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Analysing Climate Impact on Energy Demand Using the MOLAND Model

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Abstract

The importance and contribution of climate to energy demand are discussed. A linear regression model is developed to analyse future energy demand corresponding to climate change. The methodology for spatial analysis and integration to MOLAND are also provided in order to investigate possible consequences of different urban development paths on energy consumption patterns.

Keywords: *Climate change, Energy demand, spatial analysis, MOLAND.*

1 Introduction

In Ireland, temperatures increased by 0.7 °C during the period 1890–2004, at a rate of 0.06 °C per decade (McElwain and Sweeney, 2006) and are likely to continue increasing by 0.25 °C per decade over the coming century (Fealy and Sweeney, 2007). Rising temperature will change the energy consumption patterns of our cities. As shown in a national assessment of Israel, Segal and Shafir (1992) estimated an increase in temperature of 4 °C is associated with a 10% increase in average summer peak loads. In Greece a 1 °C temperature increase is projected to decrease energy consumption for heating by 10% and increase energy used for cooling by 28.4%, assuming a business-as-usual scenario (Cartailiss and Synodinou, 2001). Valor et al. (2001) analyse the relationship between electricity load and daily temperature in Spain, using a population-weighted temperature index. The electricity demand shows a significant trend due to socio-economic and demographic factors, in addition to daily and monthly seasonal effects that have been taken into account to isolate the weather influence on electricity load. From those previous research studies, we find energy demand may be directly and immediately affected by climatic variation, especially the variation of temperature. Consumption for space heating and cooling is strongly related to the climatic variation, and can be quantified reliably to provide an assessment of energy consumption (Warren and Leduc, 1981). Furthermore, improving the efficiency of energy offers the largest and cheapest potential for limiting emissions and other problems associated with energy systems. As for the residential sector, heating requirements can be reduced by better controls, vacuum and other insulating panels, and advanced window technologies, whilst heat can be supplied more efficiently by using condensing boilers and heat pumps (Grubb et al., 1991).

The Greater Dublin region, which accounts for almost half of the Republic of Ireland's population and employment includes Dublin City, Dún Laoghaire-Rathdown, Fingal, South Dublin and the surrounding counties of Louth, Meath, Kildare and Wicklow, is chosen as the study area to analyse the relationship between energy consumption and climate variables with approximately 50 years of daily temperature data (1960–2006) and 16-year daily energy consumption data (1989–2006). The future energy consumption responses to climate change are projected using a regression model derived for the Greater Dublin region. Energy consumption has also been categorised by housing mix and will be integrated into the MOLAND model to spatially analyse the effect of climate change on energy demand for different development patterns in the study region.

2 Background and analysis

A series of national daily electricity peak demand data, spanning the period from January 1994

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through December 2005 has been used in the study. The data comprise electricity consumption in all economic sectors (industrial, residential and commercial) for Ireland. Unfortunately, regional or sectorially disaggregated data are not currently available. The electricity consumption data was obtained from Ireland's National Grid.

Natural gas is one of the primary heating fuels in Ireland. Daily natural gas sales to residential and non-residential users for the Dublin area, from December 1989 to December 2006 were obtained from Bord Gáis Éireann (the national gas board).

One factor which affects energy demand for space heating and cooling is local climate (Lehamn and Warren, 1994; Valor et al., 2001; Warren and Leduc, 1981; Yan, 1998). The energy demand for space heating and cooling is sensitive to climate variables, e.g. air temperature radiation and wind seep and so on. Of particular importance for thermal comfort in the built environment are heating degree day and cooling degree day both accumulated from base temperature (Douglas et al., 1981). The Irish climate data consist of daily maximum and minimum temperatures from Irish National Meteorological Service. Daily heating degree-days (HDD) and cooling degree-days (CDD) were derived for the base temperature 15.5 °C to coincide with the time-step for which the energy data is reported. Figure 1 displays the 1961–2004 average and projected increases of 0.4 °C and 3.1 °C respectively, for 2030 and 2080.

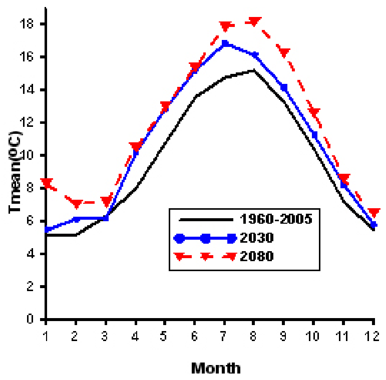

Figure 1 – Projected Increases in Mean Monthly Temperatures for Dublin.

Aside from the local climate, realising the potential reductions in energy consumption available within the domestic building sector requires an understanding of the profile of the housing stock (Considine, 2000; Bojić et al., 2007; Gaterell and McEvoy, 2005). The current profile of the house stock in terms of age, dwelling type and floor area need to be considered as they are related to the thermal properties of buildings which affects the building energy demand for space heating and cooling. Building with different thermal insulation levels and solar or internal gains will have different base temperature, which need to be factored into the degree-day method for the determination of energy demand.

The regression model used includes the effect of the HDD, CDD and GNP (Gross national product) values as well as one climate-related variable namely radiation. The predicted daily electricity demand per capita E_{elec} and daily gas sales per capita E_{gas} can be formulated as follows:

$$(E_{gas})^{\frac{1}{2}} = \alpha_0+\alpha_1 DD+\alpha_2 GNP+\alpha_3 Ra+\alpha_4 H \quad (1)$$

$$(E_{elec})^{\frac{1}{2}} = \alpha'_0+\alpha'_1 DD+\alpha'_2 GNP+\alpha'_3 Ra+\alpha'_4 H \quad (2)$$

where α_n are constants and Ra is radiation. The variable H takes on a value of 1 if the day is a holiday and a value of 0 if the day is a working day. If the value of degree days (DD) is positive (HDD), then the energy is required for heating purposes; where the value of DD is negative (CDD), the energy is needed for cooling.

