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Regional energy demand and adaptations to climate change: Methodology and application to the state of Maryland, USA

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Abstract

This paper explores potential impacts of climate change on natural gas, electricity and heating oil use by the residential and commercial sectors in the state of Maryland, USA. Time series analysis is used to quantify historical temperature–energy demand relationships. A dynamic computer model uses those relationships to simulate future energy demand under a range of energy prices, temperatures and other drivers. The results indicate that climate exerts a comparably small signal on future energy demand, but that the combined climate and non-climate-induced changes in energy demand may pose significant challenges to policy and investment decisions in the state.

Keywords: Climate change; Residential energy demand; Commercial energy demand

1. Introduction

To date, the bulk of climate change research has concentrated on biogeochemical processes, and where this research interfaced with human systems, it was much concerned with the identification of strategies to mitigate climate change through the reduction of greenhouse gas emissions and the quantification of impacts on agriculture, forestry and fisheries (IPCC, 2001). Only very recently did researchers start to investigate potential impacts and adaptation strategies in urban areas—the places of much economic and social activity (US Global Change Research Program, 2000; Rosenzweig and Solecki, 2001; Ruth and Kirshen, 2001). Since these are also the areas in which most energy is consumed, significant synergies may exist between mitigation, to reduce greenhouse gas emissions, and adaptation, to reduce climate impacts.

The results of the few studies that have examined the effects of climate change on the energy sector suggest, in general, noticeable impacts on energy demand, capital requirements or expenditures. For example, Linder's assessment of climate change impacts on the US electricity sector finds that between 2010 and 2055 climate change could increase capacity addition requirements by 14–23% relative to non-climate change scenarios, requiring investments of $200–300 billion ($1990) (Linder, 1990). In a national assessment of Israel, Segal et al. estimate that an increase in temperature of 4 °C is associated with a 10% increase in average summer peak loads (Segal et al., 1992). 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%, assuming a business-as-usual scenario (Cartalis et al., 2001). A study examining potential changes in US commercial energy use due to climate change finds that a 4 °C increase in average annual temperature results in a 0–5% reduction in total energy use in the commercial sector in 2030, after accounting for changes in the building stock (Belzer et al., 1996). Rosenthal et al. estimate that a 1 °C warming in the US would reduce energy expenditures by $5.5 billion and primary energy

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use by 0.70% in 2010 relative to a non-warming scenario (Rosenthal et al., 1995). In contrast, a study examining the impacts of climate change on total US energy use finds that a 2 °C increase in average temperature would increase energy expenditures by $6 billion in 2060 (Morrison and Mendelsohn, 1998). The work by Amato et al. (2005) suggests that by 2030 climate change may account for up to 40% of increased energy demand in Massachusetts.

This paper specifically concentrates on the potential impacts of climate change on energy demand in the residential and commercial sectors of one state in the US—Maryland—and explores demand changes in the broader context of economic and population changes. Impacts on manufacturing energy use are not analyzed here because previous studies (Lakshmanan and Anderson, 1980; Sailor, 1997, 2001) as well as our own preliminary analyses strongly suggest that manufacturing energy use is not temperature sensitive.

Maryland was chosen, in part, because the state's energy use infrastructure has evolved to deal both with high cooling demands during summer months and heating demands during winter. As a consequence, it is a more intruiging case to investigate than, for example, the more "obvious" cases of Arizona or Florida, where the predominant energy demand is for cooling, or Maine and Minnesota, where much of the demand is for heating.

In lieu of adequate empirical data, possible impacts of severe weather events on the reliability of regional energy transmission and distribution are not dealt with here. However, anecdotal evidence (see, e.g., Murphey, 2002) suggests that severe weather impacts—in the form of ice storms, heat waves, high winds, etc.—can seriously impact local energy supply.

In the following section we briefly review climate-related drivers behind energy demand in the US and in the state. In Section 3 we describe the data used in this study and Section 4 addresses the methodology to simulate—on the basis of sub-regional climate and population data, as well as energy prices—possible future scenarios under a range of socioeconomic assumptions. Section 5 closes the paper with conclusions about adaptation strategies for the region.

2. Energy demand sensitivity to climate and climate change

Much of society's use of energy is to satisfy heating and cooling preferences. In the United States, residential households devote 58% (EIA 1999), commercial buildings 40% (EIA, 1995), and industrial facilities 6% (EIA, 2001a, b) of energy consumption to space-conditioning requirements, not including water heating. As these sectors account for 20%, 16%, and 38% of total US end-use energy demand, respectively, roughly 22% of all end-use energy is directly utilized for space-conditioning purposes. Such a large share of energy devoted to heating and cooling suggests climatic change may have real and measurable effects on energy consumption and, subsequently, emissions from the combustion of fossil fuels. Clearly, while emphasis has been placed on the influence of energy consumption in a changing climate "it is equally important to realize that climate variability and climatic change can itself impact both energy supply and demand" (Sailor, 1997, p. 313).

The link between weather and energy use has been widely documented and utilized to explain energy consumption and to assist regional energy suppliers with short-term planning (Badri, 1992; Lehman, 1994; Lam, 1998; Yan, 1998; Morris, 1999; Pardo et al., 2002). The majority of climate-impact studies examining consequences for the energy sector typically quantify impacts at relatively course spatial resolutions, usually at the national level. As a consequence, they capture only an average response for a large geographic area. However, average responses have little value in guiding place-specific adaptation response (Wilbanks and Kates, 1999) and may result in the prescription of inappropriate policy recommendations. Therefore, if the objective of a study is not only to quantify impacts but also identify policy solutions it must be conducted at a scale where, as the IPCC notes, "the impacts of climate change are felt and responses are implemented" (IPCC, 2001, p. 25).

The research of this paper is based on the premise that for policy analyses, not just short-term planning, energy demand sensitivities to climate and climate change should be performed at the regional scale for a number of reasons. First, global climate change is anticipated to have geographically distinct impacts. For example, global climate models predict that the Mid-Atlantic region of the US (within which Maryland is situated) will experience warming trends that differ from the US average (Barron, 2002). As a consequence, analyses that apply a uniform temperature increase over the entire nation may miss important geographic impacts on energy use.

A second justification for carrying out a regional assessment lies in the regional differences of energy infrastructures (Boustead and Yaros, 1994). Regional energy systems differ in terms of energy sources, efficiencies and characteristics of supply and conversion infrastructure, age of transmission and distribution systems, end use technologies, and characteristics of end users. In part, structural differences between regional energy systems have arisen as the built end use infrastructure and housing stock have evolved to service location-specific heating and cooling requirements (Pressman, 1995).

