Energy Policy 106 (2017) 404–414

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

# Extreme temperature events affecting the electricity distribution system of the metropolitan area of Buenos Aires (1971–2013)

Daniela M. Santágata[a,b], Paula Castesana[c], Cristina E. Rössler[a,c,*], Darío R. Gómez[a,**]

[a] Gerencia Química, Comisión Nacional de Energía Atómica, Av. Gral. Paz 1499, B1650KNA San Martín, Prov. Buenos Aires, Argentina
[b] Universidad de Belgrano, Zabala 1837, Ciudad Autónoma de Buenos Aires, Argentina
[c] Instituto de Investigación e Ingeniería Ambiental, Universidad Nacional de San Martín, Campus Miguelete, 25 de Mayo y Francia, 1650 San Martín, Prov. Buenos Aires, Argentina

ARTICLE INFO

*Keywords:*
Extreme weather events
Heat waves
Cold waves
Electricity distribution
Power outages
Logistic regression model

ABSTRACT

We studied the role of cold waves and heat waves on major power outages in the metropolitan area of Buenos Aires. Impacts of events occurring in the tails of distributions were assessed estimating deviations of minimum temperature, maximum temperature and hourly electricity consumption with respect to statistically derived thresholds and using three sets of data: temperature observations (1911–2013); major power outages reported in a disaster database (1971–2013) and hourly electricity consumption (2006–2013). These deviations (exceedances) proved to be adequate indicators of the stress posed by extreme temperature events to the electricity distribution system leading to major blackouts. Based on these indicators, we found that the electricity distribution system was under similar stress during cold waves or heat waves, but it was much more vulnerable to heat waves (three blackouts under cold waves against 20 under heat waves between 2006 and 2013). For heat waves, the results of a binomial regression logistic model provided an adequate description of the probability of disastrous supply interruptions in terms of exceedances in extreme temperatures and electricity consumption stress. This approach may be of use for other cities wishing to evaluate the effects of extreme temperature events on the electricity distribution infrastructure.

## 1. Introduction

### 1.1. Brief background and overview of the study

Electricity demand depends on socioeconomic factors, weather conditions and the course of seasons, months and calendar days. A reliable power infrastructure should have the capacity to supply electricity over the range of expected weather conditions. Outdoor temperature is generally viewed as the most significant weather variable influencing electricity consumption (Apadula et al., 2012), while other variables are of less importance (Mirasgedis et al., 2006). The relationship between electricity consumption and normal weather conditions have been addressed by many papers, contrariwise few studies have considered the effect of extreme temperature events (cold waves and heat waves). This may be associated with difficulties in assessing impacts of extreme temperature events (ETEs), requiring long time series of observed meteorological variables for valid statistical analysis of extremes in the tails of the distribution.

Major power outages (MPOs) or large blackouts are typically caused by either cascading failures propagating through a power system or natural events such as earthquakes and damaging storms. Recent literature have analyzed patterns in blackouts resulting from both types of causes (Hines et al., 2009 and references therein); however the effect of ETEs has received relatively little attention. Throughout the course of an ETE the infrastructure of an urban area can be subject to excessive stress. Significant increases in peak electricity demand during heat waves constitute a major challenge for the power supply chain (Zuo et al., 2015) and many areas in different countries have experienced MPOs during these critical periods (Habeeb et al., 2015). The electricity network has been identified as the most vulnerable part of the power supply system by a study that considered ~40 major blackouts worldwide over the past 40 years; being extreme weather events (EWEs) followed by lack of maintenance or asset replacement their leading causes (Boston, 2013 and references therein). The distribution network is critically susceptible to high temperatures, which reduce the efficiency of operation and the subsequent life expectancy of transformers and lead to significantly greater loadings prompted by higher demand for air conditioning and refrigeration

* Corresponding author at: Gerencia Química, Comisión Nacional de Energía Atómica, Av. Gral. Paz 1499, B1650KNA San Martín, Prov. Buenos Aires, Argentina.
** Corresponding author.
*E-mail addresses:* crossler@cnea.gov.ar (C.E. Rössler), dgomez@cnea.gov.ar (D.R. Gómez).

http://dx.doi.org/10.1016/j.enpol.2017.04.006
Received 13 June 2016; Received in revised form 21 February 2017; Accepted 5 April 2017
0301-4215/ 

(Chapman et al., 2013). Outdated or poorly maintained components deserve attention because they can be less effective at supplying power during extreme heat (Habeeb et al., 2015).

Electricity supply in the metropolitan area of Buenos has been vulnerable to disruptions resulting from ETEs, which have been supposedly associated with poor asset management with under-spending in both renewal and maintenance. To better understand the nature of this type of temperature-related power outages, this study examines the influence of cold and heat waves on extreme temperature-related faults on the distribution network of this megacity and analyzes which indicators best represent the occurrence of this type of MPOs. The relation between blackouts and ETEs was assessed on the basis of historical temperature data and records of weather-related power failures contained in a disaster information system (Section 3.2). A threshold exceedance analysis of hourly temperature and electricity consumption was used to identify the best indicators that allow distinguishing risks of disastrous power outages on the basis of the magnitude of stress in power supply and the exceedance of an air temperature threshold (Section 3.3). Our study is of general nature and our findings can be used to plan adaptation measures and to improve maintenance and asset replacement policies. Nevertheless, results of cold and heat waves affecting the metropolitan area of Buenos Aires between 1911 and 2013 are reported in Section 3.1 to provide relevant background information specific to the area.

