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Using Weather Sensitivity to Forecast Thailand's Electricity Demand

S. Parkpoom* and G.P. Harrison*[1]

Abstract – *As part of a study into the potential impact of climate change on Thailand's electricity demand it has been necessary to find an efficient and effective way of linking climate to demand levels. The paper sets out a multiple linear regression approach to modelling the influence of temperature on demand by representing demand as hourly time-slices for each month across the year. The application of the models in determining the impact of uniform rises in temperature are presented along with a preliminary exploration of what such sensitivity could mean in terms of Thailand's future demand levels.*

Keywords – Electricity demand, Thailand, weather sensitivity.

1. INTRODUCTION

The growth in electricity demand in Thailand and other Asian economies is being driven primarily by increases in Gross Domestic Production (GDP) and population. It has been estimated that the high demand growth will continue into the medium term at least with annual increases of 5% to 8% up to 2016 [1]. It is anticipated that this and longer-term growth will be affected by the changes in weather patterns brought about by climate change which project temperature rises of between 1.4 and 5.6°C by 2100 [2].

Thailand's electricity demand is very much influenced by the seasons (winter, summer and monsoon). This seasonality can be seen in Figure 1 which shows the mean daily demand profiles for each of the months in 2004 with summer demand exceeding that of winter by approximately 4500 MW [3]. The differences are, to a significant degree, related to temperature with the hotter temperatures in necessitating additional air-conditioning of offices and domestic properties. Prevailing precipitation, humidity, wind-speed and cloud cover also play a role in determining demand.

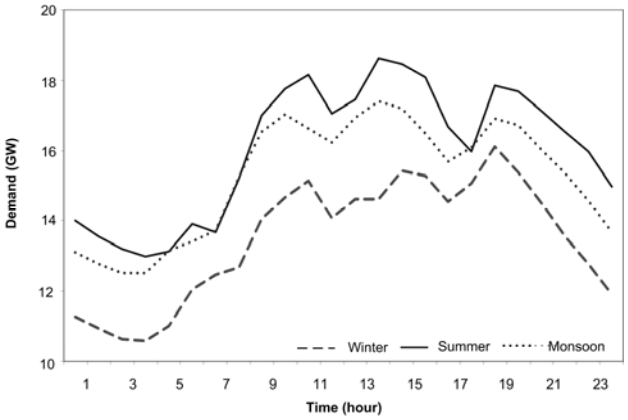

Fig. 1. Daily demand profiles in Thailand for 2004 [4].

The work presented here forms part of an investigation into the potential for climate change to influence electricity demand in Thailand. As reported previously [5]-[6], the work is aiming to model the changes in daily and monthly demand profiles over the long term horizon during which the climate is expected to change. The purpose of this paper is to highlight the development of a series of models that allow weather-dependant demand to be projected. The paper is organised as follows: the next section looks at weather-sensitive modelling of demand and Section 3 sets out an example of their application in the ongoing research project.

2. MODELLING WEATHER SENSITIVITY

The broader research required a means of translating future projections of climate into demand. The requirement was for a model or models that allowed anticipated changes in mean, maximum and minimum temperature (and potentially other climate variables) to be used to indicate future changes in daily and seasonal load profiles with particular interest in peak demand levels.

One option was to construct detailed bottom-up demand models of each sector (domestic, commercial, industrial etc.) from demographic information as well as load characteristics like building construction, air-conditioning take-up and so on. Such an approach would potentially allow accurate weather-dependent demand projections to be made. The downside to this is the range of economic and other data required as well as the need for disaggregated weather and electricity demand information. This information is perhaps more readily available in an industrialized economy.

Given this as well as the fact that this study is of a preliminary nature a simpler approach was adopted that formulated regression models linking demand with temperature on a time-of-day and monthly basis. This approach is broadly similar to that reported in [7]. In making projections with such a model there is an implicit assumption that the relationships hold over time. However, the benefits of the simpler weather sensitivity model appear to offset this risk.