A third justification for energy demand sensitivity analysis to be carried out at regional scales is that residential, commercial, and industrial sectors exhibit distinct demand sensitivities to climate. Since sectoral compositions vary across regions, the structure of a region's economy significantly influences the sensitivity of regional energy demand to climate (Lakshmanan and Anderson, 1980; Sailor and Munoz, 1997).

Several empirical studies support these arguments for regional assessments of climate impacts on the energy sector. For example, in a state-level analysis of residential and commercial electricity, Sailor observes significant variation in sectoral demand sensitivities between states (Sailor, 2001). He finds a temperature increase of 2 °C is associated with an 11.6% increase in residential per capita electricity use in Florida, but a 7.2% decrease in Washington. Even in neighboring states, such as Florida and Louisiana, residential and commercial demand sensitivities are noticeably different. Similarly, Sailor and colleagues estimate the sensitivity of state-level electricity and natural gas consumption to temperature variables and find considerable variation (Sailor and Munoz, 1997; Sailor et al., 1998). Warren and LeDuc statistically relate natural gas consumption to prices and heating degree-days in a nine-region model of the US and find noticeable regional differences (Warren and LeDuc, 1981). Scott et al. use a building energy simulation model to assess the impacts of climate change on commercial building energy demand in four US cities (Seattle, Minneapolis, Phoenix, and Shreveport) (Scott et al., 1994). Each city was found to have a unique demand response to climate changes with, for instance, a 7°F increase in daily temperature increasing cooling energy use 36.6% in Phoenix and 93.3% in Seattle. Absolute changes in cooling energy demand, however, may be larger in areas with already high demand, even if relative changes are lower.

The observed spatial and temporal variations in energy demand across the US and across seasons suggest that it is important to treat climate impacts on heating-related energy needs separate from those for cooling. Analyses focusing on total energy use may find only negligible changes in aggregate, annual physical quantities or in monetary expenditures because changes in cooling and heating may offset one another. Yet, differences in intra-annual energy use profiles will have different implications for cooling and heating energy system expansion and contraction. For example, higher electricity demand in summer months may—in physical terms—be offset by lower heating oil demand in winter, requiring larger investment in peak load electricity generation without comparable changes in heating oil delivery capacities.

3. Data sources

Our analysis uses monthly energy consumption and degree-day data, which produces more robust estimates of the energy–climate relationship than analyses of annual time-series since there are more observations and larger variability between observations. Additionally, the use of monthly data allows for the assessment of non-uniform seasonal climatic changes, such as a more pronounced warming during the winter season than in other seasons of the year for higher latitude regions, as predicted by global climate models (Greco and Moss, 1994). In contrast, analyses that apply a uniform temperature increase over the entire year may miss important seasonal impacts on energy use. The following sections describe the data used in our regional energy demand sensitivity analysis.

3.1. Energy data

The Maryland energy consumption data used in this study comes from the US Energy Information Administration (EIA). Monthly electricity sales and price to residential and commercial end users are available from the Electric Power Monthly (EIA various years). The electricity sales data cover January 1977–December 2001 while monthly electricity price data are for January 1990–December 2001 (Fig. 1). The overall upward trends for both the residential and commercial sector's electricity use are driven, in large part, by changes in the size of the local population combined with changes in household sizes, building stock and increased proliferation of electric heating and air-conditioning, as well as increases in overall economic activity in the region.

Prices of electricity demonstrate intra-annual oscillation but, in general, no inter-annual trend. To adjust for inflation, the electricity price data is deflated with the Bureau of Labor Statistics' consumer price index for electricity in the Mid-Atlantic region (BLS, 2003)

Monthly natural gas sales to residential and commercial end users are from the Natural Gas Monthly (EIA, various years). Natural gas sales and price data for the residential and commercial sectors span from January 1989 to December 2001 and are shown in Fig. 2. Monthly sales of heating oil (distillate fuel oil No. 2) to all end users are published in the Petroleum Marketing Monthly (EIA, various years). Because sales to individual end use sectors are not available we treat them in their aggregate. Heating oil sales and price data cover the January 1983–December 2002 period (see Fig. 3). The prices of both natural gas and heating oil are adjusted for inflation using the Bureau of Labor Statistics' consumer price index for fuels in the Mid-Atlantic region (BLS, 2003).

3.2. Socio-economic data

Annual population estimates for Maryland come from the Census Bureau (US Census Bureau, 2004) and employment data from the Bureau of Economic

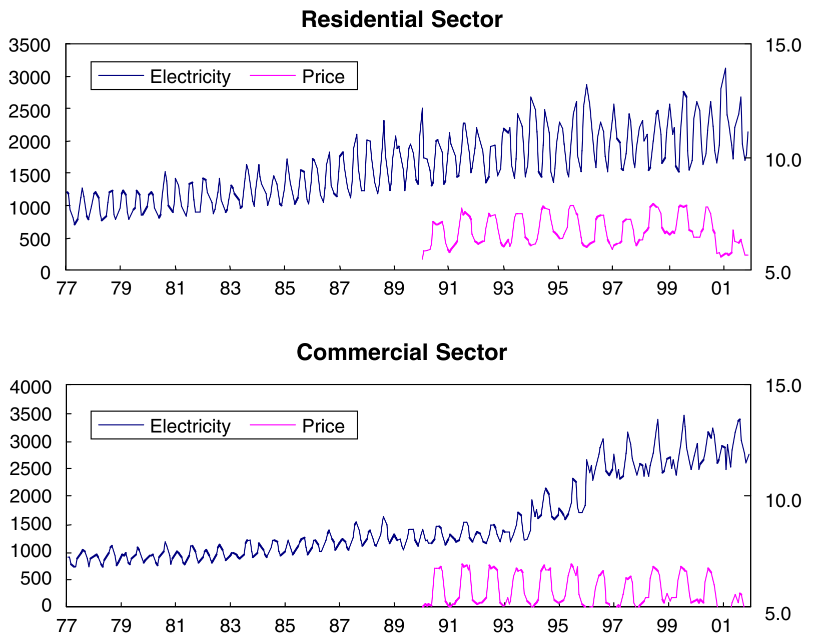


Fig. 1. Maryland's residential and commercial monthly electricity consumption (million kWh) and price (constant 1990 cents per kWh), 1977–2001.

