The Socio-Economic Impacts Of Climate Change On Energy Security

THE CASE OF EGYPT

The 2021 US re-entry into the Paris Climate Agreement has raised again the global debate on climate. This paper analyses the trilateral relation between global warming, energy security (both production and consumption) and population. Following the non-linear regression method, Egypt is studied during the period 2007-2010 based on daily meteorological and electrical-load data and annual population data. The study argues that electricity production contributes to global warming, Population growth also raises the need for electricity production, transportation and cooling systems. Since Egypt is a sub-tropical country, load is almost independent of temperature in warm winter, while temperature affects more than 64 per cent of load variation in summer. One of the solutions is to enhance reliance on relatively clean sources of energy, such as renewable and atomic power.

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MUTUAL IMPACTS BETWEEN CLIMATE CHANGE AND ENERGY

On the day Joe Biden was sworn in as the President of the United States, he brought his country back into the Paris Agreement. Adopted on 12 December 2015 and entered into force on 4 November 2016, the Agreement is a legally binding international instrument to limit global warming to well below 2°C preferably to 1.5°C, compared to pre-industrial levels, through global peaking of greenhouse gas emissions, and thence achieving a climate-neutral world by the mid-century. (https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement) Climate change is caused by global warming, which is mainly attributed to greenhouse gases that trap heat radiated from Earth in the atmosphere and oceans. Those gases include mainly carbon dioxide (CO_2), methane (CH_4), ozone (O_3), nitrous oxide (N_2O) and water vapour (H_2O). Large quantities of these gases are released as a result of deforestation and burning of fossil fuel since the mid 20th century. (Parkpoom, S et al, "Climate Change Impacts on Electricity Demand", In Nouri, H (Ed), *Proceedings of the 39th International Universities Power Engineering Conference*, Bristol, UK, September 2004, Section T 14.2) Global warming could cause the rise of sea levels. Electrical power plants emit large amounts of greenhouse gases, particularly when coal is used as a fuel. For example, electricity production generates the second largest share of greenhouse gas emissions in the US (26.9 per cent of 2018 greenhouse gas emissions). Approximately 63 per cent of the US electricity comes from burning fossil fuels, mostly coal and natural gas. (Online at the official website of the US Environmental Protection Agency (EPA): https://www.epa.gov/ghgemissions/sources- greenhouse-gas-emissions#:~:text=Electricity per cent20production per cent20(26.9 per cent20per cent per cent20of,mostly per cent20coal per cent20and per cent20 natural per cent20gas)

Table 1: Estimation of World's Population and Economy and Resulting Emissions, Warming and Sea Level Rise

Year	World's Population (billions)	World's GDP (10^{12} US$)	CO_2 Level (ppm)	Temperature Change (°C)	Sea Level Rise (m)
1900	5.3	21	354	0	0
2000	6.1 – 6.2	25 – 28	367	0.2	0.02
2050	8.4 – 11.3	59 – 187	463 – 623	0.8 – 2.6	0.05 – 0.32
2100	7 – 15.1	197 – 550	478 – 1099	1.4 – 5.8	0.09 – 0.88

Source: McCarthy, J J et al (Eds), *Climate Change 2001: Impacts, Adaptation and Vulnerability*. Cambridge University Press, 2001, p27.

Climate change is no longer an intelligentsia-monopolised topic. The tremendous negative effects of environmental disturbance have disrupted vital aspects of daily life as clearly experienced in the COVID-19 pandemic. These effects increasingly constitute non-traditional security challenges, involving the security sector to directly address them, as witnessed in the curfews, lockdowns and national emergencies to contain the propagation of the pandemic. The securitisation of the climate debate became a fact, essentially with regard to addressing the impact of climate change on energy security and the production of low-or-zero-carbon non-conventional energy like nuclear energy. Nuclear safety and security is an inherent component of nuclear power programmes to avoid unauthorised access to nuclear materials which could lead to incidents of nuclear theft, sabotage and/or terrorism, and to avoid nuclear disasters as experienced in Chernobyl and Fukushima. In addition are the associated concerns of using nuclear power for military perposes.

The economic impacts of climate change on energy security have rapidly become a worldwide concern. For instance, the impact of climate on electricity production and consumption have acquired more importance as a direct result of electricity shortage. Climate change impacts on the electricity sector will account for the majority of global economic damages by the end of the current century and beyond. (Rose, S et al, *Understanding the Social Cost of Carbon: A Technical Assessment* Electric Power Research Institute (EPRI), 2014) From this standpoint, the importance of this study is attributed mainly to the need to increase electrical power generation globally and to control the consequences of climate change, especially those affecting energy generation and utilisation. This control should be preceded by a large process of evaluation of those consequences. In addition, there is a need to estimate the values and times of extreme electrical loads based on weather forecasting. Thus, relating variable loads to various seasons bears high significance in order to overcome any shortage in electrical supply, by applying proper transmission plans in order to redistribute electrical power through the electrical grid, along with inventing new electrical storage means with a view to recovering the peak-load times. Obviously, the world has experienced increasing electrical consumption. Electrical load has become globally greater than the drawn power at the terminals of distribution networks. The International Energy Agency (IEA) estimates that until 2040, the worldwide gross electricity consumption will increase from 25,679 billion kWh to 40,443 billion kWh. (Electricity Generation 2019/2020, VGB PowerTech, Online at https://www.vgb.org/en/data_powergeneration.html?) With the recovery of the world economy in 2021, electricity demand is forecast to grow by around 3 per cent. (Online at the official website of the International Energy Agency (IEA): https://www.iea.org/news/ global-electricity-demand-to-rebound-modestly-in-2021-after-historic-shock-from-pandemic) In tropical and sub-tropical countries, summer is usually associated with frequent interruption in electrical power for mainly two reasons: the increased population (with increased electrical consumption) and climatic change, as well as other logistical factors such as the shortage of power plants' fuel supply. On the one hand, the world population has increased in the recent years, accompanied with greater demand for energy in general and electricity in particular. The increased means of transportation, installation and expansion of electrical power plants, use of air conditioners (ACs) and other heat-emitting machines contribute heavily to global warming. On the other hand, global warming induces heavy usage of cooling appliances, fans and ACs causing increased pressure on electrical grids.

