The impacts of climate change on domestic natural gas consumption in the Greater Dublin Region

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Abstract

Purpose – This paper aims to investigate the relationship between domestic natural gas consumption and climate change in the Greater Dublin Region.

Design/methodology/approach – Based on historical climate and natural gas use data, a linear regression model was derived to estimate the impact of future climate change on natural gas consumption under different climate scenarios.

Findings – Generally, under controlled socioeconomic development, the climate scenarios by Hadley model and the Ensemble GCMs are likely to decrease future natural gas consumption per capita and related CO_2 emissions compared to present. These results indicate that climate change has become as one of the most important factors affecting the energy system.

Originality/value – This study contributes understanding of the long-term impact of climate change on regional domestic natural gas use. It provides the national and local authorities a methodology to anticipate the potential impacts on domestic energy use and enable urban areas to maximise any benefits and minimise any losses from climate change.

Keywords Climate change, Natural gas consumption, Degree day, The Greater Dublin Region, Ireland, Fuel consumption, Energy consumption

Paper type Research paper

1. Introduction

Climate change is expected to lead to changes in energy consumption patterns in several regions, as has been demonstrated by several studies of the relationship between climate and energy demand. For example, some regions have their annual peak energy use in summer time because of large requirements for space cooling (Yan, 1998), while others have annual peak energy consumption in winter caused by high demand for space heating, mainly due to the strong relationship between energy

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consumption and regional climate (Hor *et al.*, 2005). In these climate-energy studies, temperature is usually transformed into degree days which have been identified by several previous researchers as the most important climatic variable influencing energy demand (Warren and Leduc, 1981; Douglas *et al.*, 1998; Amato *et al.*, 2005).

Initial investigations analysed residential electrical and fuel oil consumption together with heating degree days for 40,000 dwelling units in an area of 6,500 km^2 surrounding Asheville, North Carolina in the southern Appalachian Mountain over an 11-year period (Quayle and Diaz, 1980). A study by Lehman and Warren (1994) focused on the relationship between monthly residential natural gas sales and degree-day data for customers of the Columbia Gas Company. Timmer and Lamb (2007) carried out a similar study for the states of the Rocky Mountains for the period 1989-2000 on monthly and seasonal time scale. This study used two temperature indices: days below percentile (DBP) and heating degree days calculated for three daily temperature measures (maximum, minimum and mean). The results show very strong temperature-gas consumption relations and suggest the regression equations developed in this study could be used effectively for the real-time prediction of regional gas consumption.

In a European context, regional models predict a warming for Athens by the twenty-first century that would be associated with a decrease in demand during the milder and shorter winter period, and an increase in demand during the hotter and longer summer period (Giannakopoulos and Psiloglou, 2006). In Switzerland, the energy demand for space cooling is expected to increase by up to 28.4 per cent, and for space heating to decrease by 10 per cent compared to current values (Cartalis and Synodinou, 2001). The potential impact of climate change on heating and cooling energy demand show a 33-44 per cent decrease in the annual heating energy demand for Swiss residential buildings for the period 2050-2100, whilst the annual cooling energy demand for office buildings will increase by 223-1,050 per cent (Frank, 2005). In Slovenia, significant changes in useful energy demand can be expected during a building lifetime with a decrease between 23 and 40 per cent in heating energy demand (Sjösten *et al.*, 2003).

Some previous studies have only analysed electricity peak demand. A study that examined the effect on peak electricity demand in Thailand indicated that the projected increase in temperature of 3.43°C by 2080 would increase Thai peak electricity demand by 1.5-3.1 per cent in the 2020s, 3.7-8.3 per cent in the 2050s and 6.6-15.3 per cent in the 2080s (Parkpoom and Harriso, 2008). Increases in peak demand also necessitate a disproportionate increase in energy infrastructure investment to meet the temporal high peak demand (CCSP, 2007). For a 3°C increase in the mean daily maximum temperature at Toronto in summer, the increase in mean peak power demand was 7 per cent (1,200 MW) while the increase in the standard deviation of peak power demand was 22 per cent (Colombo *et al.*, 1999).

These studies indicate that there are many significant interactions between the energy consumption pattern and climate. However, only a few analyses address the long-term impact of climate change on natural gas consumption (Ruth and Lin, 2006; Amato *et al.*, 2005). For example, a study by Ruth and Lin (2006) indicates that, in Maryland, climate have a relatively small impact on future energy demand including natural gas, electricity and heating oil use, compared with other socioeconomic factors. However, Amato *et al.* (2005) find that future climate change has significant impact on the overall energy demand, which is the energy mix of residential and commercial sectors in the Commonwealth of Massachusetts. These studies demonstrate that the uncertainty is involved in the analysis of climate change impact on regional energy demand. It is therefore essential that energy demand sensitivities to climate change should be employed at the regional scale and considered a range of climate scenarios derived from different GCMs.

This study aims to investigate the natural gas consumption sensitivity to climate change based on daily domestic and non-domestic natural gas consumption and temperature data. A linear regression model was derived for the Greater Dublin Region (GDR) and used to estimate natural gas consumption response to climate change under scenarios derived from two different GCMs.

2. General description of the study area

Figure 1 shows the case study area, the GDR, which includes Dublin City, Dun Laoghaire-Rathdown, Fingal, South Dublin, Kildare, Meath, Louth and Wicklow. In 2006, the population of the GDR was 1,772,079 which accounted for nearly 42 per cent of the total population (4,234,925) of Ireland (CSO, 2007). Additionally, over one million citizens, approximately 30 per cent of the national population, live in the Dublin Metropolitan Area (Dublin city, Dun Laoghaire-Rathdown, Fingal, and South Dublin) which extends over only 922 km^2, 1.3 per cent of total state's area. The GDR has also turned into one of the fastest growing regions within Europe since Ireland joined the European Union 30 years ago. The population in the GDR has increased by 11.5 per cent in 2006 compared with 2000. Projections indicate that the GDR's population may reach 2.3 million by 2026 with an average growth rate of 1.7 per cent/yr (Walsh and Twumasi, 2008). With rapidly increasing population, energy for domestic and transport use is likely to significantly rise in the GDR in the next two decades.