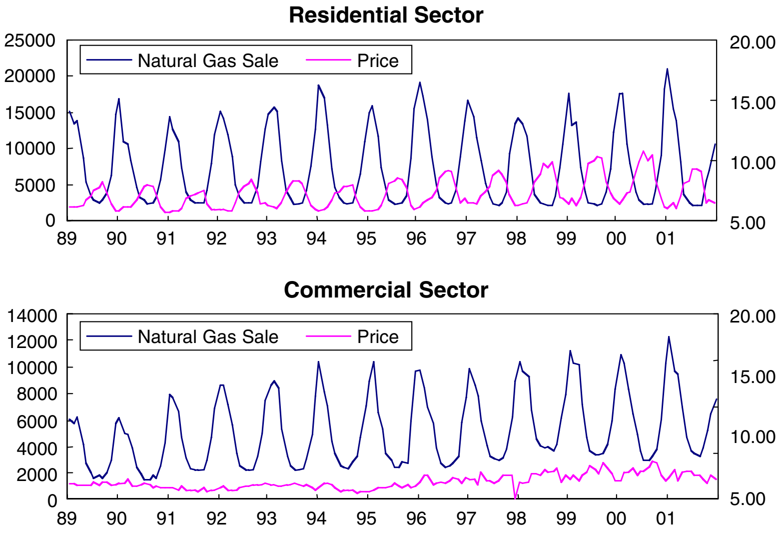


Fig. 2. Maryland's residential and commercial monthly natural gas sales (MMcf) and price (constant 1990 $ per 1000 cf), 1989–2001.

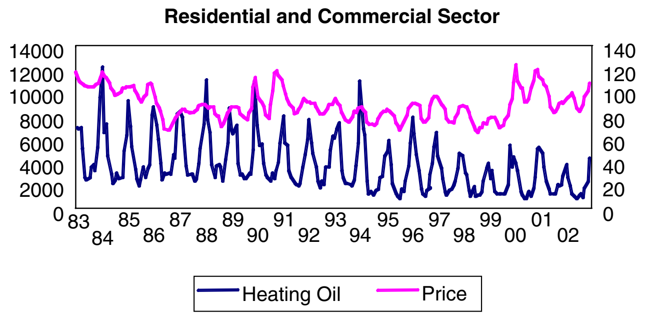


Fig. 3. Maryland's monthly heating oil sales (MMgal/d) and price (constant 1990 cents per gallon), 1983–2002.

Analysis (US Bureau of Economic Analysis 2002). Commercial employment data were disaggregated from the overall Maryland's employment data based on commercial enterprises that compose commercial energy use as defined in the State Energy Report 1999 (EIA, 2001a, b). Population and commercial employment data are held constant throughout each month of the year.

3.3. Climate data

The historic climate data consist of monthly average temperature series generated by the National Weather Service of the National Oceanic and Atmospheric

1. Southeastern Shore (Worcester/ Somerset / Wicomico Counties)
2. Central Eastern Shore (Dorchester/ Caroline/ Talbot Counties)
3. Lower Southern (Saint Mary's/ Calvert / Charles Counties)
4. Upper Southern (Anne Arundel / Prince George's Counties and D.C area)
5. Northeastern Shore (Queen Anne's / Kent Counties)
6. Northern Central (Harford/ Baltimore/ Montgomery/ Frederick/ Howard/ Cecil/ Carroll Counties)
7. Appalachian Mountain (Washington / Allegany Counties)
8. Allegheny Plateau (Garrett County)

Fig. 4. Climate divisions in Maryland (*Source*: National Climate Data Center).

Administration for eight different climate divisions in Maryland and Washington, DC (NCDC 2004). From that data we derive monthly heating degree-days (HDD) and cooling degree-days (CDD) for each of the eight divisions (see Fig. 4) to coincide with the time-step of the energy data. Degree-days are a common energy accounting practice for forecasting energy demand. The degree-day methodology presumes a V-shaped temperature–energy consumption relationship as shown in Fig. 5 (Jager, 1983). At the balance point temperature (the bottom of the V-shaped temperature–energy consumption function) energy demand is at a minimum since outside climatic conditions produce the desired indoor temperature. The amount of energy demanded at the balance point temperature is the non-temperature sensitive energy load. As outdoor temperatures deviate above or below the balance point temperature, energy demand increases proportionally. Energy demanded in excess of the level at the balance point temperature is the temperature-sensitive energy load.

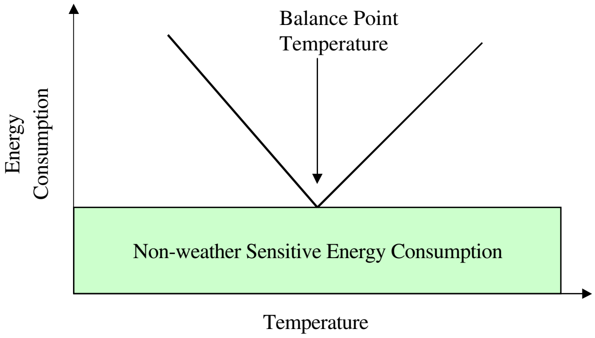


Fig. 5. Theoretical relationship between temperature and energy consumption.

Each degree deviation from a predefined balance point temperature is counted as a degree-day. For example, if a balance point temperature of 65°F is chosen for a region and the average temperature in that region is 70°F, this would result in 5 cooling degree-days in that region. Aggregate, state-wide degree-day data for the residential sector can be generated by weighting region-specific temperatures by population in the respective climate division. These population-weighted temperatures are then used to calculate aggregate, state-level heating and cooling degree-days for given base temperatures. Similarly, aggregate degree-day data for the commercial sector can be generated by weighting region-specific temperature by commercial employment in the respective climate division.

In addition to the climatological variables, we calculated daylight hours in each month of the year. Information on daylight hours helps us reduce bias in the econometric estimates of demand sensitivity because daylight hours are correlated with temperature and related to energy use. Daylight hours influence energy use for lighting needs as well as other energy use that may change as individuals are more likely to be indoors. We use the hours of daylight on the 15th day of each month, calculated as the time elapsing between sunset and sunrise, as a proxy for the number of daylight hours per month in Maryland (NOAA, 2003).

4. Methodology

In order to estimate climate-impacts on regional energy demand, we follow a three step modeling and estimation procedure similar to the one by Amato et al. (2005). First, we empirically identify region-specific heating and cooling degree-days as outlined above. Second, we use the monthly time-series data of heating and cooling degree-days, together with energy prices, daylight hours and trend variables, in a fixed-effects regression model to quantify the historic sensitivity of end use energy demand by the residential and commercial sectors.

For each sector the demand for electricity, natural gas and heating oil is separately estimated. Separating the energy used predominantly for heating (i.e. natural gas, fuel oil) from energy used for cooling (i.e. electricity) is important because climate change is anticipated to have unique impacts on the use of each form of energy and, subsequently, on the different energy delivery systems. As winters and summers get warmer, heating oil demand decreases and electricity use increases. Since the warming trends are asymmetrical, *ceteribus paribus*, electricity demand will go up more rapidly than the use of heating oil declines. Furthermore, to separate the influence of climate on energy use from socioeconomic factors, we modify the raw electricity and heating fuels data by accounting for consumption on a per capita level in the residential sector and a per employee level in the commercial sector.

