Climate change impacts on electricity demand

CLIMATE CHANGE IMPACTS ON ELECTRICITY DEMAND

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ABSTRACT

Climate change is expected to lead to changes in ambient temperature, wind speed, humidity, precipitation and cloud cover. As electricity demand is closely influenced by these climatic variables, there is likely to be an impact on demand patterns. The potential impact of future changes in climate on electricity demand can be seen on a daily and seasonal basis through the fluctuation of weather patterns. The magnitude of the impact will depend on the electricity use patterns in the absence of climate change, as well as long-term socio-economic trends. 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. This paper reviews existing studies on climate impacts on electricity demand and outlines how this is being assessed for the rapidly growing Thailand electricity sector.

Keywords: climate change, weather sensitivity, electricity demand

INTRODUCTION

Short-term weather variability and, in the longer term, climate variability has a major impact on the generation, transmission and demand for electricity. Pre-deregulation, utilities generally managed to limit weather and climate impacts through central planning and vertical integration. In the long term, sufficient plant was planned and constructed to meet anticipated peak demand, whilst the costs arising from short-term variability were absorbed and passed on to consumers. With deregulation market participants are becoming exposed to these effects. Hence, there is greater need to manage the impact of weather and climate uncertainty.

Weather is defined as the atmospheric conditions existing over a short period in a particular location. It is often difficult to predict and can vary significantly even over a short period. Climate, on the other hand, is generally viewed as the average weather conditions over a long-term period (say 30 years) for a defined area. It varies from place to place, depending on latitude, distance to the sea, etc. Climate also varies in time: seasonally, annually and on a decadal basis [1].

This paper examines the basis for climate change, the projections for South East Asia and outlines the potential impact of climate change on electricity demand, particularly in Thailand.

GLOBAL CLIMATE CHANGE

The state of the Earth's climate is largely affected by heat stored in the atmosphere and oceans. Processes that affect this heat storage can cause global climate change (GCC). Greenhouse gases (e.g. Carbon Dioxide, CO_2) in the atmosphere tend to trap heat and, whilst changes in levels have occurred naturally over history, it is the extent of man-made greenhouse gas emissions that is causing concern, given the potential to significantly and rapidly alter climate. For the past few hundred years, and particularly from the mid-20th Century, the burning of fossil fuels and deforestation have released increasing quantities of greenhouse gases.

During the last 100 years, global mean temperatures have risen by almost 1ºC with much of the warming in the past few decades. Further rises in man-made greenhouse gas emissions are likely to increase the warming by between 1.4 and 5.8ºC by 2100 [2]. Figure 1 shows the range of historic and projected temperature rises, and clearly demonstrates that the rate of increase has accelerated.

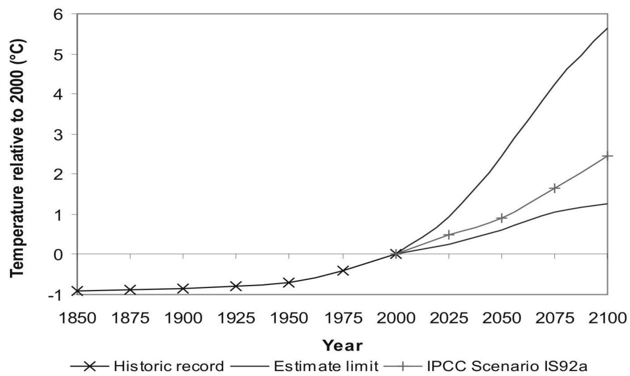

Figure 1 Historic and future temperature rise [3, 4]

Projections of climate change are often based on the output of General Circulation Models (GCMs), complex numerical models that simulate physical processes in the oceans and atmosphere. There is a wide variation in the output from such models, partly due to the range of input assumptions made (Table 1). They project changes in a range of climatic variables that have the potential to make significant impacts on sectors in every region.

Date	Population (billions)	GDP (10^{12}US$)	CO_2 Level (ppm)	Temp Change (ºC)
1990	5.3	21	354	0
2000	6.1-6.2	25-28	367	0.2
2050	8.4-11.3	59-187	463-623	0.8-2.6
2100	7.0-15.1	197-550	478-1099	1.4-5.8

Table 1: Scenarios and resulting CO_2 and climate [2]

CLIMATE CHANGE IN SOUTH EAST ASIA

GCM simulations project that the climate in Asia as a whole will undergo an annual mean warming of 3ºC by the 2050s and 5ºC by the 2080s. Accompanying this, an annual mean precipitation increase of 7% and 11% will be seen by the 2050s and 2080s, respectively [5].