3. Data and methodology

3.1 Climate data

Climate data, consisting of daily maximum and minimum temperature, was obtained from Met Eireann (Irish National Meteorological Service). Four synoptic weather stations (Dublin Airport, Glasnevin, Phoenix Park, and Casement Aerodrome) for which there are complete records were used in this study. Table I illustrates the start date and end date for daily temperature records from the four weather stations.

Mean annual temperatures for the four stations are shown in Figure 2. The daily mean temperature, T_{mean}, is defined as:

$$T_{mean} = \frac{(T_{\max} + T_{\min})}{2}$$

where $T_{\max}$ is the daily maximum temperature, and $T_{\min}$ is the daily minimum temperature.

The average daily mean temperature of the GDR is about 14°C during summer (June-August) for the period 1961-2006 and about 5°C during winter (December-February). Regarding extremes since 1961, the highest maximum temperature recorded was 31°C at Glasnevin for 2 August 1990, while the lowest daily minimum temperature was −13.8°C at Phoenix Park on 31 December 1961.

The warming trend of mean annual temperature of the four stations is shown in Figure 3. The average annual temperature is 10.2°C for the period 1991-2006. Mean annual air temperature has increased 0.4°C during this period compared with that for

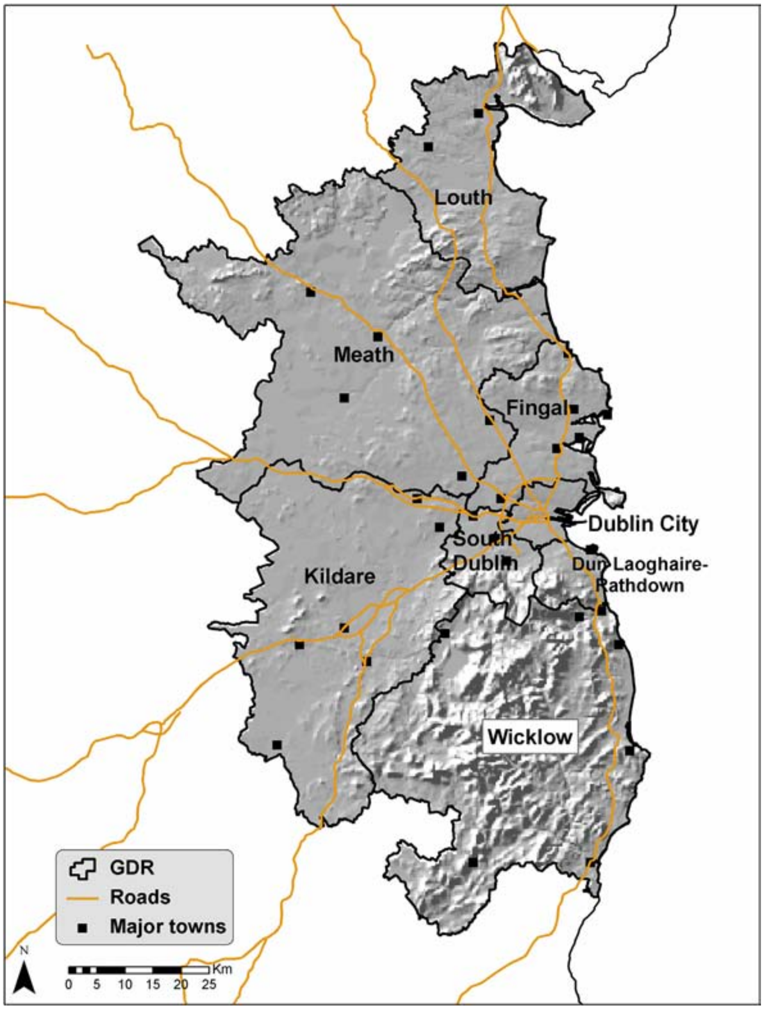


Figure 1.
Case study area: the GDR

Table I.
Start date and end date for daily temperature data

Stations	Start date	End date
Dublin airport	January 1961	May 2005
Glasnevin	January 1961	March 2005
Phoenix park	January 1961	December 2006
Casement aerodrome	January 1961	May 2005

the period of 1961-1990. The highest annual average temperature was 10.6°C in 1997, whilst the lowest annual average temperature of 8.7°C occurred in 1962. The climate of the GDR has experienced much greater inter-annual variability than the global norm, with deviations of more than 1°C from the mean. Significant global warming