Weather cannot be easily controlled. Therefore, counter-climate-change measures are much needed with a view to decelerating global warming. Those measures aim at mitigation of climate change or at adaptation to its effects. Mitigation includes efforts to reduce emissions and to enhance sinks. The United Nations Framework Convention on Climate Change (UNFCCC) requires all parties to formulate and implement programmes containing measures to mitigate climate change. (Online at https://unfccc.int/ topics/ mitigation / the-big -picture /introduction-to-mitigation) Adaptation to life in a changing climate aims at the reduction of vulnerability to the harmful effects of climate change, such as sea-level encroachment, more intense and extreme weather events or food insecurity. (Online at https://climate. nasa.gov/solutions/adaptation-mitigation)

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Under the Paris Agreement, countries established an enhanced transparency framework (ETF). Starting in 2024, countries must report transparently on actions taken and progress in climate change mitigation and adaptation measures and support provided or received. ETF also provides for the international review of the submitted reports. Since the entry into force of the Paris Agreement, more and more regions, countries, cities and companies are establishing carbon-neutrality targets. Zero-carbon solutions are becoming competitive across economic sectors representing 25 per cent of emissions, especially electrical power and transport sectors, creating new business opportunities. By 2030, zero-carbon solutions could be competitive in sectors representing over 70 per cent of global emissions. (Online at https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement) Nevertheless, those measures would be rendered insufficient and useless unless they are coupled with multifaceted policies. For example, population growth must be optimally managed through advanced plans for healthcare, housing, education and employment in order to generate more economic power in form of mainly sustainable economic growth and inclusive social development to compensate for the economic damages of climate change, predominantly the increased pressure on the electricity industry.

A direct approach to the impacts of weather on electricity is neither to control the atmospheric factors nor to control the population growth, but to address the electrical load itself. This control could be via the installation of more power plants, though, this option leads to releasing more greenhouse gases aggravating climate change. Other options could include the maximisation of generation, transmission and distribution efficiencies and redistribution of electrical energy among various areas according to their actual needs and activities. Stored extra generated electrical energy can be used during the peak-load periods or transmission of this energy through a single electrical grid to other countries, which have different patterns of electrical consumption, their peak load being in winter, for instance due to heating requirements, and minimum load in summer since ACs are not largely used in such countries. This approach creates room for regional cooperation and pacifies regional conflicts. Nevertheless, the approach implies socio-economic costs, deducting from the financial resources which could be allocated to other aspects of inclusive social development, like raising the quality of education, enhancing the standards and availability of healthcare and finding smart cheap solutions for housing challenges.

The first step in designing solutions is to have enough knowledge on the impact of weather on load in order to achieve optimum utilisation of electrical energy and minimise electrical loss. Electrical loads are significantly affected by various weather factors, such as air temperature and atmospheric pressure, notably in the form of difference in load values due to the value difference of weather factors in different seasons. As a result of the rise in temperatures, the growing phenomenon of global warming has come about and affected the electrical consumption. Many studies have empirically shown significant increases in impacts of weather on electrical load. Unfortunately, the available literature has rarely focused on the economic cost of the increased values and frequency of peak loads. Hence, this paper finds a two-variable equation describing the relation between weather and load. The first variable of that equation is an independent parameter which is the dominant weather factor, while the second variable is a dependent parameter which is electrical load. The paper argues that electrical consumption is non-linearly proportional with the dominant weather factors. This relation is statistically and graphically examined throughout this study. It is of utmost importance to determine the dominant weather factor and to estimate the annual and seasonal variation of this factor and electrical load in order to predict the occurrence of extreme loads.

IMPACTS OF WEATHER ON ELECTRICITY CONSUMPTION

Since electricity demand is closely influenced by climatic variables, there is an impact of climate change on demand patterns. The impacts of air temperature and atmospheric pressure on load capture the interest of scientists and engineers. In general, the weather factors influence air-conditioning, space heating, refrigeration and water pumping loads, which add to the electrical peak demand and 24-hour demand. As developing countries improve their standard of living, their use of air conditioning and other weather-dependent consumption may increase their sensitivity to climate change. (Parkpoom et al, Op cit) In recent years, public demand for summer air conditioning has introduced a new and volatile factor in load variability. In many systems, summer air conditioning has resulted in a change from winter to summer annual system peak load. (Tafreshi, S M M and Farhadi, M, "A Linear Regression-Based Study for Temperature Sensitivity Analysis of Iran Electrical Load", *IEEE International Conference on Industrial Technology*,

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April 2008, pp1-7)

A study supported by the European Union Adaption and Mitigation project (ADAM). (supported by the European Commission under the Sixth Framework Programme. See: www.adamproject.eu) indicated that an increase in temperature has an impact on electricity consumption four times the size of the equivalent decrease in temperature. This could be because cooling requires more energy than a 'similar' amount for heating, especially since there are, on the one hand, other options for heating, such as wood and gas, but cooling can only be powered by electricity. Subsequently, there is an increase in electricity demand in Southern Europe, while in the Northern European countries, it is estimated that there will be a fall in consumption. Based upon the fact that the electricity demand also depends on the mix of resources used for heating and cooling, then if air conditioning is provided by electrical means, but heating is provided by gas boilers, global warming will increase electricity demand but overall energy use could decrease (Parkpoom et al, Op cit)

At the same line, heating oil and natural gas use in the US peaks in winter, while electricity use peaks during the summer when air conditioning use spikes. However, the exception is the Pacific Northwest, where most heat is produced by electricity, resulting in a wintertime electricity use peak. Electrical energy used in heating and cooling for residential consumption is about 58 per cent, and about 40 per cent for commercial consumption. A 1.6-degree Fahrenheit increase in average temperature decreases residential space heating needs by 6 to 10 per cent and increases space cooling needs 5 to 20 per cent. The same increase in average temperature decreases commercial space heating needs by 7.4 to 9 per cent and increases space cooling needs by 9.4 to 15 per cent. (Online at http://www.earthgauge.net/wp- content/CF_Weather_and_Energy.pdf)

The peak loading is fundamentally important, because extreme temperatures put stress on electricity systems in meeting demand. This was the case in France in 2003, where extremely high temperatures gave rise to a significant increase in air conditioning. At that time, restrictions on output from nuclear stations, brought about by cooling limitations, threatened blackouts (Parkpoom et al, Op cit). Thus, the importance of load forecasting is attributed to its role in paving the way to expand the power system or at least maximising its efficiency to meet the future increase of load. Gupta (1996) stated that load forecasting studies have to predict the increase in load for the next 30 years because a modern power station takes 5 to 10 years for completion (and some hydro-electric stations take even longer time), and the power system planning must be done about 20 years in advance. (Gupta, B R, *Generation of Electrical Energy*, Ram Nagar, New Delhi: Eurasia Publishing House (PVT) LTD, 1996)

Since there is no formal model of how load depends on temperature or other environmental data, non-formal methods are used. Load model of special off-days shows a big difference to working days. (Soozanchi-K, Z et al, "Modeling and Forecasting Short Term Electricity Load based on Multi Adaptive Neural Fuzzy Inference System for Short by Using Temperature", *IEEE*, vol 3, 2010, pp18-22) This difference reflects the impact of population activities on electrical load. Parkpoom et al assessed the climate impacts on electricity demand in Thailand using the simplest approach to perform a two-variable regression between hourly demand levels and temperature. They illustrated that relation using the data of peak electricity demand and temperature for Thailand over one month in order to draw the scatter plots and trendlines. Still, they showed a relatively low coefficient of determination (R^2 = 0.2). (Parkpoom et al, Op cit) meaning that the relation they established governs only 20 per cent of load variation. Tafreshi and Farhadi concluded that Iran's load pattern is heavily dependent on temperature according to a linear relation. (Tafreshi and Farhadi, Op cit)