In the third part of the analysis we estimate future energy consumption in Maryland under various climate change and socioeconomic scenarios, using the energy sensitivity relationships developed in the first step of the analysis. A comparison of model results against a base case, which assumes average historic temperature and energy prices, then helps discern climate-induced changes in energy demand in the region.

4.1. Identification of balance point temperatures

Energy analyses commonly use a base temperature of 65°F as the balance point threshold in the space-conditioning temperature relationship (see Nall and Arens 1979; de Dear and Brager 2001 for examples). However, the 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. For example, a region with a housing stock comprised of well-insulated homes will have a relatively low balance point temperature. Nonetheless, while place-specific variations in base temperatures exsit, most assessments continue to use the 65°F base because of the ease of data collection since degree-days are commonly calculated with 65°F as the base. However, using 65°F as a universal base temperature implicitly assumes that the temperature where energy is demanded for heating and cooling service is the same everywhere.

The method used in this paper is to tailor the balance point temperature to the characteristics of Maryland, using a quantitative approach, rather than a priori postulating it. In this way, the functional relationship between energy demand and temperature will be better specified. Similar to the methodology used by Belzer and colleagues (Belzer et al., 1996), a set of statistical models are iteratively run for the state over a range of balance point temperatures. Each iteration is performed using degree-days formulated with a different base temperature at 1°F intervals. Then energy use is regressed against degree-days, energy prices, daylight hours, and trend variables. The base temperature that explains the largest share of changes in energy use (the one that produces the highest R^2) is then designated as the balance point temperature. The approach is used for each energy type in each end use sector.

We assume that balance point temperatures for heating and cooling-related electricity use are identical. However, we do not make the simplifying assumption that for all fuels all heating degree-days are derived from the same balance point temperature. Instead, we empirically find a balance point temperature for electricity of 60°F in the residential sector and 53°F for the commercial sector (Fig. 6). The balance point temperature for natural gas used for heating is 71°F in both the residential sector and commercial sector (Fig. 7), while the balance point temperature for heating oil is 64°F (Fig. 8). Because natural gas and heating oil are predominantly used for heating purposes, the relationship with temperature is a downward sloping function.

4.2. Energy demand sensitivity analysis

We use a fixed effects regression model to estimate end use energy demand in the residential and commercial sectors for each of the different energy types as a function of heating and cooling degree-days, energy prices, daylight hours, and trend variables. The dependent variable (energy use per capita or per employee) in each energy model is specified in natural log format. The output coefficients for the independent variables, therefore, represent the percentage change in energy use associated with a unit change in the independent variable. The constant terms indicate the level of non-temperature sensitive energy use. The coefficient for the HDD and CDD variables indicate percentage changes,

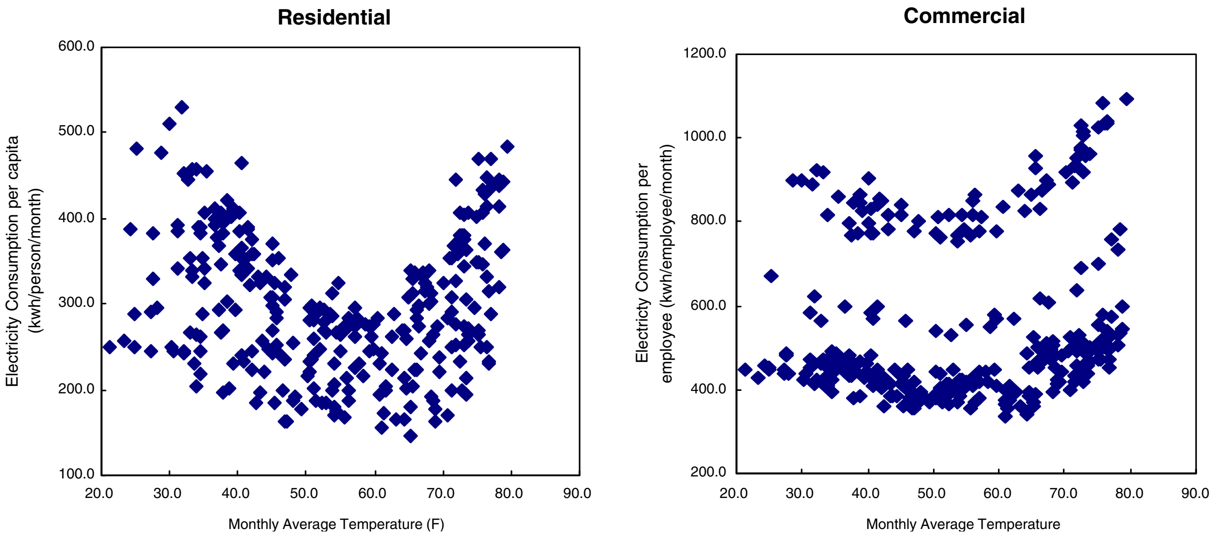


Fig. 6. Monthly average temperature and sectoral electricity consumption, 1977–2001.

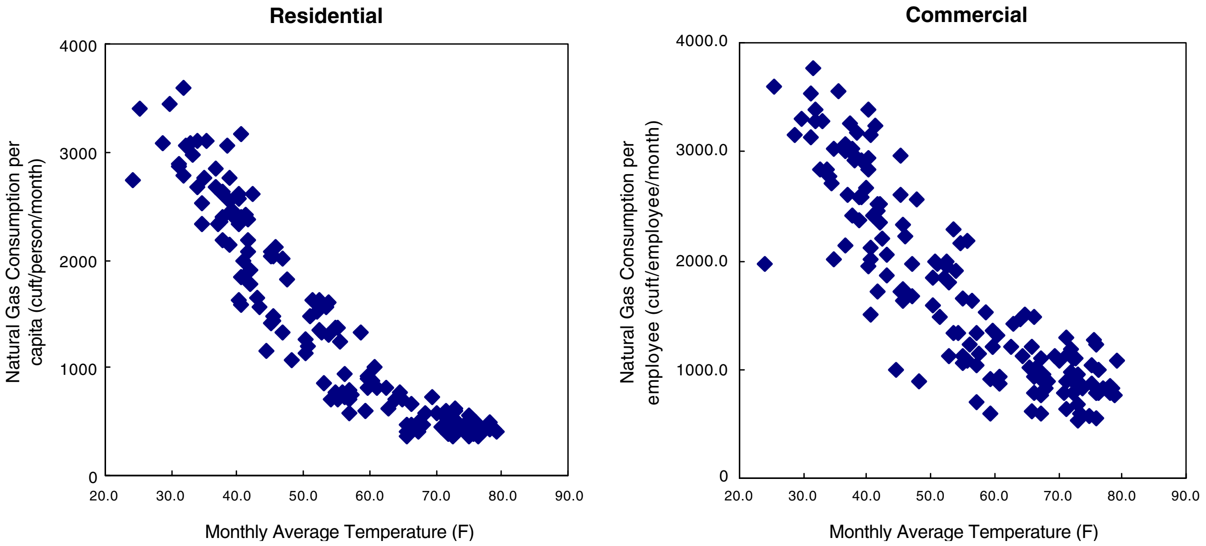


Fig. 7. Monthly average temperature and sectoral natural gas sales, 1989–2001.

respectively, in heating and cooling energy use associated with changes in heating degree-days and cooling degree-days.