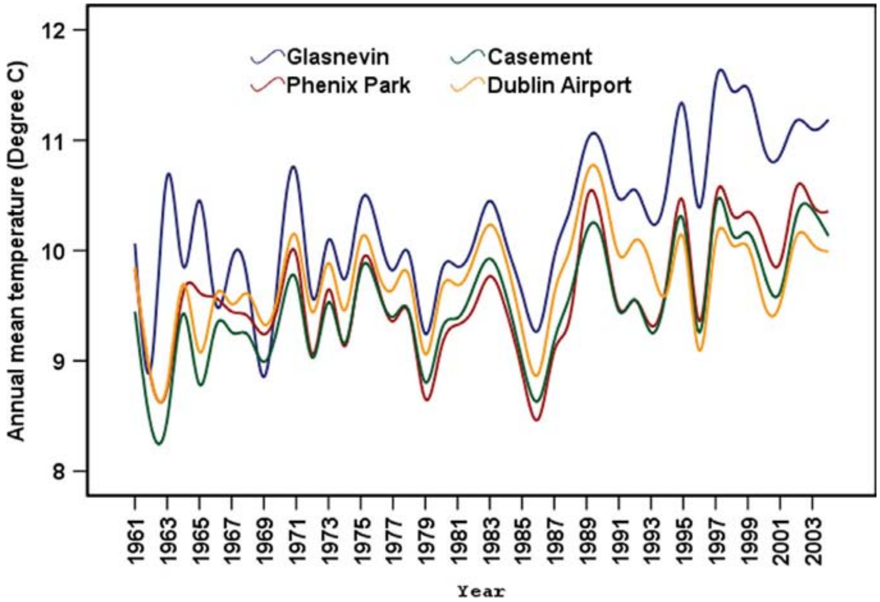
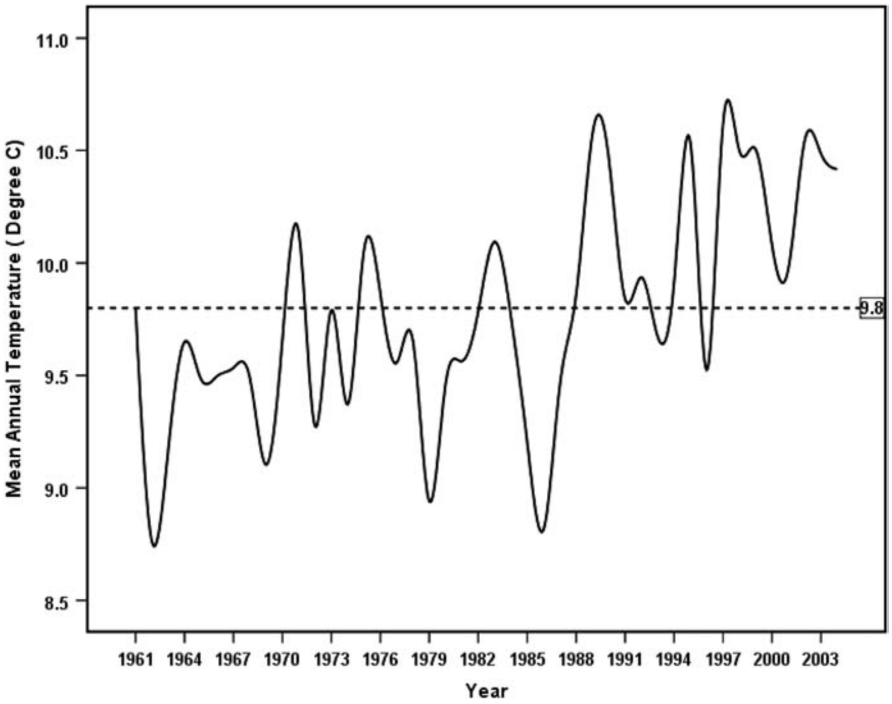


Figure 2.
Mean annul temperatures (°C) for the four stations in the GDR, 1961-2006



Note: The dot line shows the average temperature for the period from 1961 to 2005

Figure 3.
Annual mean temperatures in the GDR, 1961-2006

is apparent from the 1990s. The warmest year globally was 1998, which had an anomaly of +0.58°C (Sweeney *et al.*, 2002). However, the warmest year of the last four decades (1997) in the GDR was +0.8°C above the average for 1961-2006.

3.2 Natural gas data

In Ireland, natural gas is one of the primary heating fuels and is mainly used for domestic space and water heating, cooking and natural gas fires. Additionally, natural gas has a range of applications for business customers, such as restaurants, pubs, hospitals and hotels. Over half a million homes and businesses in Ireland are connected to natural gas (CIB, 2009) which accounts for approximately 25 per cent of primary energy demand in Ireland compared to a European average of 24 per cent. In 2006, the residential sector, which includes domestic natural gas use mainly for cooking, space and water heating and natural gas fires, consumed nearly 40 per cent of total gas usage, similar to the demand from industry, mainly power generation. Figure 4 shows that the total natural gas consumption has considerably increased from 1990. This is due to increasing economic activity and rapidly growing population and to the extension of the distribution network.

In the GDR, daily natural gas sales data to residential and non-residential users were obtained from Bord Gais Eireann. Figure 5 shows the daily residential gas sales during the period January 1990-December 2006. Natural gas usage for power stations is shown in Figure 6. The residential sector, exhibits regular seasonal changes while the non-residential sector shows a smaller seasonal change. This phenomenon is primarily caused by seasonal changes of energy demand for space heating. The overall power station natural gas supplied in the GDR also increased from 1990 and experienced

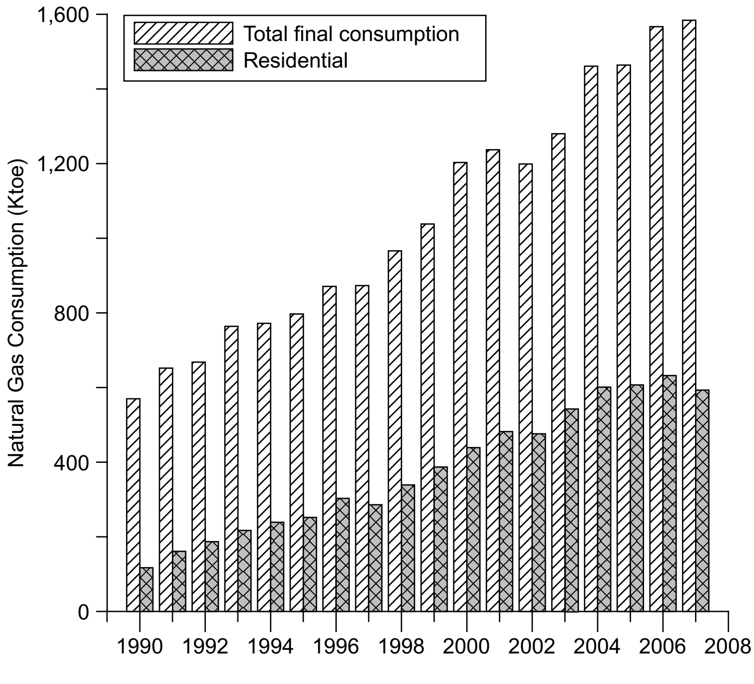


Figure 4.
Natural gas consumption in Ireland, 1990-2007

a decline from 2004 to 2006. Since this data related to gas supplies primarily from the Kinsale gas field, this decline may relate to depletion of this source or increase in renewable production and electrical interconnection with Great Britain (BG, 2006). Residential natural gas consumption has risen from 1990, principally as a result of rapid growth in population in the GDR.