Electrical consumption is non-linearly proportional with the dominant weather factors. This relation is statistically and graphically examined throughout this study. It is of utmost importance to determine the dominant weather factor and to estimate the annual and seasonal variation of this factor and electrical load in order to predict the occurrence of extreme loads

Franco and Sanstad found a relationship between the daily electrical demand for the area serviced by the California Independent System Operator (CalISO) in 2004 as a function of the simple average of daily temperatures in four sites, namely San Jose, Sacramento, Fresno, and Los Angeles, including demand during weekdays (excluding holidays). This relation was expressed by a third- degree equation with a high determination coefficient (90.98 per cent), showing that electricity demand is proportional to temperature, so peak demand occurs mostly in summer and is well predicted by maximum daily temperatures. (Franco, G and Sanstad, A H, *Climate Change and Electricity Demand in California,* California Climate Change Center, February 2006, p5) Valor *et al* analysed the relation between electrical load and daily air temperature in Spain, using a population-weighted temperature index. They indicated that load shows maximum values in winter and summer and minimum values in spring and autumns. The relation between load and temperature was found to be non-linear, and the sensitivity of load to temperature has increased over time. (Valor, E et al, "Daily Air Temperature and Electricity Load in Spain", *Journal of Applied Meteorology and Climatology*, vol 40, August 2001)

EGYPT AS A CASE STUDY

Egypt lies in Northeast Africa between latitudes 22° and 32°N, and longitudes 24° and 36°E. The total area of the country is 1,001,450 square kilometres, with land area of 995,450 square kilometres and water area of 6,000 square kilometres. Its total land boundaries account for 2,665 kilometres, while the coastal zone of Egypt extends over more than 3500 kilometres. The Egyptian terrain is characterised as a vast desert plateau interrupted by the Nile Valley and Delta. The lowest point in the country is the Qattara Depression at -133 meters and the highest point is Mount Catherine in the Sinai at 2,629 meters. (Online at http://www. climate-zone.com/climate/egypt)

Egypt has a large population currently amounting to more than 101 million people. (Central Agency for Public Mobilisation and Statistics, Egypt: https://www.capmas.gov.eg/Pages/populationClock.aspx). Due to the aridity of the climate, about 99 per cent of the population resides in the coastal regions and in the fertile Nile Valley using only about 5.5 per cent of the total land area of the country. (Hamza, W, "Land Use and Coastal Management in the Third Countries: Egypt as a Case", *Proceedings of the International Conference on the sustainable development, of the Mediterranean and Black Sea Environments*, Thessalonica, Greece, 29-31 May 2003) and the rest of the area is desert. Therefore, the population centres are concentrated along the narrow Nile Valley and Delta. This population density causes the electrical needs to be greater within a narrow area of Egypt.

Egypt is selected as a case study for its location between Africa, Asia and Europe. As a result, the climate of Egypt is affected by the characteristics of the Mediterranean, Southwest Asia, African Sahara and the Nile Basin. In addition, the relatively large area of the country implies various climate characteristics based upon latitudes and topography.

The average annual temperature increases moving southward from the Delta to the Sudanese border, where temperatures are similar to those of the open deserts to the east and west. Throughout the Delta and the northern Nile Valley, there are occasional winter cold spells accompanied by light frost and even snow.

At Aswan, in the south, June temperatures can be as low as 10°C at night and as high as 41°C during the day when the sky is clear. The hot or Khamsin winds blow across Egypt in late winter and early summer (often in April but occasionally in March and May). Unobstructed by geographical features, the desert's Khamsin depressions are always associated with strong, hot and dry winds with high velocities (up to 140 kilometers per hour) and great quantities of sand and dust from the deserts, increasing the atmospheric pollution and causing temperatures to rise as much as 20°C in two hours. (Online at http://www.our-egypt.com/en/practical-information/ climate/) Khamsin-like depressions cross Egypt during late September marking the breakdown of summer. The higher humidity in this month favours greater frequency of thunderstorms and heavier precipitation particularly in November. (Robaa, S M and Hasanean, H M, "Human Climates of Egypt", *International Journal of Climatology*, 2006, vol 27, pp781–782)

DATA AND METHODOLOGY

Statistical data required for undertaking this study were provided mainly by Egyptian official agencies. Electrical data include daily peak electrical loads (MW) over Egypt spanning the period from 1 January 2007 to 31 December 2010 (1461 data). Those data were provided by the Egyptian Ministry of Electricity and Energy (MEE). Two kinds of meteorological data were provided by the Egyptian Meteorological Authority (EMA) and used for the purpose of this study. The first kind is the Climatological Normals for Egypt from 1976 to 2005 (30 years) drawn from 46 meteorological stations throughout Egypt. Those normals present a complete description for the climate of Egypt. Accordingly, they are used to get the normal monthly and annual values of the various weather factors. Annual statistics on total population of Egypt during the studied period are provided by the Central Agency for Public Mobilisation and Statistics (CAPMAS).

Based upon the fact that the electricity demand also depends on the mix of resources used for heating and cooling, then if air conditioning is provided by electrical means, but heating is provided by gas boilers, global warming will increase electricity demand but overall energy use could decrease.

The dominant weather factor is the most sensitive to time variation. This factor is identified through two steps. Firstly, the behaviour of the previously mentioned four weather factors over time is examined annually and seasonally in order to determine the weather characteristics of time. For instance, daily mean air temperature is plotted versus time for every year during the studied period. Afterwards, the trends of temperature in different years are graphically compared and used in order to derive and plot the daily variation of the average values of daily mean temperature over the year. This plot is divided into two sections representing the daily variation of the average values of daily mean temperature during the two main seasons. The same analysis is reiterated with the daily mean values of the other three studied weather factors. Secondly, the mutual impacts between various weather factors are characterised.

The behaviour of electrical load over time is examined in order to determine the load characteristics of time (the trend of load). Daily peak load is plotted versus time for every year during the studied period, and the trends of peak load in different years are graphically compared and used to derive and plot the variation of the average values of daily peak load over the year. This plot is divided into two sections representing the variation of the average values of daily peak load during winter and summer. In addition, the weekly pattern of daily peak load variation is studied in order to include the impact of population activities on load.