The annual trend variables capture potential time-varying components of energy demand sensitivities to changes in degree-days over the period of analysis. For example, with the expansion of air-conditioning it is expected that electricity demand more readily increases as the number of cooling degree-days increases. The coefficient of the daylight variable indicates the percent change in energy use associated with a 1 h change in daylight. Similarly, the coefficient for the energy price variable, which itself is expressed in natural log form, represents the percent change in energy use associated with a percent change in the price of energy.

The regression results for monthly per-capita and per-employee energy consumption in Maryland are shown in Table 1. The results were derived separately for each of the climate-sensitive end use sectors and for each of the energy types. The different balance point temperatures used in the regressions were chosen to give the best fit. The signs of the estimated parameters are largely consistent with expectations and the patterns hypothesized in Fig. 5. For example, the coefficient for the degree-day variables indicates that deviations of the number of heating and cooling degree-days from the

60°F balance point result in increased electricity consumption. Those increases, however, are not symmetrical. Rather, 100 more colling degree-days lead to a 10.3% increase in electricity use while 100 more heating degree-day increase electricity use by only 6.5%.

Estimated coefficients for energy price variables and the number of daylight hours are not statitistically significant in several cases, such as for electricity use in the residential and commercial sectors. The heating oil regression is the only one with a significant negative parameter for the trend variable, reflecting the declining importance of oil-based heating of homes and businesses in the state.

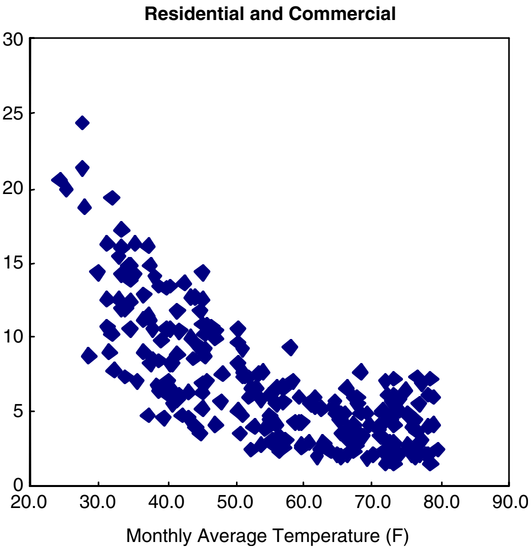


Fig. 8. Monthly average temperature and heating oil sales, 1989–2001.

5. Scenarios of future energy use

In the third part of our analysis we use the regression results for electricity, natural gas and heating oil use in conjunction with climate change and energy price scenarios to explore possible future energy use in the residential and commercial sectors. Since our historical time series used to estimate past relationships between energy use and temperature is rather short, and since any trend variables used to explain past behavior are the less valid the further we project into the future, we limit our future scenarios to only explore potential energy use until 2025.

To explore potential impacts of future climate conditions on energy use, we calculate average monthly temperatures for each of the eight climate regions in Maryland and Wahington, DC, using the historical data from 1977 to 2001. We then calculate new monthly population-weighted heating and cooling degree-days from population forecasts for each of the regions (Maryland Department of Planning, 2004; US Census Bureau, 2004) and assume that regional employment remains at the historic average ratio of employment to population. The result is a future scenario for regional climate, which is consistent with average past climate. This scenario establishes a benchmark against which we compare alternative futures.

To reflect climate change, we gradually adjust the temperatures in the eight climate regions in accordance with trends from the United Kingdom Hadley Centre climate model (HadCM2) for the mid-Atlantic region. HadCM2 accounts for both greenhouse gases and aerosols, and is used, among others, by the Intergovernmental Panel on Climate Change for projections until 2100.

Table 1
Regression results

	Residential sector		Commercial sector		Residential and commercial
Independent variables (base point temperatures in brackets)	Log electricity per capita (kWh/person/month)	Log natural gas per capita (ft^3/person/month)	Log electricity per employee (kWh/person/month)	Log nat. gas per employee (ft^3/person/month)	Log heating oil per capita (gal./person / month)
Constant	5.35969***	9.665865***	4.929313***	5.876947***	2.585665***
Annual trend	0.0127386***	0.0335183***	0.0772271***	0.0554748***	−0.0590547***
CDD (53°F)			0.0004013***		
CDD (60°F)	0.0010355***				
HDD (53°F)			0.0002052***		
HDD (60°F)	0.0006528***				
HDD (64°F)					0.0010945***
HDD (71°F)		0.0009751***		0.0011024***	
Daylight	0.0005867	0.0051253	−0.0062064	0.0259723	−0.0384377**
Log price	−0.0499648	−1.984442***	0.0010849	−0.2968363*	0.0463627
Adj. R^2	0.8441	0.9069	0.6243	0.8119	0.8324
Transforned DW	1.942146	2.004448	2.418751	1.925123	2.132796
N	143	155	143	155	239

*Significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

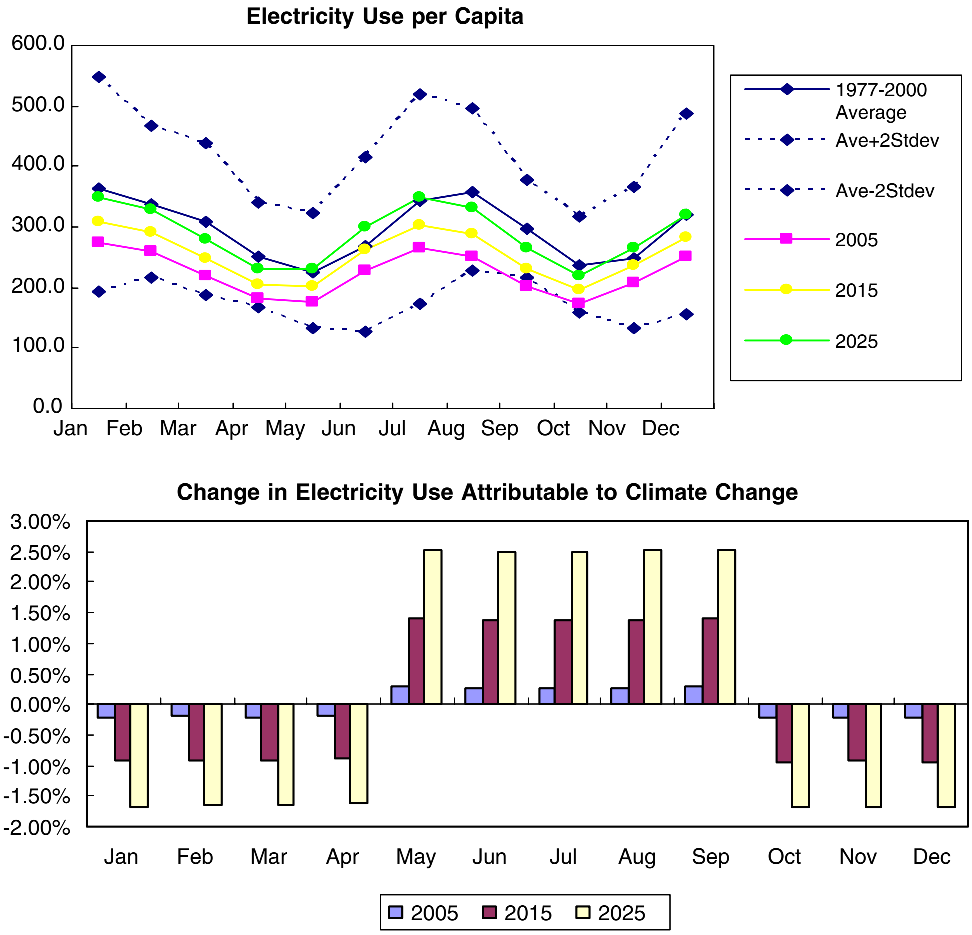


Fig. 9. Electricity use per capita and percentage change attributable to climate change. (Future electricity price is assumed to be equal to the average historical price.)

According to HadCM2, temperatures in Maryland could increase by 3°F (with a range of 1–7°F) in spring and 4°F (with a range of 2–9°F) in summer, fall and winter by the year 2100. Results for the low and high assumptions of future temperature changes are not qualitatively different from the mid-range projections and therefore not discussed in detail here. On the basis of these future temperature scenarios, and forecasts of population and employment in the eight climate regions, we calculate new population-weighted future heating and cooling degree-days for each fuel.

Other climate models yield different projections. Over the 25 years modeled here, these differences are relatively small for temperature changes (but more pronounced for precipitation changes, which do not enter our analysis). Choosing forecasts from other climate models does not qualitatively alter our simulation results below.

The assumptions about temperature changes can be combined, for example, with a range of assumptions about future energy prices. One scenario would posit that future energy prices remain at current (2003) levels, which is tantamount to assuming that the lowest historical prices can be maintained over the next 25 years. Alternatively, future energy prices could be at the average observed over the historic record. This assumption implies higher energy cost and thus, *ceteribus paribus*, lower-energy demand, because historic prices on average are above current prices. Assuming even higher prices merely drowns out the climate signal on energy demand further than already done when assuming average prices. Qualitatively, no new insights will be gained from a high-price scenario, though obviously the magnitude of the effects will change.

The following graphs show results for the mid-range of temperature changes (+3°F in spring and +4°F in summer, fall and winter), as well as energy prices at their average historic levels. To filter out the potential effects of climate change on energy demand, we compare the results to a scenario of average energy prices and average temperatures.

The projections for residential monthly electricity are shown in Fig. 9. The results suggest that demand for residential electricity by 2025 would closely resemble average demand over the 1977–2000 time period, and that if future prices were like the historical average, then residential electricity use in the near future would be noticeably below average use. To illustrate how close to the historical experience may be to modeled future energy use, Fig. 9 (as as well each of the remaining figures) depicts an envelope of two standard deviations around the historical data. Of course, modeled future energy use itself is uncertain, with some of the uncertainties reflected by the confidence intervals of the statistical estimates and the potential temperature ranges provided by the climate model (Table 1).

To separate the changes in monthly per capita energy use attributable to climate change, the bar chart of Fig. 9 shows the difference between the amount projected for a year with and without climate change. The graph suggests that total change attributable to climate change is small, though seasonally not uniform. To push, *ceteribus paribus*, modeled future energy use outside the range of historically observed trends would require larger deviations from the mean changes in temperatures assumed here than found in HadCM2, i.e. the uncertainties in future climate predictions are too small to significantly alter the model results.

If we assume, in contrast, that electricity prices would stay at their current, historically low levels, future electricity use per capita would increase with warmer climate scenarios (see Fig. 10). As with the previous scenario, electricity use per capita is fairly consistent with past electricity use patterns. However, since energy prices are assumed to remain low, climate impacts on electricity use are felt more in the region, resulting consistently throughout each year of the forecast period in increased per capita use by more than 20% (see bar chart of Fig. 10).

Fig. 11 shows that residential per capita gas consumptions would in the future, with climate change, decrease during the early and late parts of the year, yet increase during summer months, in part because of increased non-energy sensitive demand. While much of the change in natural gas use is outside the historically observed range, the percentage change in per capita natural gas use that is attributable to climate change is rather small (see bar chart of Fig. 11).

Fig. 12 shows future heating oil consumption per capita. Because of persistent trends to replace heating oil as a residential energy source, per capita demand goes to zero by 2015, with higher winter temperatures speeding up that trend.

Results for the commercial sector differ from those for the residential sector, with future electricity use per employee clearly exceeding the range of the historically observed pattern (Fig. 13). During spring, summer and fall, up to 10% of the increase in commercial electricity demand in 2020 is driven by climate. The remaining 90% are the result of increases in economic activity.