3.3 Relationship between temperature and domestic natural gas consumption

3.3.1 Identification of balance point temperature. In this study, the degree-day methodology was employed to estimate the relationship between temperature and natural gas demand. The degree-day methodology presumes a V-shaped temperature-energy consumption relationship (Jager, 1983). The temperature at the bottom of the V-shaped temperature-energy consumption function is referred to as the balance point temperature (T_{base}). At the balance point, energy demand is at a minimum since outside climatic conditions produce the desired indoor temperature. Each degree deviation from the balance point temperature is counted as a degree-day, each calculated as $[T_{base} - T_{mean}(i)]$, where $T_{mean}(i)$ is average mean temperature in day i. The monthly and annual heating degree days are accumulated for months and years as $\sum_i^n [T_{base} - T_{mean}(i)]$.

The HDD values can also be used to relate the cost of heating with temperature: the higher the HDD values, the colder the temperature, and therefore, more space heating will be required. Cooling and heating degree days can be accumulated over time to give monthly or annual degree-day totals. Large deviations in temperature from the balance point temperature result in large increases in energy consumption (Amato *et al.*, 2005). Actual balance point temperature of an energy system varies depending on the place-specific characteristics of the building stock, non-temperature weather conditions (e.g. humidity, precipitation, wind), and cultural preferences (Nall and Arens, 1979; Ruth *et al.*, 2006; Ruth and Lin, 2006).

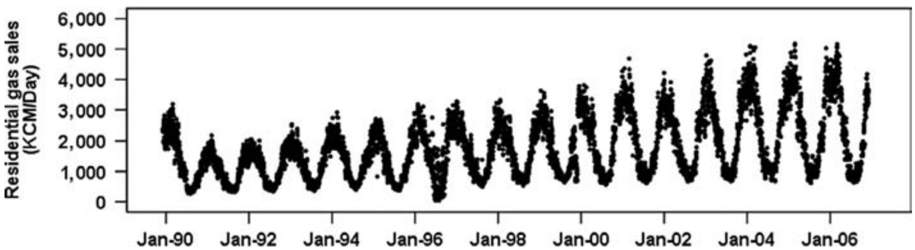


Figure 5. Daily residential natural gas usage in the GDR, 1990-2006

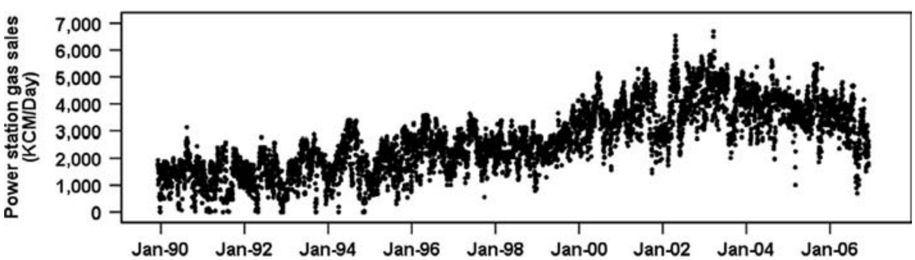


Figure 6. Daily natural gas usage for power stations in the GDR, 1990-2006

Usually, a base temperature of 18.3°C was used to estimate this energy-climate relationship. However, the generally accepted base temperature of 18.3°C does not seem to always work for all regions. For example, the optimum temperature for the low level energy demand in the Greater Athens areas is 22°C instead of 18.3°C (Giannakopoulos and Psiloglou, 2006). The balance point is 14°C over Greece (Cartalis and Synodinou, 2001; Matzarakis and Balafoutis, 2004), 15.0°C for Spain (Valor *et al.*, 2001) and Turkey (Kadioglu *et al.*, 2001), while 21°C for Florida (Sailor and Munoz, 1997). The actual base temperature of an energy system varies depending on the place-specific characteristics of the housing stock and local weather conditions.

The balance point temperature for the GDR is shown in Figure 7 which illustrates the relationship between daily residential natural gas consumption *per capita* and daily temperature in the GDR. Since residential natural gas is predominantly used for heating purposes, there is a strong inverse relationship between *per capita* natural gas sales and temperature. Temperature would appear to be the main driver for residential natural gas consumption. A base temperature of 15.5°C, which was also generally employed in climate-energy studies for the UK (Hor *et al.*, 2005; Beggs, 2009), has been specified to illustrate the biggest variations of natural gas uses. The natural gas sales to power station users, shown in Figure 8, are not responding to temperature due to ultimate uses for many purposes other than space heating.

3.3.2 Changes in heating degree day in the GDR. Mean monthly heating degree days, shown in Figure 9, have been derived for the GDR based on 1990-2006 daily mean temperature from a base point temperature of 15.5°C. Mean monthly heating degree days are greatest in January at 305, while lowest in August at 19. For winter (December-February), the mean seasonal heating degree days are 873 in the GDR.