### 1.2. Literature review

Daily electricity demand exhibits distinct seasonal patterns that may peak according to specific circumstances in each country or region during solstices (Hekkenberg et al., 2009). In winter, shorter daylight period imply higher electricity use because of increased lighting needs (Ruth and Lin, 2006), other contributing factors may include heating demand, as individuals are more likely to be indoors, and higher average economic activity compared with that during summer holidays. The use of cooling appliances, especially air conditioners (A/C), is usually linked to demand peaks during summer. Furthermore, domestic electricity consumption can increase steadily once temperature values within urban regions exceed their rural values as a consequence of the urban heat island (UHI) effect (Radhi et al., 2013).

Earlier publications considered the influence of air temperature on electricity consumption at the level of individual residential or commercial building, which were analyzed under idealized conditions (Sailor and Muñoz, 1997). In the last decades, the need for accurate electric load forecasting at different temporal and spatial scales, preferably disaggregated by type of user (residential, commercial, and industrial), coupled with concern on climate change impacts have promoted further studies regarding the link of energy consumption not only with observed weather conditions but also with future requirements posed by climate change. Time horizons for load forecasts used for dispatch or within a utility company vary from very short (≤hour) to long-term ( > year) (Apadula et al., 2012).

Previous studies have identified a non-linear relation, frequently U-shaped, between daily values of electricity demand and temperature (Apadula et al., 2012; Valor et al., 2001). To assess this relationship, original demand data are typically filtered to subtract trend, calendar effects and non-climatic seasonality (Moral-Carcedo and Vicens-Otero, 2005). In the vicinity of the minimum of the U-shaped plot, electricity load is insensitive to temperature whereas, out of this interval, electricity demand increases with both decreasing temperatures (winter branch) and increasing temperatures (summer branch) (Valor et al., 2001). Two different temperature-derived variables, namely the heating degree-days (HDD) and the cooling degree-days (CDD), have been often used to simplify the characterization of the non-linear influence of temperature on electricity demand by separating the winter and summer branches to build linear models (Apadula et al., 2012 and references therein). The idea of degree-days is based on the difference of ambient temperature from a certain temperature threshold, which is usually defined as a balance point temperature (Ahmed et al., 2012). One limitation of this method concerns the selection of a single or dual temperature threshold, which is often quantified by a simple graphical approach (Moral-Carcedo and Vicens-Otero, 2005). Nevertheless, HDD and CDD have been acknowledged as relevant indicators for the climate-driven heating and cooling loads (Sailor, 2001). The shape of the response of electricity demand to temperatures depends primarily on the local climate and latitude and on socioeconomic conditions (Psiloglou et al., 2009).

Much research published on the effects of ETEs concerns the impacts of heat waves on human health, which has become a rapidly growing area of epidemiological research (Kovats and Hajat, 2008); while relatively little has been published regarding the influence of ETEs on infrastructure and productive systems. Recent literature on the influence of ETEs on the electricity system has addressed issues such as (*i*) the impacts of extreme-heat days on peak electricity demand for major cities in heavily air conditioned California under projected climate change scenarios (Miller et al., 2008); (*ii*) forced capacity reductions and its impacts on electricity prices, production costs and the surplus of consumers and producers (Pechan and Eisenack, 2014); (*iii*) the relatively little attention that researchers have given to the impact of changes in cooling water temperature on the thermal efficiency of fossil-fuel based and nuclear power plants (Mideksa and Kallbekken, 2010); (*iv*) the drawbacks of using air source A/C relative to its discharge of condensing heat into the air that can contribute to increase the street temperature, adding to the UHI effect (Tremeac et al., 2012) and (*v*) the incremental risk for low-income residents because of limited use of A/C associated with the financial burden of increased electricity cost (Kovats and Hajat, 2008; Sheridan, 2007).

Extreme weather and growing urbanization are making cities more vulnerable to MPOs; the ability to prevent damage to the electricity infrastructure from ETEs that are likely to occur during its lifetime requires knowledge of the behavior and impacts of extreme weather. Knowledge gaps exist in the relationship between exposure to extreme temperature and a range of outcomes including increased demand and supply disruptions and in harmonizing episode and long-term analysis. Identifying longer trends, if any, faces difficulties because the available information on the impacts of extreme weather events (EWE) is biased towards recent years (Klein Tank et al., 2009), however a narrow focus on recent MPOs may obscure long-term patterns that may have further implications for policy and investments decisions (Hines et al., 2009).

## 2. Methodology

Our study was conducted with data available for the metropolitan area of Buenos Aires (AMBA, according to the acronym used in Spanish), which is the third largest city in Latin America. It is home to ~15.6 million inhabitants while its surface of ~700 $km^2$ represents 0.3% of the national territory. Two distribution companies supply electricity to 5.2 million customers in this area, which concentrates the largest population (~32%) and the largest demand (~40%) of all regions of the Argentine electricity system.

### 2.1. Data sets

We analyzed three data sets for the AMBA to (*i*) characterize ETEs occurred between 1911 and 2013; (*ii*) assess the influence of cold and heat waves on MPOs between 1971 and 2013 and (*iii*) evaluate the role of temperature in electricity consumption pattern and the stress posed by ETEs on demand levels possibly leading to “disastrous” supply disruptions between 2006 and 2013.

Frequency, duration and timing of cold and heat waves were identified using a 100-year series of meteorological information from the National Weather Service (NWS) of Argentina for the Buenos Aires Central Observatory. Air temperatures were obtained and measured by