The relation between weather factors and electrical load can be derived using a non-linear regression, expressed by n^{th} degree polynomial model:

$$L = a0 + a1\ W + a2\ W^2 + \ldots.. + an\ W^n$$

This non-linear regression model correlates a dependent variable (electrical load) to an independent variable (dominant weather factor), where L is the vector of daily peak load (MW), W is the vector of a weather factor, a1, a2, ….. and *an* are the transposed vectors of regression coefficients and a0 is the vector of regression errors (random errors), which is the constant term indicating the value of load (L) when the value of weather factor (W) equals to zero.

In order to find the values of a0, a1, a2, ….. and *an*, the above model is applied at four approaches, namely the whole-period approach, annual approach, average- values approach and seasonal approach. Consequently, many comparisons can be made between those relations in terms of dependency of load on weather, represented by the determination coefficient R^2 which indicates the significance of this relation. For total dependency, R^2 equals to 1, which means that the equation interprets 100 per cent of cases. However, if R^2 equals to 0.5 and above, the relation is said to be significant and vice versa. Moreover, the occurrence of extreme values of the dominant weather factor and electrical load is studied in terms of timing and synchronisation. Furthermore, the relation between annual size of population and load during the whole studied period is studied.

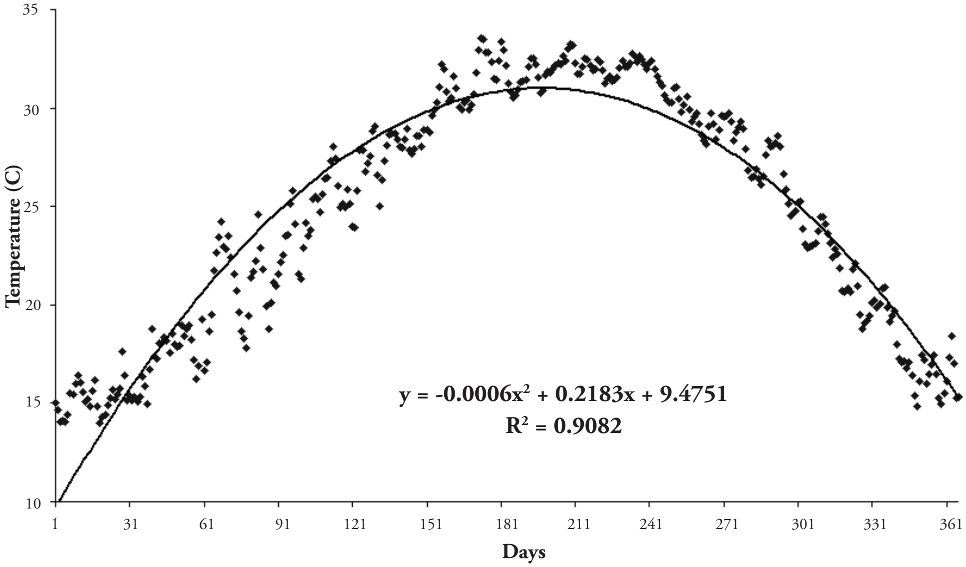
WEATHER BEHAVIOUR

The variation of daily mean air temperature over the whole studied period (2007-2010) shows that for most days, temperatures recorded in 2010 are the highest while those recorded in 2007 are the lowest. It is quite evident that temperature increases over years. The annual mean temperature of 2010 was 31.4°C which is 9.7°C above the previously mentioned normal value of annual mean temperature (21.7°C). This temperature increase indicates warming and it may be attributed to various reasons, of which human activities are significant factors. The increased CO_2 emissions from human beings, cars, cookers and industrial activities principally contribute to the increase of temperature which causes global warming and climate change. CAPMAS (2011) reported that the CO_2 emissions of Egypt reached 225.06 million tons in 2007/2008 and 235.5 million tons in 2008/2009 which form 0.71 per cent of the world's CO_2 emissions. Moreover, the CO_2 emissions of Egypt increased by about 37.1 per cent during the period 2006-2009. It is found that variation of temperature throughout a year follows a dome- shape. As per this pattern, temperature increases gradually until reaching its maximum value in summer, and then decreases gradually until reaching its minimum value in winter. Using the daily mean temperatures of the entire studied period, the average values of daily mean temperature are calculated and plotted in figure 1, where x-axis represents the days and y-axis represents the average values of daily mean temperature (°C). The figure shows that the variation of daily mean

It can be said that the load is generally proportional to temperature. This proportional relation becomes more significant over the years. Temperature affects load quite evidently in summer, and it is almost irrelevant in winter.

temperature over a year is governed in almost 91 per cent of cases by a second-degree equation: $T(d) = -0.0006\, d^2 + 0.2183\, d + 9.4751$, where T(d) is the average value of daily mean temperature (°C) on the d^{th} day of the year.

Figure 1: Average Value of Daily Mean Temperature the Period 2007-2010



The variant daily mean temperature retains its second-degree pattern from one season to another, however it follows a dome-shape in summer and a reversed dome-shape in winter. Nonetheless, temperature behaviour keeps its uniformity in more than 81 per cent of its variations in winter and 85.58 per cent in summer. Distinctly, summer has more uniform temperature behaviour than winter.

Following the same steps, it is found that behaviour of atmospheric pressure follows a reversed-dome-shape. Pressure decreases until reaching its minimum value in summer, and then increases until reaching its maximum value in winter. The variation of daily pressure over the studied period indicates that mostly, pressure recorded in 2010 is the lowest while pressure recorded in 2008 is the highest. It is clear that pressure decreases over years. The daily variation of pressure over a year is governed 86.43 per cent by a second-degree equation: $P(d) = 0.0364\, d^2 - 13.818\, d + 102169$, where P(d) is average value of daily pressure (Pa) on the d^{th} day of the year. This equation indicates that pressure varies according to a reversed dome-shape in summer and a dome-shape in winter. Same as temperature, the daily variation of pressure is more uniform in summer than in winter.

Generally, it is noticed that relative humidity decreases until reaching its minimum value in summer, and then increases until reaching its maximum value in winter. Still, humidity does neither increase nor decrease uniformly over years. For some days, humidity values recorded in 2010 are the lowest, but for other days, the 2010 humidity values are the highest. In addition, the behaviour of daily humidity did not follow a certain pattern (a linear variation in 2008 and a reversed-dome-shape variation in the rest of studied years). Moreover, that behaviour is found to be non- uniform in all studied years since the values of determination coefficient (R^2) are below 0.5. Like temperature and pressure, daily variation of relative humidity is more uniform in summer than in winter (R^2 = 69.1 per cent in summer and 63.88 per cent in winter).

Over the next 100 years, climate change could cause up to a 20 per cent decrease in demand for electricity for heating in Northern Europe and up to a 20 per cent increase in demand for electricity for cooling in Southern Europe. About 27 per cent of residential consumption in Europe is for heating and cooling.