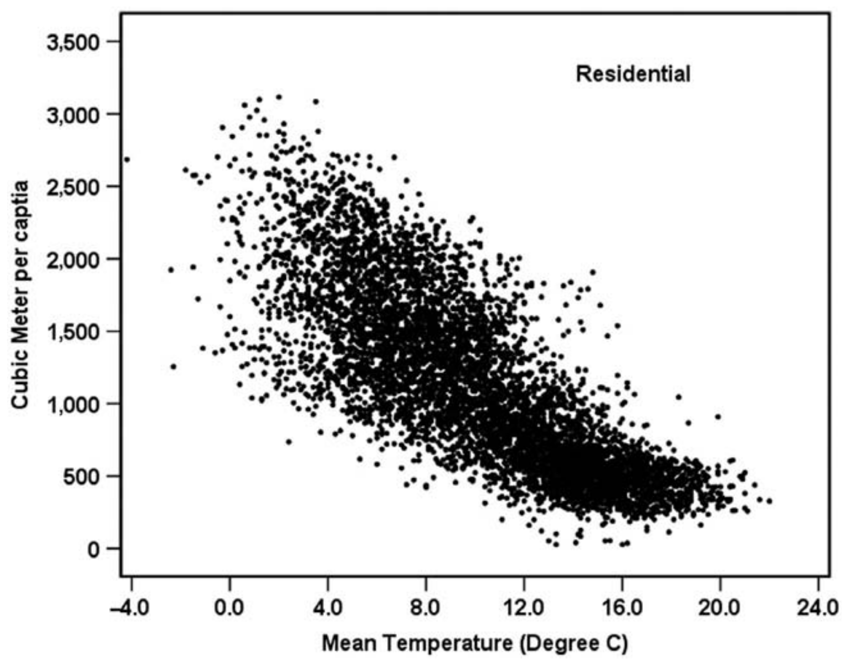


Figure 7.
Daily residential natural gas consumption and daily temperature, 1989-2006

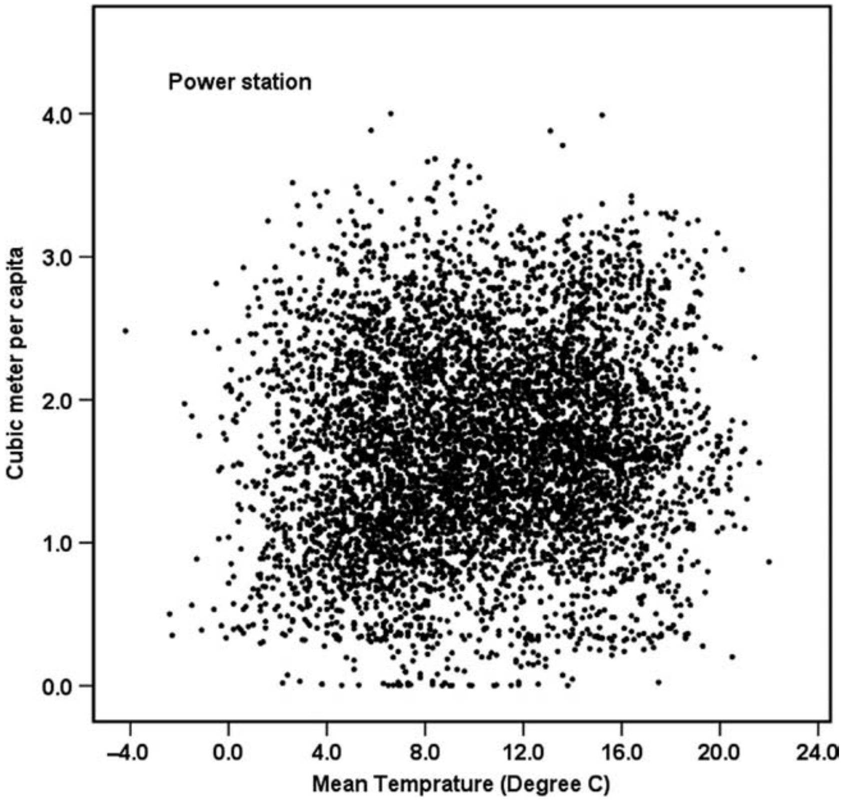


Figure 8.
Daily non-residential natural gas consumption and daily temperature, 1989-2006

Figure 10 shows that a strong positive linear relationships is apparent between monthly heating degree days and monthly natural gas consumption. However, the monthly natural gas use is likely to be distorted by differences in the number of days of the assessment interval along with the varying number of weekends, public holidays, etc.

The use of just one GCM and one emissions scenario in impacts analysis was common practice until recently. However, GCMs usually produce significantly different regional climate responses even when forced with the same emissions scenario (Fealy and Sweeney, 2010). To cater for these uncertainties, future daily degree days were estimated from statistically downscaled projections for Dublin of future daily temperature derived from both the Hadley Global Climate Model (HadCM3) and a multi-model ensemble GCM, involving the Hadley Model (HadCM3), Canadian Centre for Climate Modelling and Analysis (CGCM2), Commonwealth Scientific and Industrial Research Organisation (CSIRO2) (Fealy and Sweeney, 2010).

The average monthly heating degree days for four 30-year periods: 1961-2008, 1991-2020, 2021-2050 and 2051-2080 are shown in Figure 11 for the three model ensemble. Similarly, Figure 12 shows changes in the average monthly heating degree days for those periods, with reference to the Hadley model. It can be seen that an appreciable decrease in heating degree days occurs in the winter predicted by both the Hadley model and ensemble GCMs. As estimated by the Hadley model, January