The data kindly made available by the Electricity Generating Authority of Thailand (EGAT) consisted of hourly demand for the whole of Thailand over the period 1996-2004. In addition, hourly weather information for the same period was sourced from a weather station in the Bangkok metropolitan area. As over 70% of Thailand's

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*Institute for Energy Systems, School of Engineering and Electronics, University of Edinburgh, Mayfield Road, Edinburgh EH9 3JL, United Kingdom.

[1] Corresponding author;
E-mail: Gareth.Harrison@ed.ac.uk.

electricity is consumed in the Bangkok area this obvious simplification of the weather situation is believed to be a reasonable approximation. With heating demand representing only 3% of Thailand's consumption and being uncommon in the Bangkok area, only cooling effects were considered.

The weather sensitivity models are constructed by using linear regressions to encode the patterns in the daily electricity consumption over each month. A wide range of combinations of variables and temporal detail were tested. These included single linear regression models using, e.g., temperature alone, as well as multiple linear regressions combining variously temperature, precipitation, humidity etc. In each case the time step was also tested across a range of intervals from one up to three hours. The models that appeared to offer the most consistent and high quality regressions were based on cooling degree hours (CDH, derived from temperature) and hourly demand. To allow exploration of the impact of temperature on the daily load profile, one regression was performed for each hourly time-slice (e.g. 5 to 6pm) in each month, each of the form:

$$D = \beta_1 + \beta_{CDH}(CDH) + \varepsilon \qquad (1)$$

where D is the hourly electricity demand, β_1 is the intercept of the regression line on the demand axis, β_{CDH} is the slope of the regression line giving the sensitivity of demand to cooling degree hours (in MW/CDH) and ε is the random error.

The use of cooling degree hours (or degree days) is relatively common in demand modelling (e.g., [8], [9]) as it attempts to account for human comfort by defining a threshold temperature above which air-conditioning is required and below which it is not. Temperature changes that serve to raise the temperature beyond the threshold will have the greatest impact on electricity demand. Cooling degree hours are given by:

$$CDH(T_h) = \begin{cases} \sum_{h=1}^{N} (T_h - T_b) & \text{for } T \geq T_b \\ 0 & \text{otherwise} \end{cases} \qquad (2)$$

where N is the number of hours in the period of interest, T is the air temperature and T_b is the threshold temperature. In Thailand the threshold temperature is taken to be 24°C.

The results of using Equation 1 for the three months that are broadly representative of the Thai seasons are shown in Figures 2 to 4 for January (winter), March (summer) and July (Monsoon), respectively. The actual and estimated demand over the average day in each month is presented along with a further trace depicting the sensitivity coefficient (β_{CDH}) which represents the relative sensitivity of each hour to changes in CDH acting as a proxy for temperature. The models indicate a reasonable fit with actual demand with mean absolute percentage errors of 0.62-3.26% for January, 0.77-4.10% for March and 0.27-1.42% for July. These are backed up by reasonable coefficients of determination (R^2): for summer these range between 0.61 and 0.95 and 0.30 to 0.90 for winter. A low R^2 does not necessarily imply a poor model; rather the winter months have many periods when temperature is below the CDH threshold and as such, the demand variation is less well explained by CDH.

In each case, the pattern of demand broadly reflects the temperature profile with demand starting to rise around 8am achieving a peak around 2pm before falling back until the evening load pickup. The relative sensitivity of demand to temperature level is consistent with the higher temperatures during the working day requiring cooling of workplaces and with an additional increase in sensitivity during the evening as people return home and require cooling to reduce the heat accumulated during the day.