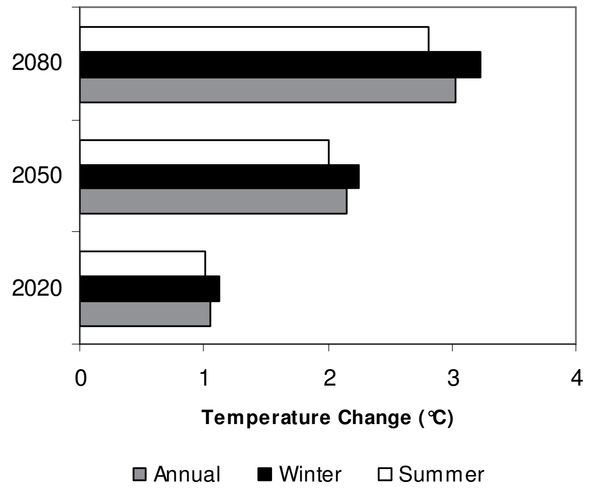

Figure 2 Temperature changes in tropical SE Asia [5]

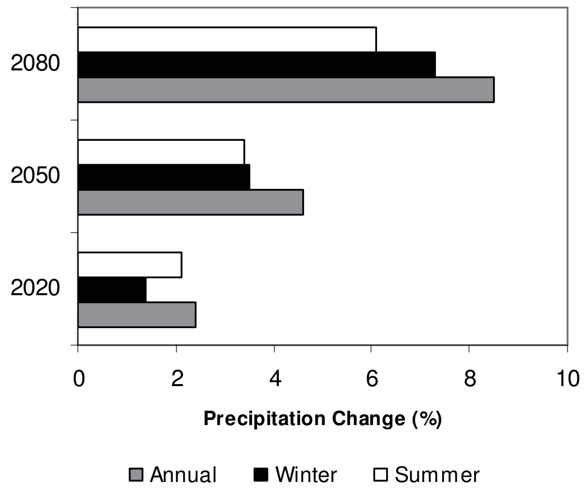

Figure 3 Precipitation change in Tropical SE Asia [5]

The projections for tropical South East (SE) Asia are less severe but are still significant, with, for example, mean annual temperature and precipitation rising by some 3% and 8.5%, respectively, by the 2080s [5]. However, these figures mask anticipated seasonal changes. Figure 2 shows the anticipated trend in annual and seasonal temperatures over this century; the greater increase in winter temperatures is clear, and the corresponding patterns for precipitation (Figure 3) indicate stronger changes in winter precipitation.

Changes of such magnitude are likely to have significant impacts in South East Asia, given the high population density and low standard of living. It is anticipated that there will be a rising demand for forestry, agriculture and livestock products and it is likely that there will also be an increased risk of fire, typhoons/tropical storms, floods and landslides. In addition to these broad risks, there will be impacts within the electricity industry.

IMPACTS ON ELECTRICITY DEMAND

The potential impact of future changes in climate on electricity demand can be seen on a daily basis through the fluctuation of demand with weather conditions. In liberalised systems such as the UK, suppliers must accurately predict weather conditions in order to manage their supply contacts. Where they fail to do so, they are exposed to significant imbalance penalties. As such, it is an area that is receiving much research attention (e.g. [6]) and has spawned interest in financial market-derived techniques such as weather derivatives. As electricity demand globally is expected to grow by at least 5% by 2015 [7] and, as climate change becomes more prevalent, it will be essential for those charged with managing demand to take account of future changes.

Electricity demand is influenced not only by temperature but also wind speed, humidity, precipitation, evaporation, evapo-transpiration and cloud cover. These influence air-conditioning, space heating, refrigeration and water pumping loads, which add to the peak and 24-hour demand. The peak loading is particularly important, since on occasions of extreme temperatures this is likely to stress electricity systems in meeting demand. This was the case in France in 2003, where extremely hot temperatures gave rise to a significant increase in air-conditioning, which when coupled with restrictions on output from nuclear stations brought about by cooling limitations, threatened blackouts.

The impact on other uses of electricity can be significant: water-pumping requirements will increase where the climate change becomes warmer but not wetter, due to higher water demand from irrigation, residential, commercial and municipal sectors. Refrigeration requirements would increase and water-heating requirements would decrease, although the direct effects are likely to be significantly less than the effects on space conditioning. Refrigeration and water-heating equipment is often located in conditioned spaces and thus is not affected by outdoor temperature changes.