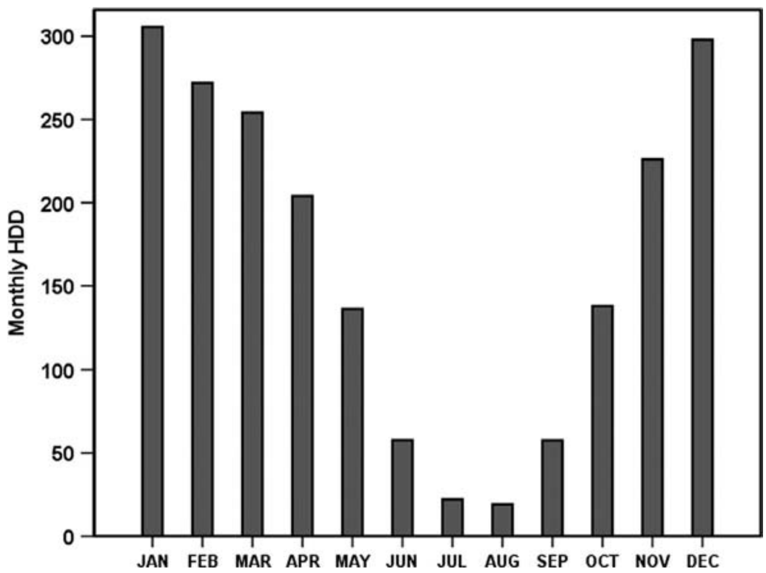


Figure 9.
Mean monthly heating degree days for the GDR, 1990-2006

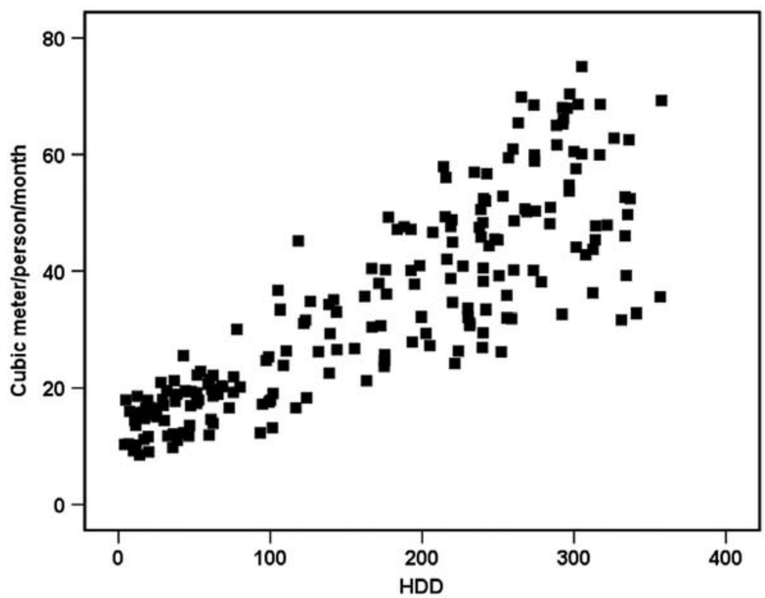


Figure 10.
Relationship between *per capita* monthly residential natural gas consumption and monthly heating degree days, 1989-2006

heating-days are projected to decrease from the baseline average of 342-339 in the 2020s, 299 in the 2050s and 289 in the 2080s scenario. This represents reductions of 3.1, 11.6 and 21.3 per cent, respectively. Similar changes in monthly heating degree days are observed for the ensemble climate scenarios. However, temporal pattern in changes of winter temperature are likely to be different for the two different climate scenarios.

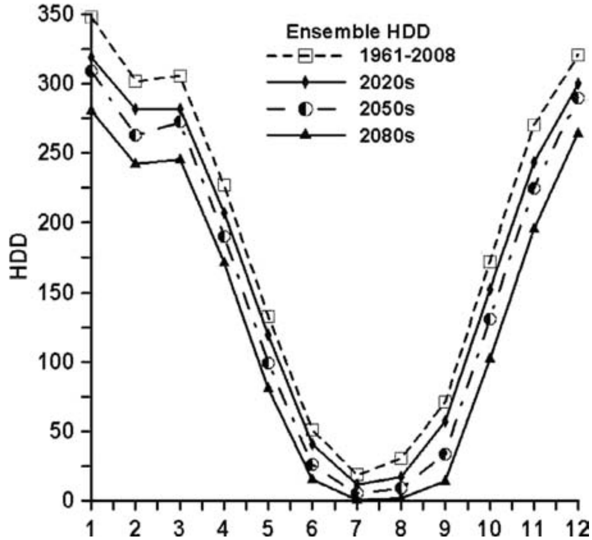


Figure 11.
Projected changes in mean monthly heating degree days by ensemble GCMs

For example, the Hadley model predicts that winter will be getting slightly cooler until 2030, resulting in slightly more heating degree days (943) in 2020s compared with 939 in the baseline period. In December, slight increases in heating degree days are observed in 2020s (314) and 2050s (310) compared with 303 for the base line of 1961-2008.

4. Energy demand sensitivity analysis

As has been discussed, there is a strong relationship between natural gas use and monthly heating degree days. A regression model was therefore employed to examine the impact of climate change on future energy demand. This also could be used to assess the impact of conservation and governmental policies on energy demand and potentially for measuring the impacts of extreme weather on energy demand. However, climate change is not the only driver of changes in energy demand. It will also be influenced by other non-climate factors, such as economic activity, efficiency of technologies, improvement in building insulation standards, changes in household structure and size, and changes in incomes and price of natural gas. Those economic and technological changes were not considered in these natural gas consumption projections in order to better illustrate and isolate the impact of climate change on energy demand.

The Gross National Produce (GNP) and population are known to have an impact on energy demand. The population trend was removed by dividing energy demand by population derived from the Central Statistics Office Ireland.

The predicted natural gas demand G is given by:

$$\log(G) = \alpha_0 + \alpha_1 HDD + \alpha_2 \log GNP + \varepsilon \qquad \text{(Model-G)}$$

where α_n are constants, HDD is heating degree days, GNP is the Gross National Produce *per capita* and ε is the standard error in the models.

Table II shows the regression results for the Model-G. The Model-Gas has values of goodness-of-fit (R^2) equal to 87.5 per cent. It indicates that this model could explain

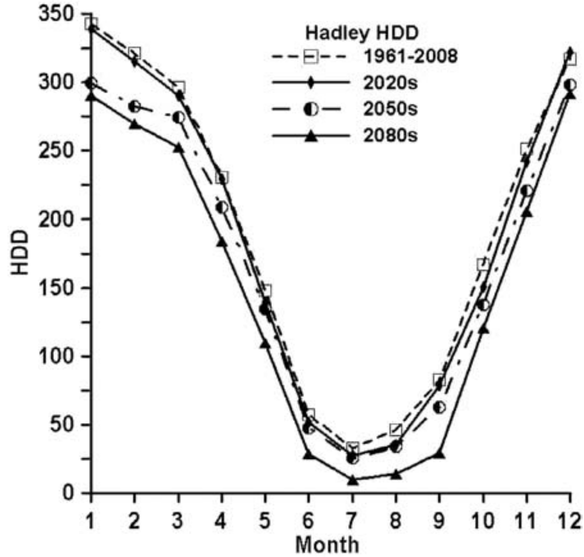


Figure 12.
Projected changes in mean monthly heating degree days by Hadley GCM

Table II.
Regression variables for Model-G

Variable	Value	SE	*t*-ratio	*p*-value	Sig.
α_0	0.4459083	0.0555969	8.020	0.000	0.000
α_1	0.0019748	0.0000054	35.745	0.000	0.000
α_2	0.5337312	0.0415078	12.859	0.000	0.000
R^2	0.875				
SE	0.08436				