The electricity and natural gas demand for the future is assessed using the regression results with climate scenarios. When social-economic parameters are controlled, climate shows a significant impact on energy demand and may decrease energy consumption in winter time.

3 Methodology for spatial analysis of energy demand

In order to integrate the energy consumption model into GIS and the MOLAND model, the relationship between energy demand and housing stock is developed. Firstly households are categorised by housing age, type and floor area. Then heating energy demand for every class of household is calculated and spatially analysed at District Electoral Division (DED) level. Housing census data are from Central Statistics Office. Dwellings have been categorised into 10 classes by dwellings age, type and floor area for the Greater Dublin Region.

The calculations of heating energy consumption are based on the method as found in Appendix C of the building regulation Conservation of Fuel and Energy – Dwellings (DOE, 2002). The heating of a building is essentially an energy balance. To maintain the internal space at a constant temperature the heat inputs into the building must balance heat losses.

Heat inputs include:

1. Input from the heating system
2. Solar gains
3. Input from occupancy including the use of energy

Losses include:

1. Heat loss through the fabric, including loss at thermal bridge
2. Ventilation losses

As this is an energy balance then all the losses and gains must equate to zero.

$$\sum Q = 0 \tag{3}$$

So, by working out all of the other loads and gains associated with the building, the heating load can be specified. Once the heating load is determined the heating energy consumption is found from

$$Q_h = Q_l - \eta Q_g \tag{4}$$

where Q_h is heating energy consumption. Q_l is the total losses and Q_g is the gains. η is added to account for the non steady state nature of the gains over time t and is a 'utilisation factor', which is a measure of how much of the heat gain can be utilised in order to reduce the energy needed for space heating. The approach taken here to determining heating load is simplified with conditions which are assumed to be steady-state. So while the actual heating load calculation may be complex, the approach taken is a simplification of reality.

Based on the energy calculation methodology, heating energy demand has been calculated for every kind of dwelling group. It provides a way to map the energy demand at local levels.

4 Integration of MOLAND

The MOLAND model is an integrated methodology that can be used for assessing, monitoring and modelling urban and regional development. The model accepts five inputs for the geographical area of interest. One of the five types of maps is socio-economic characteristics of the area, such as population, income, production and employment. Based on the alternative spatial planning and policy scenarios, the model then predicts the likely future development of land use, for each year usually over the next then to twenty-five years (Lavalle and Barredo, 2004).

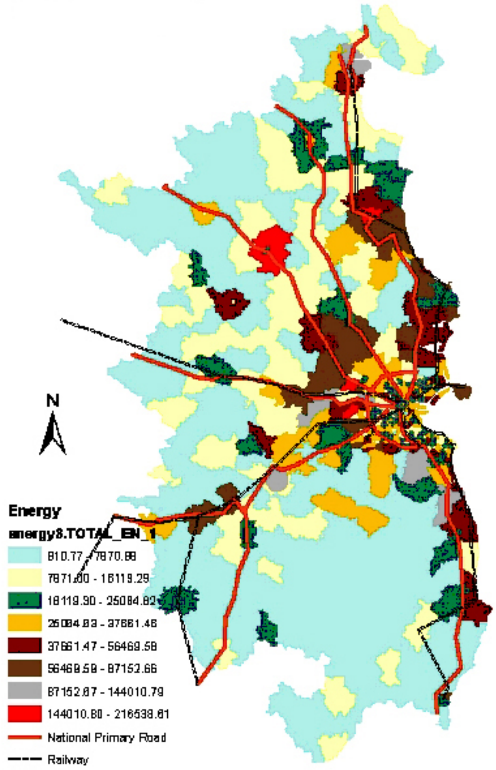

Figure 2 – Total energy demand at DED level, 2006

The current work is focused on the integration of the energy regression model with climate variables into MOLAND. MOLAND is used to predict scenarios based on land use change and population change to produce estimates of high, average and low energy demand scenarios. Figure 2 shows the total annual demand of electricity and natural gas for every DED in 2006. It can be seen that the DEDs with higher energy demand and population are located along the national roads and railways. Population and transport seem to have significant impact on total annual energy demand for each DED. An energy demand layer that associates quantified energy demand at ED level is derived based on the relationship between energy level and housing mix (which is discussed in Section 3), and is then further associated with each of 4 residential classes using population projections from MOLAND. Based on the projection of population and other economic scenarios provided by the MOLAND model, future residential energy demand can be derived for the Greater Dublin region. This may help policy makers to make adjustments to energy system intervening in other linked systems, such as the air pollution and urban sprawl systems. It also can improve the efficiency of residential energy use for limiting emissions and other problems associated with energy systems.

5 Summary

In this work, a methodology for assessing energy demand responses to climate change, with daily climate data and daily energy consumption data, has been developed. Results indicate that residential energy demand in the Greater Dublin region are sensitive to climate and that a range of future climate scenarios of climate change may noticeably decrease winter heating energy demands. The integration of an energy model into the MOLAND model has also been discussed. It seems that it is possible for the MOLAND model to estimate energy demand with future scenarios of climate and population. Further research will be focused on integration with the MOLAND model.

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