Additionally, refrigeration equipment evaporator coil temperatures are lower than those of air conditioning equipment, and since water heaters operate significantly hotter than room temperatures, the proportionate impact will be lower.

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

Clearly the degree to which electricity demand in a given country might be sensitive to changes in climate will depend very much on its climate type and its level of economic development. In high latitude countries like the UK, a warmer climate will tend to reduce space heating demand. In lower latitudes, cooling loads will increase with, for example, South East Asian electricity demand expected to increase by 5 to 10% [5] as a result. In saying that air-conditioning use in the UK commercial sector has seen 5% growth in the last five years and expects to see a further 6% rise by 2010 [8].

The most significant study to date focussed on changes in demand and consequent impacts on generation needs in the United States [9] as exemplified by Utilities in New York State (NY) and the Southeast (SE) of the country. The study identified changes in both peak and overall electricity demand. With the relatively low temperature rise expected by 2015 (0.8 to 1°C) overall electricity demand would rise by 0.45% for New York and by 3.4% for the SE. Peak demand would rise by 3.3% and 7% for NY and SE, respectively. The larger increases experienced by the SE Utility are due partly to higher expected temperatures but mostly due to a relatively greater sensitivity to temperature changes given the more extensive reliance on air-conditioning. These were estimated at 4%/°C for NY and 6.8%/°C for the SE. The knock-on effect on generation as a result of the temperature rise was significant with up to 1430 MW more capacity required in NY and 1420 MW in the SE than required by 'normal' load growth.

The research outlined in this paper is concerned with the impacts in Thailand.

ESTIMATING IMPACTS IN THAILAND

EGAT, the Thailand electricity utility, serves a relatively high growth area of the Sun Belt. Table 2 indicates that the large majority of its sales go to agricultural, residential and commercial customers. Among these customers, many are increasing their standard of living; this, and their subsequent use of air conditioning, is an important use of electricity. Air conditioning systems are heavily utilised in the summer, but there are also periods of air condition use in the other seasons. As such, a substantial portion of Thai consumer demand consists of weather-sensitive load. Climate changes which increase average temperatures are likely to increase the high air conditioning loads.

Agriculture	6
Residential / Commercial	21
Industry	36
Transport	37
Total	100%

Table 2 2003 Thai sales by customer type [10]

In analysing the effect of changes in climate this study is focussing on two aspects of demand:

- daily electricity demand profiles
- long-term peak demand.

Daily Load Profiles

The effect of changing climate may be indicated to some extent by considering the effect of changes in temperature and other variables on daily demand profiles. The simplest approach is to perform a two variable regression between hourly demand levels and temperature:

$$D_t = b_1 + b_2 T_t \qquad (1)$$

where D_t is electrical demand in hour t, T_t is temperature, b_1 is the intercept term and b_2 the regression coefficient. This is illustrated using the peak demand and temperature data for Thailand over one month: the scatter plots and trend lines are shown in Figure 4. While these clearly indicate a relationship between peak demand and temperature, the relatively low coefficient of determination (R^2 = 0.2) requires a more sophisticated approach.

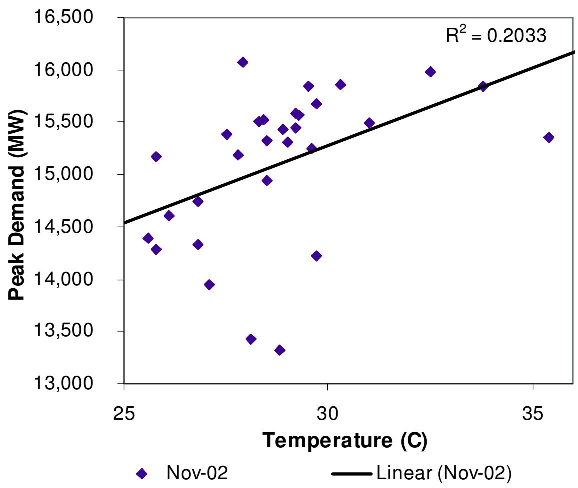

Figure 4 Regression between temperature and demand

Multiple linear regression (MLR) is one such technique and is the most commonly used short-term forecasting method. This is due to its flexibility, as it can be used as a stand-alone method for load forecasting, or to define the transfer function in a time-series load forecasting model. At its most basic, the analysis will use forecast temperatures as well as dummy variables to factor in the time of day and day of the week. It is also common to use the previous day's mean temperature to account for thermal lag, as well as the electrical demand in the previous hour (shown schematically in Figure 5).