The behaviour of daily wind speed throughout a year is non-uniform since the values of determination coefficient between time and wind speed do not exceed even 2.33 per cent. Plotting the average values of daily wind speed, it is found that wind speed linearly varies over a year in only 0.3 per cent of cases. As a result, wind speed is not crucial in influencing load unless it causes damage to electric utilities.

Based on the above results, we can conclude that summer has more uniform variation of air temperature, atmospheric pressure and to some extent relative humidity than winter.

With regard to the mutual impacts between weather factors, it may be noticed that density of hot air is physically less than that of cold air. Consequently, the weight of air above the Earth surface (atmospheric pressure) decreases when air temperature increases. Analysing the relations between temperature and pressure statistically and graphically. The higher the temperature is, the lower the pressure will be, and vice versa.

From the above discussions, it can be concluded that periods of the year can be characterised by temperature or pressure, which are the dominant weather factors. This result is useful in transforming the load behaviour over time into a relation between load and temperature or pressure. Since the behaviour of temperature is more significant than that of pressure (larger values of R^2), temperature is considered the most effective weather factor in affecting electrical load. As temperature and pressure are interrelated, reviewing the impacts of temperature on load implies also assessing the impacts of pressure.

BEHAVIOUR OF ELECTRICAL LOAD

It is found that the variation of load throughout a year follows a semi-dome-shape according to third-degree equations. Load increases gradually until reaching its maximum value in summer, and then decreases until reaching its minimum value in winter. The behaviour of daily peak load over the whole studied period reveals that load is minimum in November or December and maximum in July or August, which often witnesses the maximum values of daily mean temperature and accordingly the increasing reliance on ACs and other cooling appliances. It is clear that load increases rapidly over years. Daily peak load in 2010 is evidently the highest of the sample years while daily peak load recorded in 2007 is often the lowest. This conclusion is mainly attributed to the rising warming and population growth.

Although daily behaviour of load retains its third-degree pattern from one season to another, it is (like air temperature) of a dome-shape in summer and a reversed dome-shape in winter. Nevertheless, load keeps its uniformity in more than 56 per cent of its variation in winter and more than 85 per cent in summer. Plainly, load behaviour is more uniform in summer than in winter.

Population activities affect electrical load as reflected in load variation throughout a week. In Egypt, the week starts on Saturday and ends on Friday, and accordingly week days are numbered from 1 to 7. Load rises smoothly by the beginning of the week until reaching its maximum value on Tuesday or Wednesday, and then load falls sharply to reach its minimum value on Friday, which is the official weekend in Egypt. The average value of weekly peak load increased during the studied period by 3546.423 MW from 17233.077 MW in 2007 to 20779.5 MW in 2010.

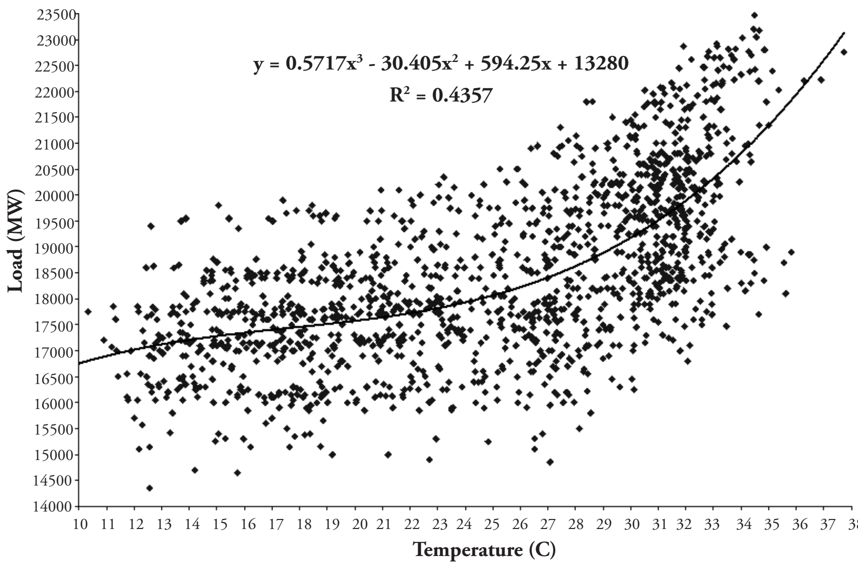
From the above analysis of load behaviour at the annual, seasonal and weekly levels, it is concluded that load varies based on weather and daily activities of the population.

RELATION BETWEEN AIR TEMPERATURE AND ELECTRICAL LOAD

Weather factors differ in their impacts on electrical load, influencing it to vary uniformly over time. Since temperature is the most effective weather factor, load can be expressed in terms of temperature. This hypothesis is examined in order to derive the temperature-load relation, which is analysed at four approaches: whole-period approach, annual approach, average-values approach and seasonal approach.

The relation between temperature and load during the whole studied period is plotted in figure 2 (n =1461 points), which shows that load is proportional to temperature according to a third-degree equation. However, that equation does not govern more than 44 per cent of load variations. This poor determination coefficient is logically expected and mainly attributed to the heterogeneity of this relatively long period since it consists of four years (2007-2010), each consisting of two seasons. Simply, the combination of eight different patterns of relations between temperature and load results in a diversified relation expressed in poor determination coefficient. Therefore, this approach will be totally dismissed. In order to overcome heterogeneity, the temperature-load relation is studied in more homogeneous periods according to other approaches.

Figure 2: Daily Mean Temperature Versus Daily Peak Load During the Whole Period 2007-2010



Plotting daily mean temperature versus daily peak load in various years, it is found that temperature-load relation keeps its non-linear proportion represented by a polynomial equation which govern at least about 54 per cent of the load variations. Furthermore, the determination coefficient visibly rises over years from about 54 per cent in 2007 to more than 73 per cent in 2010. It is clear evidence for the increasing dependency between load and temperature. It is also found that the temperature-load trendline graphically shifted up over the years. This fact points out a rising proportionality between temperature and load.

Plotting the seasonal relation between average values of both daily mean temperature and daily peak load reveals that temperature variation does not affect more than 6.56 per cent of load behaviour in winter. In summer, load behaviour is dependent on temperature variation since the latter affects 64.74 per cent of the former. Temperature-load relation in summer follows a third-degree equation: $L(T) = -3.9267\,T^3 + 355.86\,T^2 - 10424\,T + 117820$.

The values of determination coefficient (R^2) for the explained temperature-load relations are compared in table 2.

Table 2: Values of R^2 of Temperature-Load Relation at The Annual, Average-Values and Seasonal Approaches

Level of Analysis		R^2 (per cent)	Dependency
Annual approach	2007	53.97	Significant and rising over years
	2008	67.37	
	2009	68.31	
	2010	73.07	
Average-values approach		82.6	Significant
Seasonal approach	Winter	6.56	Insignificant
	Summer	64.74	Significant

Based on the above results, it can be said that the load is generally proportional to temperature. This proportional relation becomes more significant over the years. Temperature affects load quite evidently in summer, and it is almost irrelevant in winter.