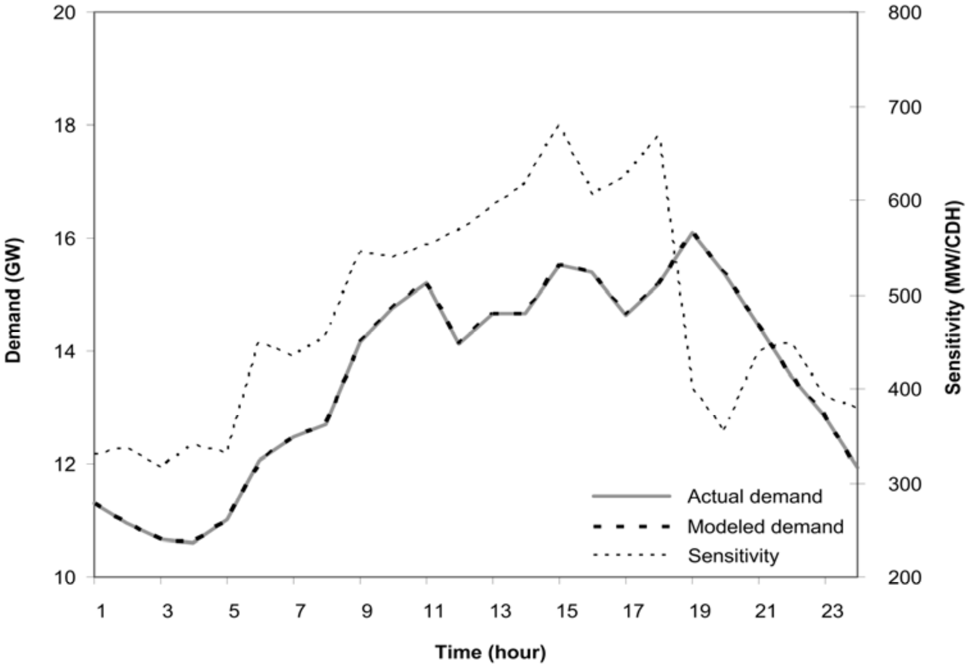

Fig. 2. Actual and estimated demand and demand sensitivity in January 2004.

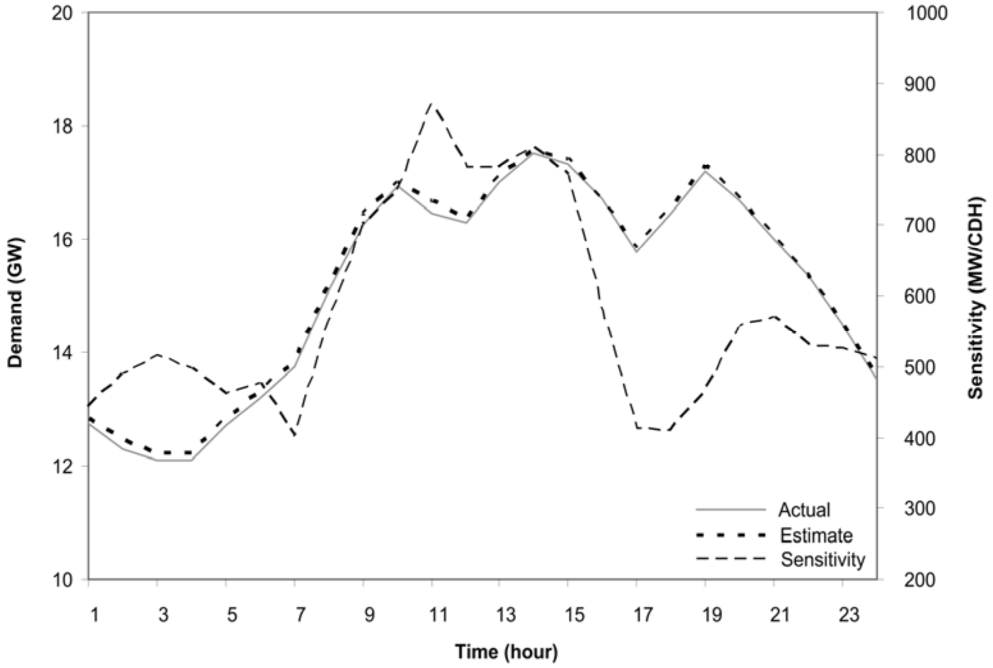

Fig. 3. Actual and estimated demand and demand sensitivity in March 2004.