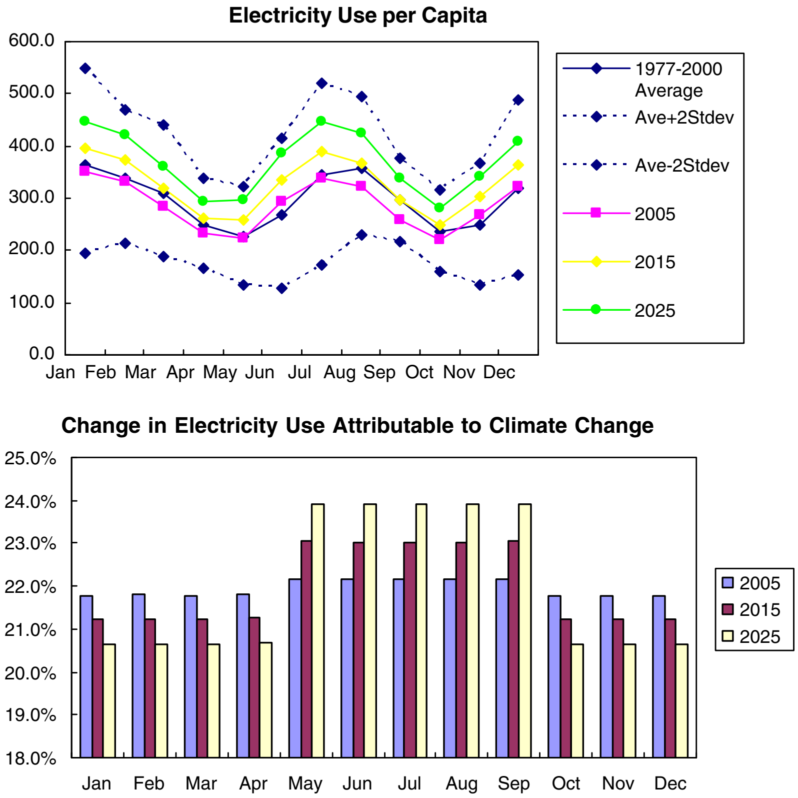
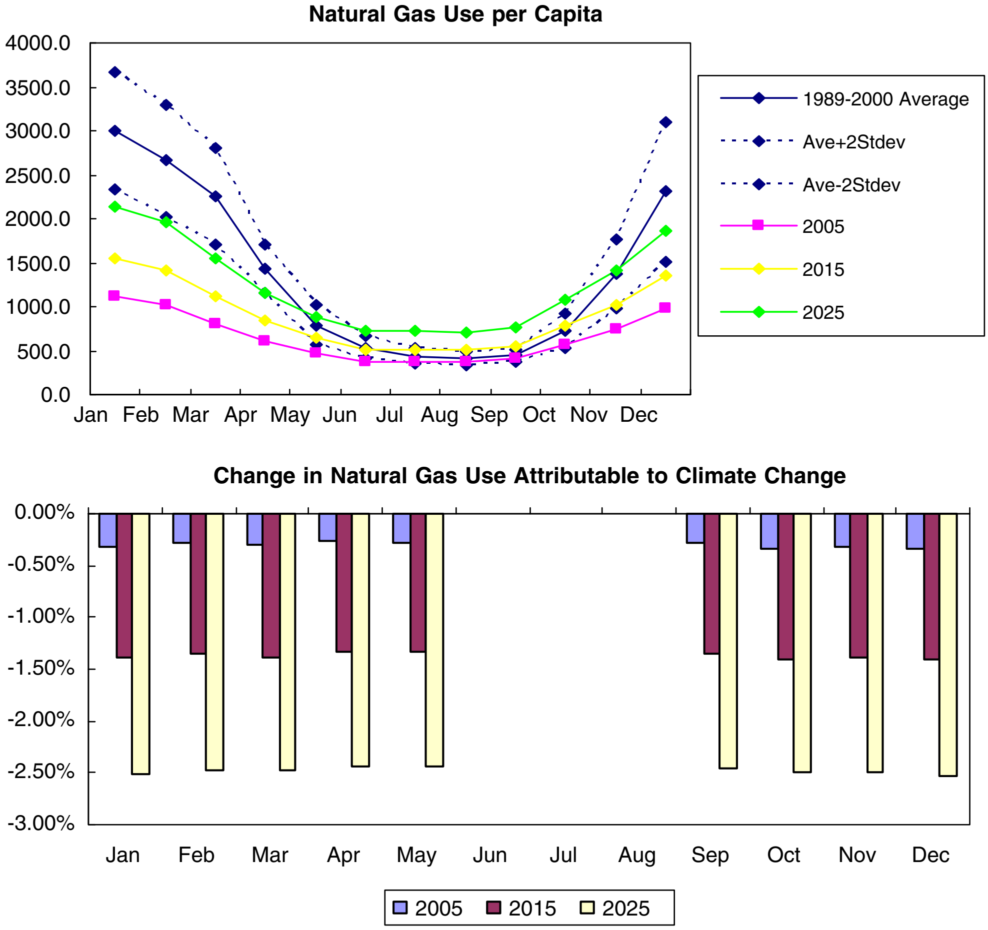


Fig. 10. Electricity use per capita and percentage change attributable to climate change. (Future electricity price is held constant at current levels.)


Natural Gas Use per Capita

Change in Natural Gas Use Attributable to Climate Change

Fig. 11. Natural gas use per capita and percentage change attributable to climate change. (Future natural gas price is assumed to be equal to the average historical price.)

Combined, climate and non-climate factors increase annually electricity use per employee during peak-demand months on average by nearly 10%. In contrast, natural gas use per employee largely falls within two standard deviations around the historical mean (Fig. 14).

6. Summary and discussion

This study investigates the potential impacts of climate change on the use of electricity, natural gas and heating oil in the residential and commercial sectors at the sub-national level, using a three-step process. First, region-specific, population weighted climate data was used to identify balance point temperatures above and below which energy use is temperature sensitive. Second, energy use by energy type and sector was regressed against heating and cooling degree-days, length of daylight hours, energy prices and trend variables to establish statistical relationships on the basis of past behaviors. Those relationsips were then used in the third step of the analysis to explore how energy use may differ for different assumptions about future climate, population and energy prices.

The results of this analysis suggest that assumptions about future energy prices and regional population changes may have much larger impacts on future energy use in Maryland's residential and commercial sector than assumptions about future climate. Although there are noticeable seasonal and annual impacts of climate change—all of which differ for electricity, natural gas and heating oil use—few of the impacts fall well outside the historically observed ranges. One of the areas in which future demand will significantly deviate from past experiences is electricity use by the commercial sector. Continuing past trends and exacerbating them by changes in climate will result in total (climate and non-climate induced) electricity use per employee to rise by approximately 10% per year during peak demand periods of the year.

Several conclusions emerge from this analysis. First, even moderate changes in energy prices can trigger demand responses that help revert climate-induced