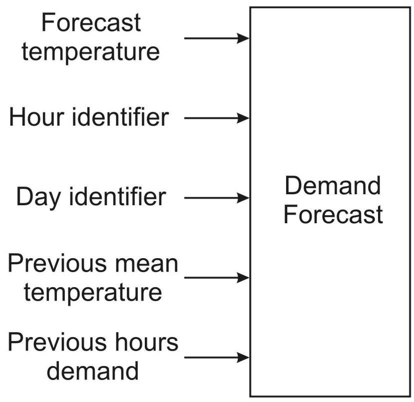

Figure 5 Schematic forecast model

The three variable MLR model is given as:

$$D_t = b_1 + b_2 D + b_3 H + b_4 T_t + u_t \quad (2)$$

where D and H are the dummy variables assigned to the day of the week and hour of the day, respectively and u_t is a random error term. b_2 to b_4 are the regression coefficients corresponding to the explanatory variables. Five consecutive weekdays in April 2004 were modelled, yielding:

$$D_t = 2373 + 251D + 113H + 351T_t \quad (3)$$

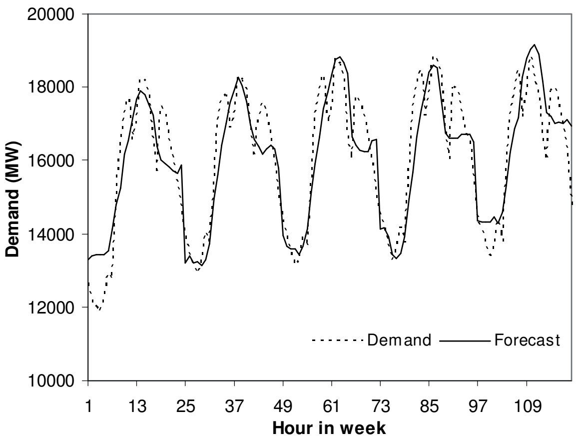

Figure 6 Actual and forecast demand over five days

Figure 6 shows the demand as forecast using Equation (3) with the actual values. As can be seen there is some success in matching the values (R^2 = 0.8). This can be used to examine temperature sensitivity.

To illustrate the sensitivity of demand to temperature changes, the demand model in Equation (3) was driven by uniformly raised temperatures in steps of 1°C up to 4°C. Figure 7 show the effect. It can be seen that there are significant shifts in demand over the day. The 4°C rise increases demand by 1400 MW – equivalent to 2.6%/°C at system peak demand. With this simple linear model, each hourly demand is raised by an equal MW amount and clearly does not indicate the relative sensitivity of different periods of the day (e.g. air-conditioning use at night versus early afternoon).

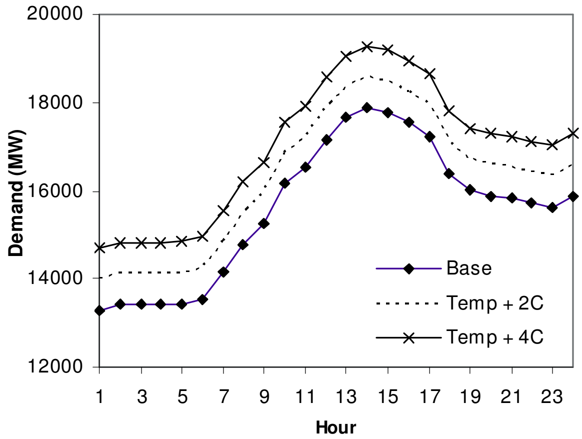

Figure 7 Demand with uniform temperature rise

A more sophisticated approach will be necessary to fully identify the changes in daily load profiles that will result from rising temperatures. Furthermore, it is anticipated that improved demand models will be gained using additional weather variables that are known to influence demand (e.g. lower agricultural water pumping requirements during the Monsoon) as well as increased use of prior demand and temperature measures.

Long Term Demand Growth

An adequate and regulated power supply may be one of the most crucial factors which supports economic growth in developing countries. Studies have found that in Thailand [11] and other developing nations there is a good correlation between growth in Gross Domestic Product (GDP) and electricity demand. For example, Figure 8 shows Thai GDP and demand growth over the period from 1994 and as forecast until the end of 2004 which have been found to have a correlation coefficient of 0.77.