It is important to predict the occurrence of maximum and minimum values of peak electrical load in order to take the necessary precautions in such circumstances. The minimum value of daily mean temperature occurs normally in January while maximum value occurs in July. The annual minimum values of daily mean temperature during the studied period did not exceed the normal minimum value of mean temperature (13.6°C). By contrast, the annual maximum values of daily mean temperature exceeded the normal maximum value of mean temperature (28.6 °C).

The annual minimum and maximum values of daily peak load during the studied period are shown in table 3.

Table 3: Annual Minimum and Maximum Values of Peak Load (MW)

Year	Annual minimum values of daily peak load	Date of occurrence	Annual maximum values of daily peak load	Date of occurrence
2007	14650	Wednesday, 19 December 2007	19250	Tuesday, 28 August 2007
2008	15000	Monday, 8 December 2008	21330	Wednesday, 27 August 2008
2009	15500	Friday, 27 November 2009	21090	Tuesday, 28 July 2009
2010	16700	Tuesday, 16 November 2010.	23470	Tuesday, 27 July 2010

Three main remarks can be made:

1. Both annual minimum and maximum values of daily peak load increase gradually over years. This conclusion could be attributed to the climate change and population growth.
2. The annual maximum values of daily peak load occur in July or August (summer) while the annual minimum values of peak load occur in November or December (winter). In other words, the higher temperature is the higher load will be. Nonetheless, table 3 indicates that the occurrence of extreme loads does not often coincide with the occurrence of extreme temperatures.
3. The annual peak load of 2010 was 4220 MW above the counterpart value of 2007. The average difference between the annual maximum and minimum values of daily peak load is 5822.5 MW, which can be theoretically generated in winter, saved in energy storage devices and distributed via the national electrical grid in summer. The other valid option is to transmit this power through a single electrical network to other countries which have different

patterns of electrical consumption due to different climate (having their peak electrical consumption in winter due to heaters usage, and minimum consumption in summer since ACs are not widely used). Then, that extra power will be back again to Egypt during summer.

IMPACT OF POPULATION AND CLIMATE CHANGE ON WEATHER-ELECTRICITY RELATION

Population is a crucial factor in characterising the temperature-load relationship since air temperature affects electrical load mainly via electricity-consuming activities. This relation is rather trilateral connecting temperature, population and load. During the studied period, the annual average values of daily peak load one plotted versus the annual size of population in figure 3.

Figure 3: Annual Population Versus Annual Average Values of Daily Peak Load in EGYPT During The Period 2007-2010

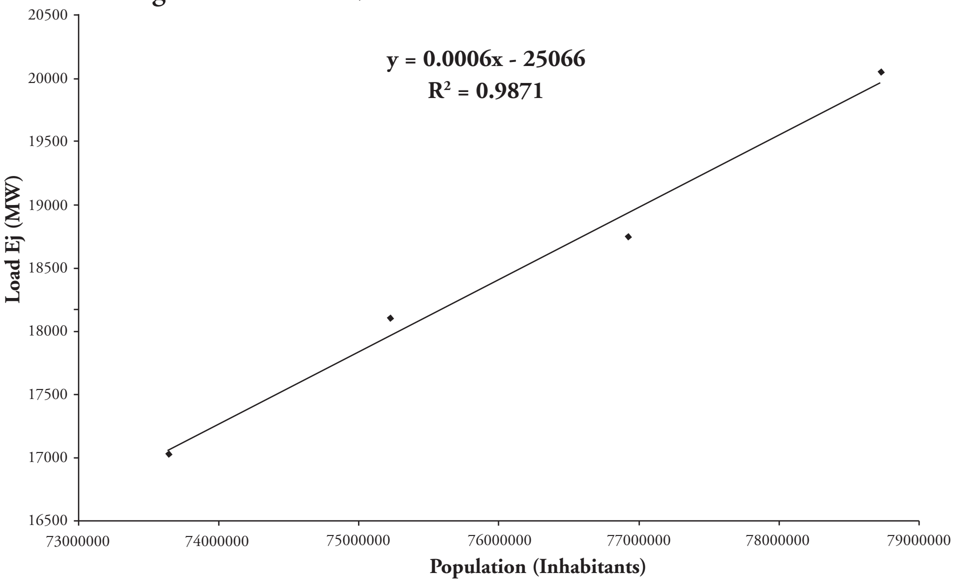


Figure 3 clearly shows that load is manifestly dependent on population (98.71 per cent) through a linear relationship. The higher temperature is, the wider the use of cooling appliances will be. Similarly, the wider the use of ACs is, the higher temperature will be, because AC absorbs heat indoor and emits it outdoor, which results in the rise of temperature by 0.75 °C. About 3 million ACs were sold in the Egyptian market during the period 2005-2010. In 2011, about 12 million ACs were used in Egypt. Consequently, summer 2011 witnessed 2 °C rise above the normal temperatures of summer.

Climate change is one of several drivers of electrical consumption. Those drivers include also demographic trends – including both the growth of population and changes in its spatial distribution – economic growth, development in energy markets, such as dramatic changes in natural gas prices, and other policy decisions affecting the electric power system. (Baxter, L W and Calandri, K, "Global Warming and Electricity Demand: A Study of California", *Energy Policy*, vol 20, no 3, 1992, pp233–244) Climate change is expected to lead to changes in ambient temperature, among other climatic variables, closely influencing electricity demand. The magnitude of the impact will depend on the electricity use patterns, as well as long-term socio-economic trends (Parkpoom et al, Op cit) In addition, climate change will alter the level and timing of electricity demands, as well as the thermal efficiency of electricity generating units. (Crowley, C and Joutz, F L, "Seasonality and Weather Effects on Electricity Loads: Modeling and Forecasting", Final Report for USEPA, 12 December 2005, p1)

Biofuel power plants may contribute to climate change through the nitrogen oxides emissions (attributed to the high nitrogen content of many biofuels). Carbon monoxide is released sometimes at higher levels than those from coal power plants, and particulate emission is also considered as a main cause of air pollution.