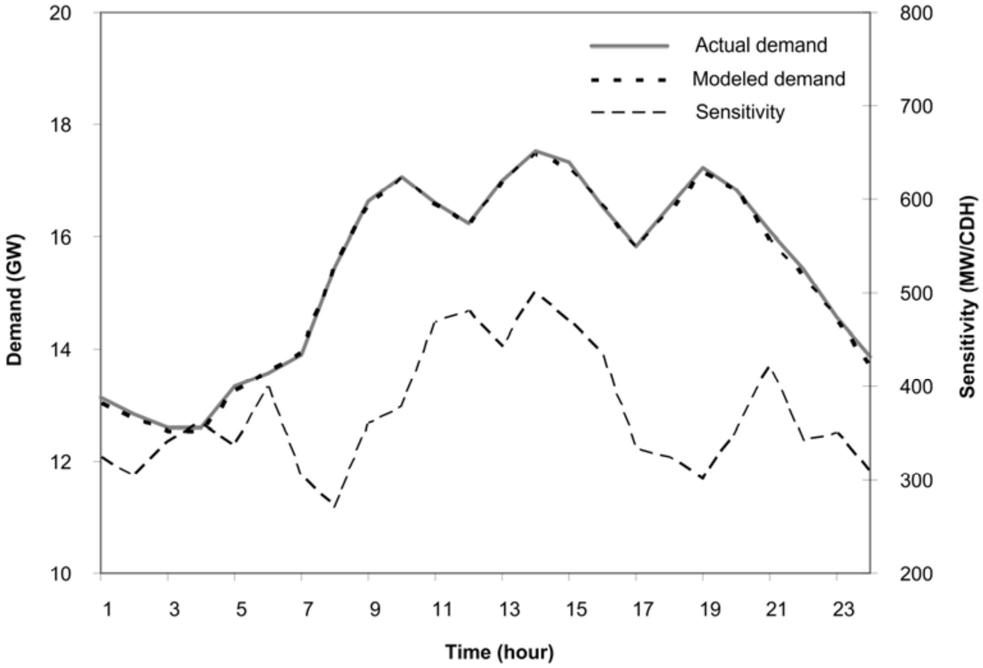

Fig. 4. Actual and estimated demand and demand sensitivity in July 2004.

What is apparent is that the peak sensitivity tends to coincide with afternoon peak demand. This implies that temperature rises from climate change will have a proportionally greater impact on peak demand levels. Also apparent is that there is a relatively greater sensitivity during the summer months (Figure 3) than in the others; this is evidenced by the higher sensitivity coefficients.

3. DEMAND SENSITIVITY

This section briefly examines the response of outlines of the weather-sensitive demand models to the hypothetical cases of uniform warming of 1 or 2°C across the year. Clearly this is rather simplified as (1) temperature rise will vary throughout the year and (2) the diurnal temperature range will also alter suggesting non-uniform changes on a daily basis. However, it is adequate for illustrating relative sensitivity.

Figure 5 indicates the impact of raising temperatures by 1 and 2°C in each of the months presented. It can be seen that in all cases the demand level does rise as temperature increases. The impact on peak and mean demand levels for all three cases is summarised in Table 1. March (summer) has the highest sensitivity coefficients and correspondingly sees the largest increase in demand as temperature rises. The range of increases across the hourly time-slices ranges from 2.5% to the peak value of 4.6%. Given the greater sensitivity, the increases at peak hours are greater than the mean change in demand. For example, a temperature rise of 1°C raises peak and mean demand by 4.6% and 3.8%, respectively. In 2004 terms these represent increases of 810 MW and 577 MW. The increases associated with peak hours for July (monsoon) and November (winter) are smaller at around 595 MW and 442 MW.