Forecasts of future electricity demand growth clearly have to take account of future economic activity which is determined by population growth, among other things. Forecasts of demand growth in Thailand suggest around 6% per year between 2001 and 2010, and 5.7% per year up to 2020 [10].

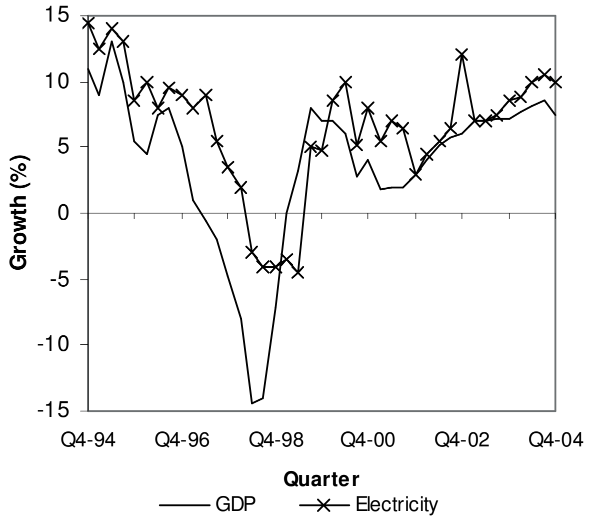

Figure 8 Thai GDP and demand growth rates

Such forecasts implicitly assume a stationary climate in that temperature in one year will be broadly similar to the next. As such, they do not account for the potential rises in demand that climate change may bring, which as was shown earlier, may be substantial.

Future Work

The research outlined above indicates the general requirements of the climate change impact programme. Further work will include:

- analysis of weather-sensitivity of electricity demand, and
- estimates of long-term peak demand that explicitly account for climate change.

These will be carried out using statistical approaches such as MLR as well as structural ones that consider the response of individual customer-groups.

CONCLUSION

Climate change is expected to lead to changes in a range of climatic variables and as electricity demand is closely influenced by these, there is likely to be an impact on demand patterns. The potential impact of future changes in climate on electricity demand can be seen on a daily and seasonal basis through the fluctuation of weather patterns. The magnitude of the impact will depend on the electricity use patterns in the absence of climate change, as well as long-term socio-economic trends. 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. This paper has reviewed existing research on climate change impacts on electricity demand and has outlined how this is being assessed for Thailand where the rapidly growing economy adds an additional level of complexity.

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REFERENCES

[1] University of Texas, http://www.geo.utexas.edu/courses/302c/W_and_C.htm.
[2] McCarthy, J.J.; Canziani, O.F.; Leary, N.A.; Dokken D.J.; White K.S. (Eds.), Climate Change 2001 Impacts, Adaptation and Vulnerability, Cambridge University Press, 2001.
[3] Houghton, J.T.; Jenkins, G.J.; Ephraums, J.J. (Eds.), Climate Change The IPCC Scientific Assessment, Cambridge University Press, 1990.
[4] Houghton, J.T.; Ding, Y.; Griggs, D.J.; Nogeur, M.; van der Linden, P.J.; Dai, X.; Maskell K.; Johnson C.A. (Eds.), Climate Change 2001 the Scientific Basis, Cambridge University Press, 2001.
[5] Lal, M.; Harasawa H.; Murdiyarso, D. Asia. In: Climate Change 2001 Impacts, Adaptation and Vulnerability. McCarthy, J.J.; Canziani, O.F.; Leary, N.A.; Dokken D.J.; and White K.S. (Eds.), Cambridge University Press, Chap. 11, 2001.
[6] Lo, K.L.; Yu, Y.K., Risk assessment due to local demand forecast uncertainty in the competitive supply industry. IEE Proc Generation, Transmission & Distribution, 150, 5, pp. 573-582, 2003.
[7] Intergovernmental Panel on Climate Change, Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change, Cambridge University Press, 1995.
[8] Wood, J., The effect of one degree. IEE Power Engineer, 17, 3, pp. 6-8, 2003.
[9] Linder, K. P., Gibbs, M. J.; Inglis, M. R., Potential Impacts of Climate Change on Electric Utilities, NYSERDA Report 88-2, December 1987.
[10] EGAT, EGAT Power Development Plan, PDP 99-02, Bankgok, 2000.
[11] Ministry of Finance, Thailand's Economic Outlook 2003-2004, Bangkok, Thailand.

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