A study estimated that increase in electricity expenditures for cooling for human comfort outweighs decrease in expenditures for natural gas used to heat residential and commercial buildings. (Mendelsohn, R, "The Impact of Climate Change on Energy Expenditures in California", In Wilson, T et al (Eds), *Global Climate Change and California: Potential Implications for Ecosystems, Health, and the Economy*, Consultant report 500-03-058CF to the Public Interest Energy Research Program (Appendix XI), California Energy Commission, August 2003) Such direct temperature-driven impacts would be exacerbated by potential losses in hydroelectric supply due to direct and indirect effects of temperature changes on hydroelectric generation. At the average level of hydro-supplied megawatt-hours (MWh) from 1990–2002 and a price of US$ 0.10 per kWh, a 10 per cent decrease in hydro supply would impose a cost of approximately US$ 350 million in additional electricity expenditures annually. (Franco and Sanstad, Op cit)

Auffhammer et al (2017) parameterised the relationship between electricity demand and temperature for the US. They couple the estimated temperature response functions for daily load with global climate models (GCMs) to simulate climate change-driven impacts on the outcomes. The results suggest significant increases in the intensity and frequency of peak loads throughout the US. As the US electricity grid is built to endure maximum load, the findings have significant implications for the construction of costly peak generating capacity, suggesting additional peak capacity costs of up to 180 billion dollars by the end of the century. (Auffhammer et al, "Climate Change is Projected to Have Severe Impacts on the Frequency and Intensity of Peak Electricity Demand Across the United States", *PNAS*, vol 114, no 8, 21 February 2017, p1886)

Over the next 100 years, climate change could cause up to a 20 per cent decrease in demand for electricity for heating in Northern Europe and up to a 20 per cent increase in demand for electricity for cooling in Southern Europe. About 27 per cent of residential consumption in Europe is for heating and cooling. For specific examples, Greece's consumption was estimated to rise by 10 per cent and Turkey's by 18.6 per cent. By contrast, Latvia would reduce its consumption by 19.5 per cent and Lithuania by 20.8 per cent. For central Europe, the increase in summer temperatures and reduction in winter temperatures come fairly close to leveling out over the year. (Online at https://climate-adapt.eea.europa.eu/metadata/publications/the-impact- of-climate-change-on-europes-electricity-demand)

ENERGY SECURITY ALTERNATIVES

Since the 1970s energy crisis, the international debate on energy security has been raging politically at the first stance to find the best strategies. However, the energy debate became more technical to secure energy supplies from non-depletable sources with unlimited production, like wind farms, solar cells and waterfalls. Nuclear power plants have emerged as an alternative to provide electrical power for economic development. With improved of nuclear safety and security, diversification of nuclear waste management, and increasing prices of conventional fuel, it seemed that nuclear power would represent a good option for energy security.

Basically, most of electrical power plants perform the same task, converting kinetic energy into electrical energy using generators. In order to provide the driving force of generators, some mechanical devices such as wind, water or steam turbines, diesel engines or others should be used. Electrical power plants can be broadly classified into three categories: conventional power stations, renewable energy stations and nuclear power plants.

Conventional power stations are divided into two types: hydroelectric plants and steam stations that use fossil fuels. Biomass-fueled power plants can also be included in this category, but they have not been used commercially, and are not widely spread. In addition, some patterns of using biofuels face increasing international opposition.

Hydropower is considered one of the most economical eco-friendly methods of electricity generation. Some the currently-operating hydroelectric plants were installed more than a hundred years ago. Still, hydropower is almost a constant source of electrical power since there is no significant increase in the contribution of dams to electricity generation.Then, it is necessary to rely on other sources to growing meet electricity needs.

According to the US Department of Energy's projections for 2030, plutonium in the US spent fuel assemblies will be enough to operate twenty nuclear reactors for forty years. This means another resource for nuclear energy in the US if the option for reprocessing is largely adopted.

Fossil fuel stations combust coal, oil or natural gas to generate heat used to run water boilers, converting water into steam piped to rotate turbines, and to generate electricity. Those stations can rapidly adapt to changes in electricity demand, as their production can be easily increased to meet peak demands. Nonetheless, many environmental flaws are associated with the use of fossil fuels to generate electricity, including the release of greenhouse gases, such as sulfur dioxide (SO_2) and nitrogen oxides (NOx) that contribute to the formation of smog and acid rain. Some coal-fueled power plants use special technologies to reduce or eliminate SO_2 and NOx.

While biomass energy could be considered as a form of renewable energy it is usually dealt with as a conventional energy source because of the erosion of forest and agricultural cover through the increasing use of biofuels and overriding encroachment of urbanisation, although biofuel energy has not been widely used for long. The term biomass refers to various fuels derived from wood, agricultural and food residues, and crops grown specifically to generate electricity. It also includes some sewage materials and animal manure. Biofuels are used primarily in two ways: burning biofuels inside direct combustion power plants to provide steam for turbines as in hydroelectric and fossil-fuel power plants, and biomass gasification by converting it into methane, which is used as fuel for steam generators, combustion turbines, and combined fuel cycle technologies or fuel cells.

Numerous advantages are associated with electricity generation using biofuels. For instance, direct combustion generates electricity at any time, unlike wind farms which produce energy only when the wind blows, and many solar technologies which require sunshine. However, the extracted gases from biomass gasification can be used in power plants with various designs, in contrast to the direct combustion method. Burning wood releases very little amount of SO_2, and gasifying wood waste results in methane used in electricity generation in a closed circuit, which reduces the release of methane into the atmosphere. Therefore, biomass is believed to be a source of carbon-neutral energy. This carbon neutrality has many environmental benefits, like reducing emissions of carbon dioxide, sulfur and mercury. In addition, biofuels can replace some or all of the coal that is burned in coal-fueled power plants. Moreover, burning waste, crop residues, sewage or fertiliser to generate electricity allows landfills to be used for development purposes.

Nevertheless, biofuel power plants may contribute to climate change through the nitrogen oxides emissions (attributed to the high nitrogen content of many biofuels). Carbon monoxide is released sometimes at higher levels than those from coal power plants, and particulate emission is also considered as a main cause of air pollution. In addition, collecting, processing and burning biofuels may cause environmental threats if the fuel source contains toxic pollutants, agricultural waste treatment contaminates local water resources, and the burning of biofuels deprives ecosystems from nutrients provided by forests or agricultural residues.

Renewable energy stations include two main types of power plants: wind farms and solar panels. In addition, tidal energy is another form of renewable energy. Wind energy is not a reliable resource for electricity production, because wind turbines can generate electricity only when the wind is strong enough. Light energy (photons) of sunlight is used to generate electricity by solar panels through the photovoltaic effect. Some modern solar panel designs contain concentrators, in which light is focused through lenses or mirrors onto a group of cells. For the use of solar cells in practical applications, three factors must be met.

Cells must be electrically connected to each other and with the rest of the system. They should be protected against mechanical damage during manufacture, transportation, installation and use, essentially against the influence of wind and snow, especially for silicon cells which are fragile. Moreover, they have to be protected from moisture, which causes the corrosion of metal connections, thin-film cells and the transparent oxide layer that conducts electricity, and reduces the performance and life of a solar cell. Nonetheless, the efficiency of solar panels decreases with high temperatures, so they need good ventilation.