87.5 per cent of historical variation in historical variation in natural gas demand *per capita*. The standard errors for both models are also shown in Table II. The *t*-ratio is the ratio of the estimated parameter value to the estimated parameter standard deviation. The large the ratio, the more significant the parameter is in the regression model (Montgomery and Runger, 2003). The *p*-value is used to test the null hypothesis for each parameter. The smaller the *p*-value, the less likely the parameter is actually zero. It is observed that the HDD variable has the largest *t*-ratio which indicates not only that heating degree days are the dominant variable in the Model-G, but also that temperature is the most important climatic determinant for natural gas consumption. The value of coefficient α_1 indicates that a 100 unit increase in monthly heating degree days is associated with a 19.7 per cent rise in natural gas consumption. The constant α_0 indicates that natural gas is consumed even in months with no heating degree-days since one of the primary uses of natural gas is for cooking purposes. All the variables have significant level.

5. Natural gas uses responses to future climate change in the GDR

Based on the regression model derived in Section 4, future natural gas use is estimated, using climate change scenarios simulated by GCMs referred to above. GNP *per capita* was held constant at the average value of the period 1990-2006.

The projections for monthly natural gas *per capita* consumption are shown in Figure 13, for the Hadley model. The results presented in this figure, as well as Figure 14, are mean model results for the period from 1961 to 2006 compared with average results for three 30-year periods: 1991-2020, 2021-2050 and 2051-2080. The bottom of each figure is a bar chart of percent change in monthly energy consumptions projected under climate scenarios by the different global climate models.

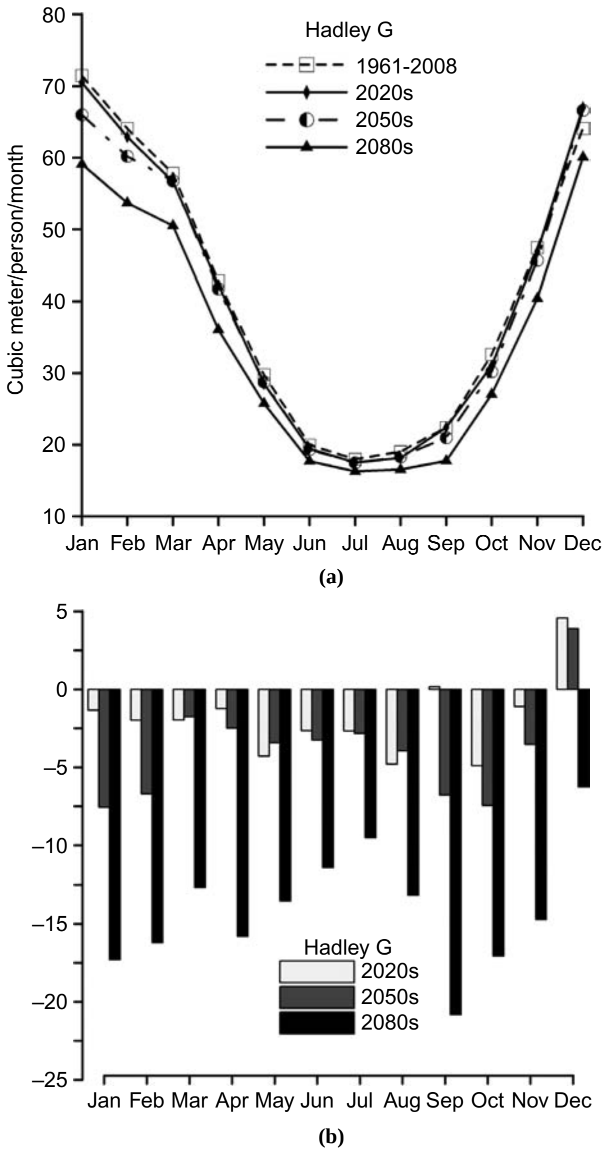


Figure 13.
Per capita natural gas consumption under the HadCM3 scenarios in (a) cubic metres and (b) percentage change

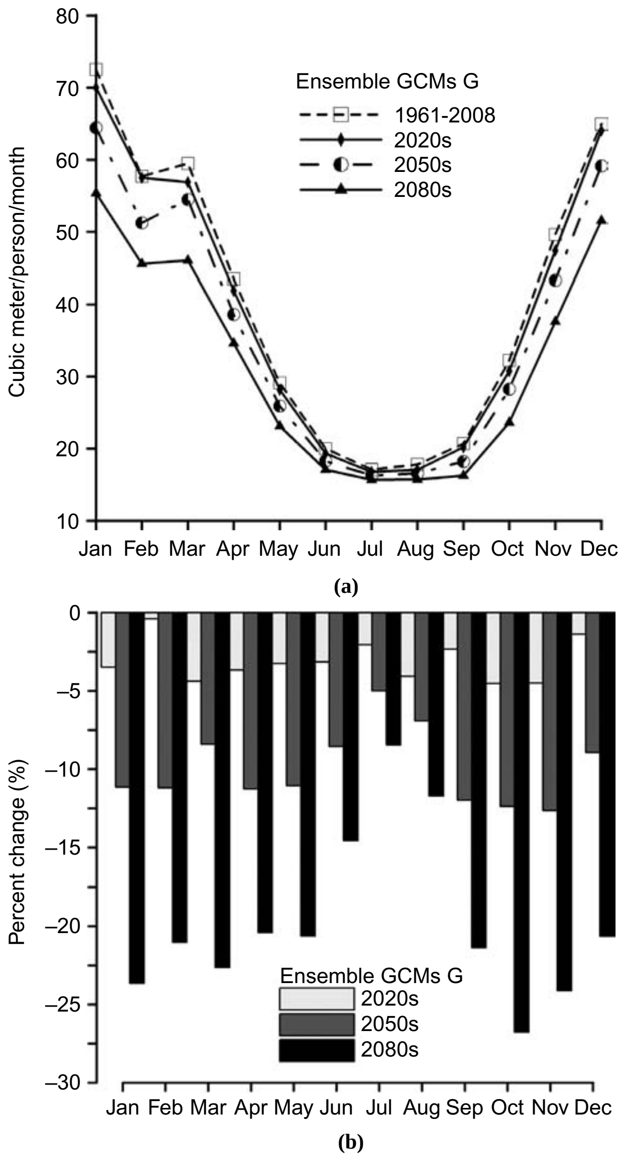


Figure 14.
Per capita natural gas under the ensemble GCMs climate scenarios in (a) cubic metres and (b) percentage change

