave, tidal and other alternative energy systems (WMO, 2011). The 2009 WCC-3 Conference that established the GFCS to improve the provision and applications of climate services in the key climate sensitive-sectors globally, identified the

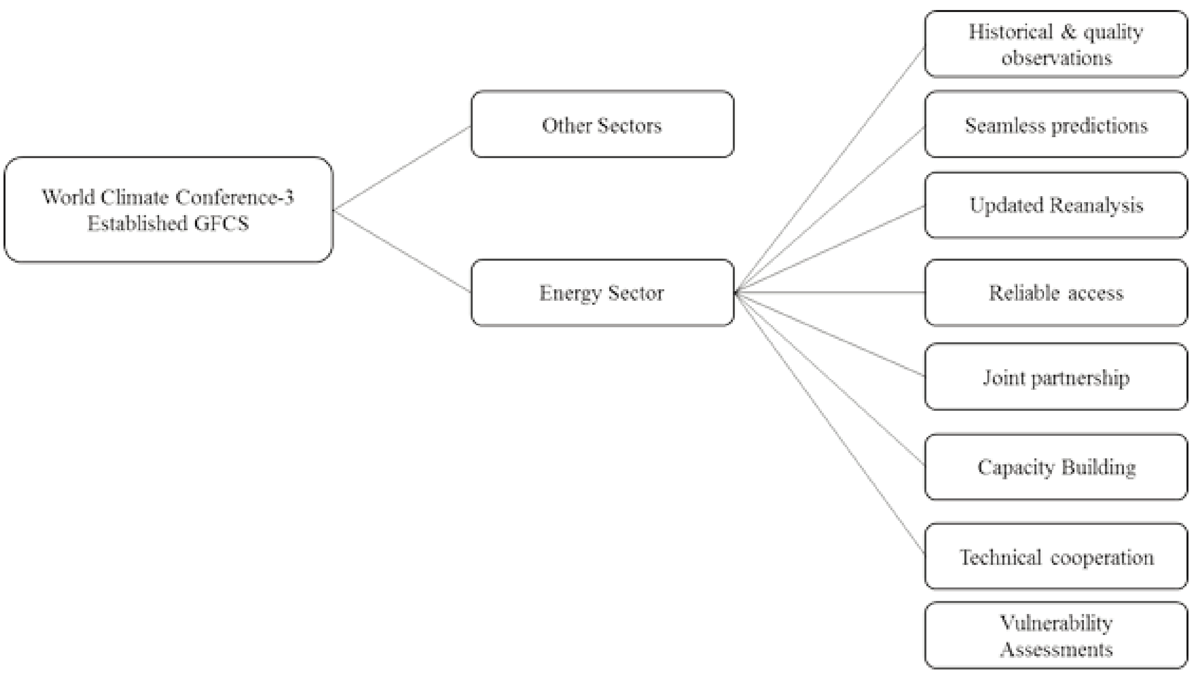

Figure 1: A graphical representation of the Global Framework for Climate Services (GFCS) priorities for the energy sector (Zillman, 2014)

following priority areas for the energy sector: historical and quality observations; seamless predictions; updated reanalysis; reliable access; joint partnership; capacity building; and technical cooperation and vulnerability assessments, as shown in Figure 1. The WMO Service Delivery Strategy is an umbrella initiative to support the implementation of the Madrid Action Plan, the WMO Strategic Plan and GFCS Implementation Plan with an international focus on new and enhanced meteorological services for the energy sector over the coming decades (WMO, 2015).

Advances have been made in the UK to incorporate the climate challenge agenda for the energy sector into law. Cooperation amongst climate scientists and the energy sector has already led to the development of a series of projects globally to enhance energy infrastructure and related technology (Majithia, 2014). In Italy, several risk mitigation initiatives have been introduced, including enhanced forecasting capabilities, intelligent grid management, and increased flexible storage capacity to better manage adverse weather phenomena (Pirovano et al., 2014). Power system engineers and meteorologists have begun to work together in Australia to improve forecasting tools to better manage the changing power supply and demand linked to climate change (Love et al., 2014). This cooperation is aimed at ensuring reliability of the increasing renewable energy sources and managing the related costs (George and Hindsberger, 2014). In Africa, the dire need for investment in the development of a climate knowledge base, improvement of observational meteorological coverage, and the reliability and timeliness of meteorological data, has been identified by Ejigu (2014) as essential for exploiting the connection between bioenergy and weather/climate.

Emanating from the GFCS, South Africa, through a multi-stakeholder engagement process initiated by the South African Department of Environmental Affairs (DEA) and the South African Weather Service, has developed a National Framework for Climate Services for South Africa (NFCS-SA) with a specific theme on energy. The NFCS-SA aims to improve resilience in the energy sector by enhancing tools for decision-makers to analyse and manage risks under current and future climate conditions associated with climate variability and change (DEA, 2016). The published research work in South Africa in the discipline of weather and climate impacts on electricity transmission is relatively low. Furthermore, there has not been adequate attention given to the assessment of the climate risks on the electricity sector, stakeholder engagement and cross-sectional collaboration in the electricity industry and academia. Within the NFCS-SA, this calls for dedicated resources to conduct these important investigations and for the power utility and research institutes to collect and share data that facilitates decision-making and sustain electricity transmission in South Africa.

5. Conclusions

According to the literature reviewed, it is acknowledged that weather and climate have a significant impact on energy supply and distribution. Several studies have shown how weather parameters are used to predict energy supply and demand. Global climate change application studies reveal an increasing demand for electricity for cooling, as opposed to a declining demand for heating in residences. Climate change projections for increasing rainfall in the interior and eastern parts of South Africa and drier conditions in the winter rainfall region in the Western Cape could present challenges for electricity generation and transportation. Several studies have also revealed the susceptibility of distribution and transmission power lines to extreme weather. South African transmission lines have been shown to be vulnerable to high winds, floods and lightning. The literature further identified global initiatives to enhance collaborative partnerships in the energy-meteorology discipline. The likely impact of climate change on the South African electricity sector remains a research gap. This provides a good motivation for a thorough understanding of weather impacts on the national electricity network. Future climate change projection-based scenarios are important for improved planning for adaptation, selection of technology choices for risk mitigation, effective management of faults on the national electricity network, and the establishment of a stable and continuous supply of electricity. The National Framework for Climate Services of South Africa provides an important policy framework for collaboration between the meteorological service and various key socio-economic sectors. There is an urgent need in the South African energy sector, however, to initiate multi-sectorial projects, similarly to those in Europe, the Americas and Australia, in order to enhance operations and mitigate emerging risks associated with climate variability and change.

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