Electricity generation using nuclear fuels has acquired more importance in the past half century due to various considerations. On the one hand, there is a rising global trend to benefit from atomic energy for peaceful purposes. On the other hand, there is no significant increase in the per centage of hydropower contribution to the total electricity production. In addition, the reserves of oil, gas and coal are no longer sufficient to cover the increasing needs of electric power plants. Furthermore, the rapid increase in oil prices has narrowed the gap between the cost of conventional and nuclear power plants, and nuclear power could be more economical. Despite the relatively high initial cost, the profits of nuclear power plants can cover that cost within a decade of operation.

In Egypt the average difference between the annual maximum and minimum values of daily peak load is 5822.5 MW, which can be theoretically generated in winter, saved in energy storage devices and distributed via the national electrical grid in summer.

Nuclear power plants are eco-friendly (as long as they operate without accident) since they release neither greenhouse gas emissions nor smog. Atomic energy is the world's second largest source of low-carbon power (29 per cent of the total in 2018). Currently, nuclear power provides about 10 per cent of the world's electricity from about 440 power reactors. (Online at https://www.world-nuclear. org/information-library/current-and-future-generation/nuclear-power-in-the-world-today)

However, nuclear waste needs to be handled with extreme care and cannot be easily disposed of. The most important fissile materials are uranium-235, uranium-233 and plutonium-239. Uranium-235 is used in nuclear reactors, where it can produce 3.7 million times the energy produced by an equivalent amount of coal. Before it is supplied to a reactor, uranium ore must pass through six main stages: mining to extract natural uranium ore; milling to produce U3O8 (also called yellowcake); conversion at two stages to purify the yellowcake and to produce uranium hexafluoride; enrichment by increasing the concentration of uranium-235 from 0.7 per cent as found in nature to an average of 3 to 5 per cent using either gaseous diffusion or gas centrifuge in order to separate uranium-238 which is heavier than Uranium-235; formation of a ceramic uranium dioxide; and coating fuel molds using zirconium-alloy which has high corrosion resistance.

Uranium-238 makes up about 95 to 97 per cent of the fuel inside a nuclear reactor. Some of this uranium is converted into plutonium-239 and plutonium-241. At the end of the cycle (usually from one to two years), very little of uranium-235 remains. About 30 per cent of the energy produced by the reactor is than produced from plutonium, which could be used for manufacturing nuclear bombs or reprocessed for electricity generation. Some plutonium residues formed during operation of the reactor, such as plutonium-240, reduce the effectiveness of plutonium as a material for the production of nuclear weapons. The United Kingdom, France, Russia, India and Japan have civilian reprocessing facilities capable of separating plutonium. According to the US Department of Energy's projections for 2030, plutonium in the US spent fuel assemblies will be enough to operate twenty nuclear reactors for forty years. This means another resource for nuclear energy in the US if the option for reprocessing is largely adopted.

Nuclear safeguards aim at the assurance of non-conversion of civilian nuclear programmes into military ones. The International Atomic Energy Agency (IAEA) plays the global international role in this area. The Electric Power Research Institute (EPRI) in the US conducted a computer modeling study on the effects of the Boeing 767 crash over a nuclear power plant, concluding that the containment structures of the nuclear reactor – as well as the storage containers of spent fuel and concrete – would withstand the impact and protect the fuel inside them.

CONCLUSIONS AND RECOMMENDATIONS

In this study, the trilateral relation between global warming, energy security (both production and consumption) and population are examined as a case study of the socio-economic impact of climate change on the energy sector.

Generally, air temperature and atmospheric pressure vary uniformly over time according to second-degree equations. The variation is more uniform in summer than in winter. In addition, there is clear interdependence between temperature and pressure. Thus, temperature and pressure are the dominant weather factors. Moreover, temperature has the most uniform variation since it has the largest value of determination coefficient (R^2 = 90.82 per cent). Subsequently, electrical load can be expressed in terms of air temperature. Hence, the impacts of weather on electricity consumption can be mathematically expressed by a temperature-load relation.

The annual minimum value of daily mean temperature in Egypt during the studied period (winter) did not exceed the normal minimum value of mean temperature (13.6°C), while the annual maximum value of daily mean temperature (summer) exceeded the normal maximum value of mean temperature (28.6 °C). Nevertheless, the occurrence of extreme loads does not often coincide with the occurrence of extreme temperatures. In general, load is proportional to temperature. Therefore, load increases gradually over the years due to warming and population growth. The curve shows that in Egypt, load rises gradually to reach its maximum value in July or August (summer) and falls gradually to reach its minimum value in November or December (winter). In Egypt the average difference between the annual maximum and minimum values of daily peak load is 5822.5 MW, which can be theoretically generated in winter, saved in energy storage devices and distributed via the national electrical grid in summer. The other valid option is to transmit this extra power through a single network to other countries which have different patterns of electrical consumption (peak load in winter due to heating usage, and minimum consumption in summer since ACs are not largely used). That extra power can be returned again to Egypt in summer.

There is an increasing dependency between load and temperature with each passing year. Moreover, the temperature-load trendline is graphically shifted up over years. This fact points out a rising proportionality between temperature and load. Load is almost independent of temperature in winter, while in summer; temperature affects more than 64 per cent of load variation. Population manifestly affects the weather-electricity relation since weekly human activities contribute to shaping the behaviour of electrical consumption. Population growth raises the need for electricity production, transportation and cooling systems, releasing greenhouse gases and aggravating global warming. On the one hand, such activities maximise electricity consumption, revealing the mutual impact between temperature and population reflected on the electrical-load patterns. On the other hand, electricity production contributes to global warming, which increases the use of heat-emitting cooling machines.State regulations can play an important role in managing the socio-economic impacts of climate change on energy sector. For example, suppliers of electrical energy in the UK must accurately predict weather conditions in order to manage their supply contracts. Where they fail to do so, they are exposed to significant imbalance penalties. (Parkpoom et al, Op cit) The impacts of climate change on the electrical grid could also be mitigated, for instance, by an increased penetration of photovoltaic (PV) systems, which reduce the effects of peak demand because this energy source closely matches the diurnal demand for electricity in addition, energy efficiency targets for utilities can provide substantial "cushioning" of the electric power system against the effects of higher temperatures. Other examples of feasible near-term actions include reducing urban heat island effects with the use of more reflective surfaces for roofs and pavement, and planting trees to shade homes and buildings. (Franco and Sanstad, Op cit)

Indeed, one of the solutions to reduce the contribution of electricity industry to greenhouse gas emissions is to increase the reliance on new and renewable sources of energy, such as solar, wind and nuclear energy. However, special technical measures apply to such options. Particularly, nuclear power programmes must include strict measures for nuclear safety and security in order to avoid the nuclear disasters as well as nuclear theft, sabotage and terrorism. In addition, nuclear safeguards must be applied in order to assure the non-conversion of nuclear power programmes into developing nuclear weapons. Those measures can contribute to the securitisation of the climate debate.

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