The demand increases with the 2°C temperature rise are approximately double that for 1°C. It should be noted, however, that although the relationship between demand and CDH is linear it does not automatically follow that the demand increase seen with a 2°C rise is twice that of the 1°C case. This is because the threshold associated with the CDH calculation introduces a non-linearity. For example, an hour where the historic temperature is below 22°C would only add to the CDH count and therefore raise demand when a 2°C rise occurred, as with the 1°C rise the temperature would remain below the 24°C threshold. When this happens demand is increased by a proportionately greater amount.

Table 1. Change in peak and mean demand with uniform rise in temperature.

Demand / Temperature Change	January	March	July
Peak +1°C	4.2%	4.6%	2.8%
Mean+1°C	3.5%	3.8%	2.4%
Peak +2°C	8.4%	9.3%	5.7%
Mean+2°C	6.9%	7.6%	4.8%

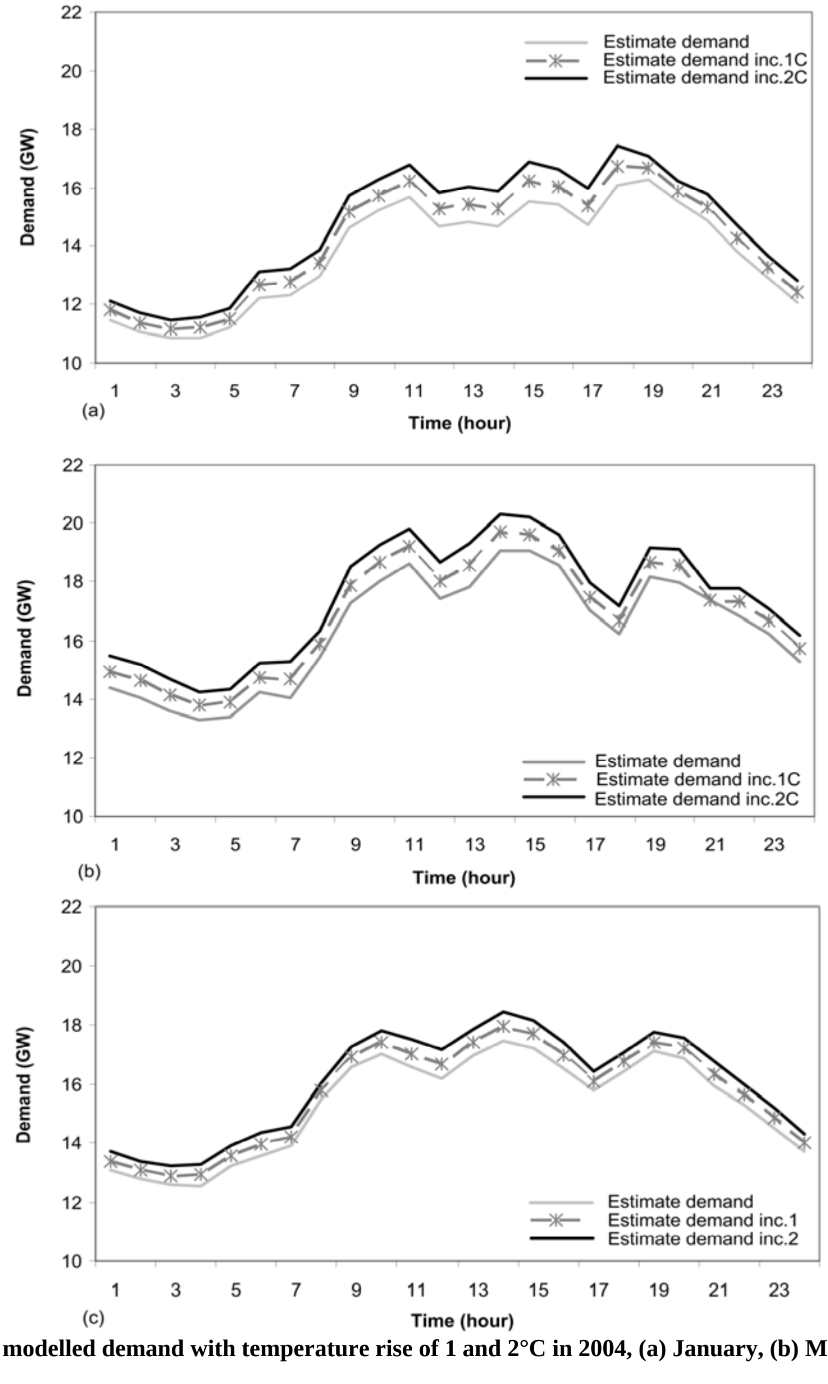

Fig. 5. Change in modelled demand with temperature rise of 1 and 2°C in 2004, (a) January, (b) March and (c) July.

4. LONG-TERM DEMAND CHANGES

A key part of the larger research programme is to provide robust assessments of climate-induced changes in demand for the years up to and beyond the 2050s. While the sensitivity model demonstrated in the preceding section can provide relative differences in demand from estimates of temperature change, absolute, i.e., MW, projections of future changes in demand additionally requires realistic estimates of baseline demand.

Long term electricity demand growth is correlated with growth in GDP and population. The most common means of projecting future demand has been with multiple linear regression models [10], [11]. The Thai Energy Policy and Planning Office (EPPO) use such an approach to forecast peak power levels and consumption. Its 2004 forecast to 2016 uses three scenarios of future GDP and population growth supplied by the Thailand Development Research Institute (TDRI): target economic growth (TEG), which is a high level of growth, Moderate Economic Growth (MEG) and Low Economic Growth (LEG), which are progressively lower [12]. All show a slight reduction in growth rates over the period but there is a big range of average economic growth rates: 4.1% for the LEG, 6.5% for the MEG and 7.6% for the TEG.

The EPPO forecasts for peak energy demand under these three GDP and population growth scenarios are shown in Figure 6. The energy demand growth rates run ahead of GDP, with simple average growth between of 4.9% and 8.6% across the scenarios. The compounding effect results in very large increases in demand over the period: peak demand is indicated to rise by up to 190% to 52,720 MW under the high growth TEG scenario. This provides a useful basis for preliminary assessment using more realistic scenarios of temperature rise.