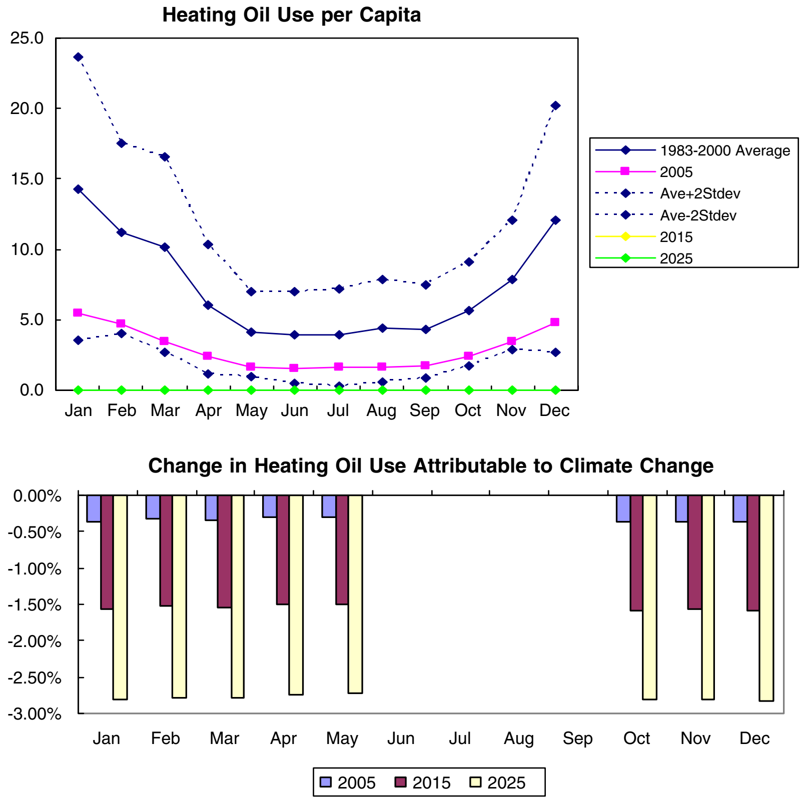


Fig. 12. Heating oil use per capita and percentage change attributable to climate change. (Future natural gas price is assumed to be equal to the average historical price.)

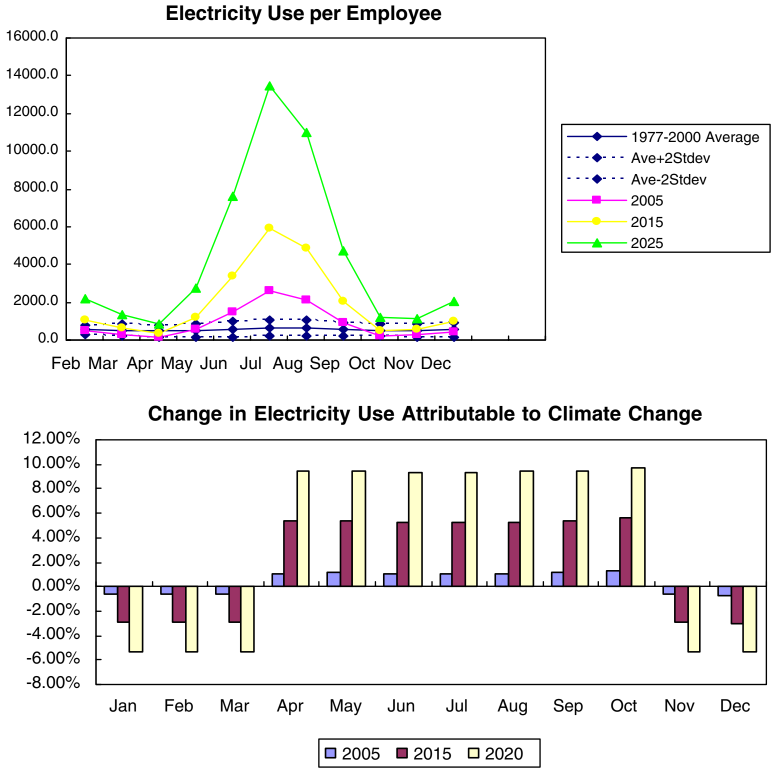


Fig. 13. Electricity use per employee and percentage change attributable to climate change. (Future electricity price is assumed to be equal to the average historical price.)

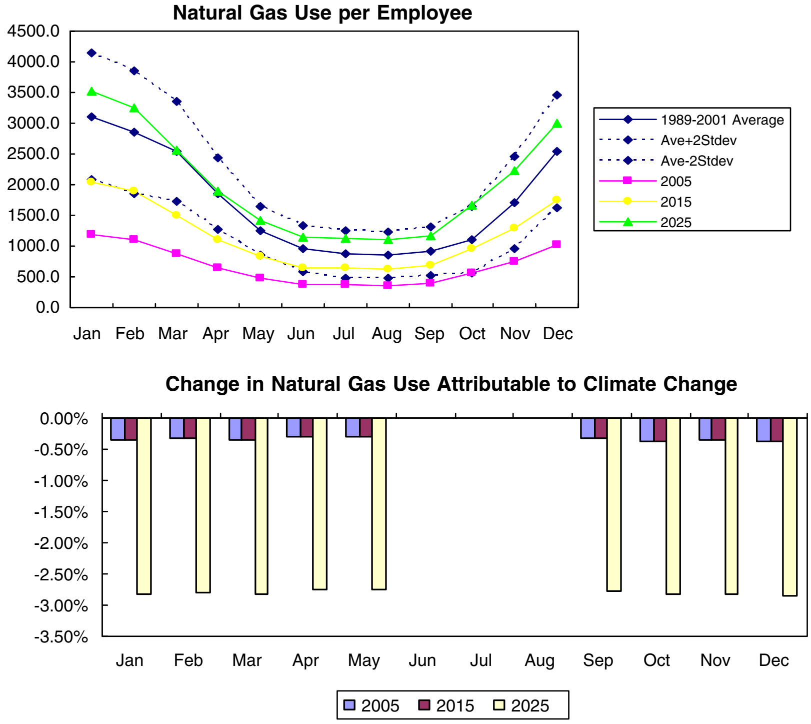


Fig. 14. Natural gas use per capita and percentage change attributable to climate change. (Future natural gas price is assumed to be equal to the average historical price.)

increases in demand. Second, with the exception of commercial electricity demand, there is no immediate need for large-scale investment in electricity generation and energy delivery systems to meet the energy demands induced by climate change. However, energy demand—and particularly electricity demand—in the region will increase considerably for reasons not directly related to climate, thus requiring aggressive policy, investment and behavioral responses to prepare for, or avoid, shortfalls in energy supply. Because there are typically long lead times between changes in demand and expansion in the infrastructure to meet that demand, the region must carefully prepare for changes in energy use well before the full impacts are felt.

Third, climate-induced increases in electricity use in the commercial sector are larger than in the residential sector. These impacts are most pronounced during the summer months—a period in which the region already on occasion battles peak load capacity constraints. Furthermore, these impacts noticeably increase non-linearly in later years. Since the commercial sector provides an important base for economic activity in the region and is particularly sensitive to power supply disruptions, prudent capacity planning becomes even more important now than it has been in the past.

Taken together, all three conclusions give hope for the region to gradually adjust its energy use profiles, assuming energy prices provide adequate signals to consumers in the residential and commercial sectors to reduce energy use, and to modify the existing supply structures and capacities to meet future demand. As these adjustments are undertaken, opportunities are opened up to reduce greenhouse gas emissions through reductions in energy use and through changes in the relative shares of the energy types used in the region.

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