Generally, the climate scenarios by both GCMs are likely to decrease future natural gas consumption *per capita* compared to present in the GDR. The climate scenarios for the 2080s estimated by the Hadley model are projected to decrease natural gas consumption during the winter months by 13.2 per cent relative to average natural gas consumption *per capita* for the period 1961-2008. For example, the monthly natural gas *capita* is high in January at 71.46 m^3/person/month, which would decrease to 65.9 m^3/person/month and 59.1 m^3/person/month, for climate scenario of 2050s and 2080s, respectively.

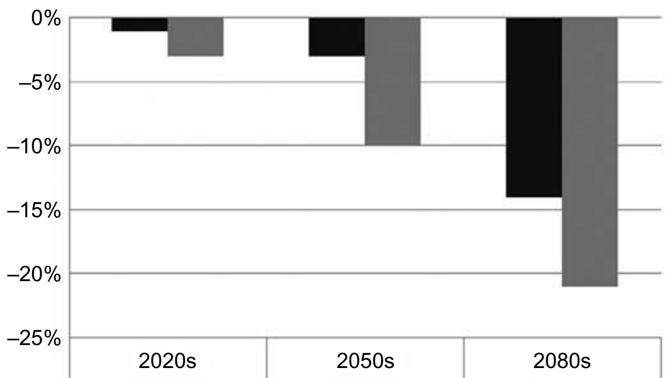
Similarly, the natural gas consumption *per capita* are also projected to decrease associated with climate scenarios from the ensemble GCMs. In January, the decreases in natural gas consumption *per capita* are 3.4 per cent in 2020s, 11.1 per cent in 2050s and 23.6 per cent in 2080s, respectively, which are slightly higher than that under Hadley climate scenarios.

However, the average natural gas consumption *per capita* in December for the 2020s and 2050s are projected to slightly increase by 4.6 and 3.6 per cent due to the Hadley model estimate that December gets cooler at least until 2030 (Fealy and Sweeney, 2008). Correspondingly, in winter, a slight increase of 0.5 per cent in natural gas use *per capita* is estimated for 2020s compared with the 1961-2008 baseline, while the decreases are 4.0 per cent in the 2050s and 13.5 per cent in the 2080s.

The energy-related CO_2 emissions were estimated based on the emission factors of 0.264 kg/KWh for natural gas. Under scenarios derived by the HadCM3 model, annual CO_2 emissions related to natural gas consumption *per capita* is expected to decrease 1 per cent in 2020s, 3 per cent in the 2050s and 14 per cent in the 2080s, respectively. The changes appear to be more significant for emissions projections with climate scenarios from the ensemble GCMs decreases of 3.0, 10.3 and 21.1 per cent, respectively. The results indicate that natural gas consumption *per capita* and related CO_2 emissions will be significant influenced by future climate change under projections by both Hadley and ensembles GCMs (Figure 15).

6. Conclusions

In this study, the impacts of climate change on natural gas consumption were analyzed based on historical energy use data and climate scenarios using a variety of different climate models. The relationship between heating degree days and natural gas consumption was also investigated. Base on this relationship, a regression model was employed to examine the sensitivity of natural gas use to future climate change in the GDR. Results indicate that natural gas consumption in the GDR is likely to noticeably decrease under a range of climate change scenarios, when the economic value of GNP was held constant as the average level of the period 1990-2006. For example, the



	2020s	2050s	2080s
Hadley	–1%	–3%	–14%
Ensembles	–3%	–10%	–21%

Figure 15. Percentage changes of annual natural gas use *per capita* related CO_2 emissions under HadCM3 and ensemble GCMs climate scenarios, respectively

monthly natural gas *per capita* is high in January at 71.46 m^3/person/month, which would decrease to 65.9 m^3/person/month and 59.1 m^3/person/month, for climate scenario of 2050s and 2080s. The annual CO_2 emissions related residential natural gas consumption is also expected to decrease by the warming climate in the GDR. By the 2080s, annual CO_2 emissions related to residential natural gas *per capita* consumption is likely to decrease by 14 per cent under the HadCM3 scenario and by 21 per cent under the ensemble GCMs scenario. These results indicate that climate change has become as one of the most important factors affecting the energy system.

Further study will focus on the impact of climate change on the electricity peak demand in the GDR. Electricity peak demand for cooling may increase due to rising temperature in summer, while heating demand may be decreased by warming winter temperature. However, temperature is not the only factor which influences residential demand and overall energy demand. Future work is needed to examine the role of other socio-economic factors, which were not been included in this climate-natural-gas-consumption model, such as population size, land use changes, improvement of efficiency technologies, etc. In the future study, a land use model is expected to be employed to investigate the impact of urban form on domestic heating energy use, based on the 2006 census data and land use data. Further study is also recommended to investigate the relationship between transport energy use related CO_2 and urban form. These studies aim to develop a possible way to promote sustainable development through the integration of energy, environment and climate risk issues in urban development in the GDR. The key findings could provide local government and organisations with some useful information regarding housing development, transportation system planning and climate change mitigation. The derived indicators can help organisations driving urban development to have sustainability considerations from the beginning and evaluate developing policy and practice in promoting sustainable development.

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