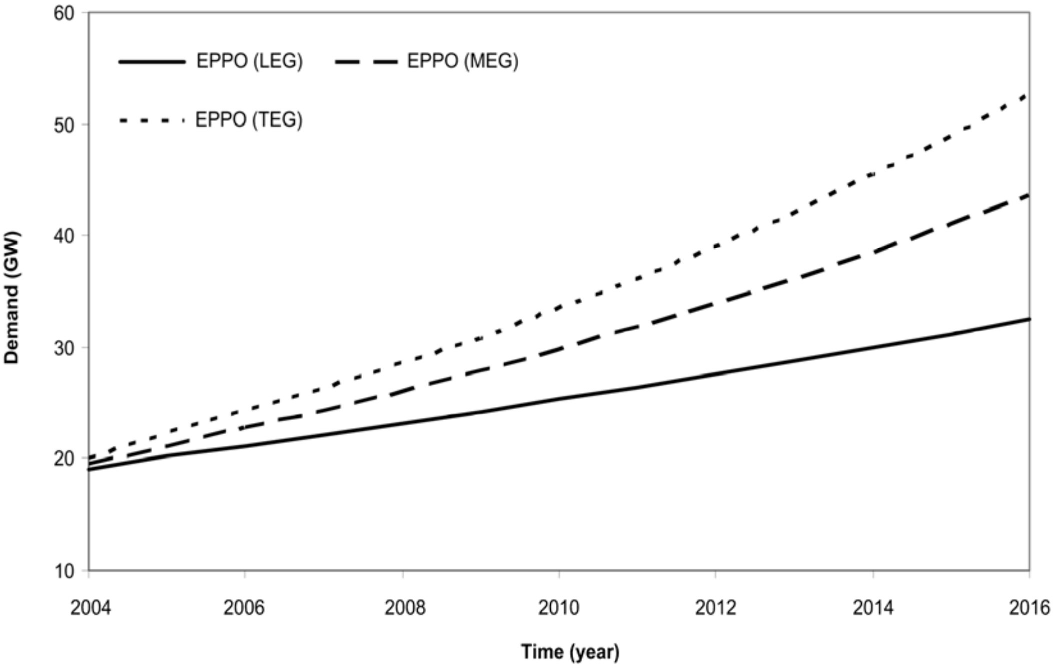

Fig. 6. Projected peak demand for the three EPPO scenarios.

The Intergovernmental Panel on Climate Change issued a Special Report on Emission Scenarios (SRES) in 2000 [2]. It defines a range of emissions and the consequent temperature rises. The emissions scenarios (referred to as A1, A2, B1 and B2) are based on assumptions regarding economic, environmental and regional drivers over the next century. The temperature projections are based on simulations from General Circulation Models (GCMs) which are complex numerical models of the atmosphere and oceans. In the SRES, a series of GCMs including that from the Hadley Centre [13], were driven by each of the emissions scenarios. In this way varying rates of economic and population growth and technological change can be effectively translated into temperature and other climate impacts. The temperature changes are defined as 30 year average changes for the 2020s (covering the years 2011-2040), the 2050s and the 2080s. Adding these changes to historic temperature profiles allows them to be used in impact assessments such as this.

A feature of the SRES scenarios is that the uncertainty surrounding future temperature change grows the further into the future. The projections for the 2020s, however, show relatively minor differences between scenarios. At this preliminary stage, a single temperature scenario can be used to give an initial indication of the impact on electricity demand. Here, the output from simulations of the UK Hadley Centre GCM [13] under the A1 emissions scenario (which assumes high rates of GDP growth and consequent high emissions) has been used for this purpose. Monthly temperature changes for the model cells covering Thailand were extracted: the annual average temperature change was found to be 0.62°C with seasonal changes spread around this. The monthly changes were applied to the demand sensitivity model and the relative changes in demand noted. Peak demand increased by 3.0% in March, 1.6% in July and 1.8% in January.

The EPPO demand projections can be used to translate these relative changes into estimates of absolute changes in peak demand. This is achieved by determining the product of the relative change in summer demand implied by the temperature change and the MW peak demand level suggested by the EPPO projections. As the temperature scenarios are a thirty year average the resulting demand value cannot be taken as a forecast for a specific year. However, it can be used to illustrate the scale of the changes. The absolute changes in summer peak demand are given in Table 2 for each of the three TDRI scenarios. It can be seen that the changes range from 1.0 to 1.5 GW which represent an additional climate-induced increase in demand equivalent to the output of 1 to 2 combined cycle gas turbine plants.

Table 2. Increase in 2016 demand with Hadley Centre GCM temperature scenario.

	TEG	MEG	LEG
Increase in peak demand (GW)	1.5	1.3	1.0

The research is believed to be one of the first to examine climate change impacts in a developing nation (Thailand). The paper presents a basic outline of a potentially useful approach to estimating the impact of climate change on electricity demand in Thailand. Work is continuing in order to fully develop the framework for projecting changes in demand that are consistent with the emissions associated with different scenarios of economic development.

5. CONCLUSION

As part of a study into the potential impact of climate change on Thailand's electricity demand it has been necessary to find an efficient and effective way of linking climate to demand levels whilst minimising data requirements. The paper sets out a linear regression approach to modelling the influence of temperature on demand by representing demand as hourly time-slices for each month across the year. The models capture existing relationships well with reasonably low percentage errors typically in the range of 1 to 2%. The models were applied to examine the sensitivity of demand to uniform changes in temperature as well as more realistic climate model temperature projections. A scenario of an around 0.6°C mean annual temperature rise by the 2020s suggested that peak summer demand would increase by an additional 3% above baseline projections.

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