Monitoring Climate Variability's Impact on Residential Energy Consumption in the United States: Approach to the Disaggregation of Heating Fuel Consumption

Kathryn Tippey
University of Alabama

Randy Beavers
University of Alabama

Analysis of the effects of temperature fluctuations on residential energy expenditures is important to the future of the energy industry. While energy usage varies regionally and seasonally, the specificity of data available for this level of investigation is limited, particularly with respect to heating fuel consumption. This paper explores an approach to the disaggregation of heating fuel consumption from national monthly data and state yearly data to state monthly data via the development of a standardized computational method.

INTRODUCTION

Analysis of the effects of temperature fluctuations on residential energy expenditures is important to the future of the energy industry. As the climate warms, energy consumption in climate-sensitive sectors is likely to change. Effects in residential, commercial, and industrial buildings may include [1] decreases in the amount of energy used for space heating and increases for space cooling; [2] decreases in energy consumed directly in certain processes such as water heating, and increases in energy used for refrigeration cooling; [3] increases in energy used to supply for climate-sensitive processes, such as pumping water for irrigated agriculture and municipal uses; [4] changes in the balance of energy use among delivery forms and fuel types (i.e., electricity used for air conditioning and natural gas used for heating); and [5] changes in energy consumption in climate-sensitive sectors of the economy, such as transportation, construction, and agriculture (Scott & Huang, Effects of Climate Change on Energy Use in the United States).

This paper explores an approach to the disaggregation of heating fuel consumption from national monthly data and state yearly data to state monthly data based on available data via the development of a standardized computational method. While energy usage varies regionally and seasonally, the specificity of data available for this level of investigation is limited, particularly with respect to heating fuel consumption.

Types of Fuels

Different types of heating fuels are refined form crude oil through a three step process: [1] separation of the petroleum components, or "fractions," into heavy and light "fractions;" [2] conversion of heavier hydrocarbon molecules into lighter ones; and [3] treatment combining specific fluids from the previous two steps (U.S. Energy Information Administration, Energy Kids, n.d.). The three main types of heating fuels are distillate fuel oil, liquefied petroleum gas, and kerosene.

Residential heating fuel consumption is defined as energy consumed in living quarters and private households (U.S. Energy Information Administration, Independent Statistics and Analysis, n.d., Petroleum Navigator, Topic: Sales). As the specific terminology surrounding the use of the three main types of heating fuels on the residential level is complicated, the following further explains the subcategories of each of these types of heating fuels.

Distillate fuel oil is a general classification of one of the petroleum fractions produced in the distillation process and includes both diesel fuels and fuel oils (U.S. Energy Information Administration, Independent Statistics and Analysis, n.d., Petroleum Navigator, Topic: Sales). Residentially speaking, this primarily refers to no. 1 fuel oil, which is used as fuel for portable outdoor stoves and portable outdoor heaters, and no. 2 fuel oil, which is more commonly known as no. 2 heating oil and is used in atomizing type burners for domestic heating (U.S. Energy Information Administration, Independent Statistics and Analysis, n.d., Petroleum Navigator, Topic: Sales).

Liquefied petroleum gases (LPG) are a group of hydrocarbon-based gases derived from crude oil refining or natural gas fractionation that are liquefied through pressurization for transportation purposes. The common residentially used subcategory is propane, which is a gaseous straight-chain hydrocarbon used mainly for heating purposes in rural areas that do not have natural gas service (U.S. Energy Information Administration, Independent Statistics and Analysis, 2010, Petroleum Explained).

Kerosene is a light petroleum distillate (U.S. Energy Information Administration, Independent Statistics and Analysis, n.d., Petroleum Navigator, Topic: Products). The common residential uses for kerosene are in space heaters, in cook stoves, and in water heaters (U.S. Energy Information Administration, Independent Statistics and Analysis, n.d., Petroleum Navigator, Topic: Products).

Heating Degree-Days

As weather and climate are frequently used to explain year-to-year changes in residential energy consumption, degree-days offer a form of quantitative index designed to reflect temperature-based energy demand (National Oceanic and Atmospheric Administration, National Climatic Data Center, 2010, Residential Energy; National Oceanic and Atmospheric Administration, National Climatic Data Center, 2010, Heating). Heating degree-days (HDD) occur when the mean temperature outside is less than a reference temperature, indicating a household would use a heating device to heat their home:

$$HDD = \begin{cases} T_{ref} - T_{mean} & T_{ref} > T_{mean} \\ 0 & otherwise \end{cases}$$

The mean temperature for a day is calculated as the average of the minimum and maximum temperatures that day (Qualye & Diaz, 1980, pp. 241-242):

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

Although studies have noted that hourly weighted averages are preferred in the calculation of daily mean temperature, the computation outlined above is the field standard and hence data processed using this equation is readily available. Studies have shown that this common method is adequate for most climatological data analysis (Qualye & Diaz, 1980, pp. 241-242).

The standard reference temperature is 65 degrees (Qualye & Diaz, 1980, pp. 241), making the heating degree-days (HDD) calculation for a day:

$$HDD = \begin{cases} 65 - T_{mean} & 65 > T_{mean} \\ 0 & otherwise \end{cases}$$

This computation implies that the amount of heating used increases as the mean temperature decreases (Qualye & Diaz, 1980, pp. 241). The HDD calculation for a month is the summation of each of the days within that month.

The population for an area interacts with the temperature in determining the amount of resources used for temperature modifications (i.e., use of heating and cooling devices). Hence, heating degree-days are commonly population-weighted to further reflect temperature-based energy demand:

$$hdd_a = \frac{\sum_{i=1}^{n_s} HDD_i Pop_i}{\sum_{i=1}^{n_s} Pop_i}$$

where hdd_a is the population-weighted HDD for a composite area *a*, HDD_i is the number of heating degree-days for a particular station, Pop_i is the population in the area surrounding a particular station, and is the number of stations in the composite area.

Prior research indicates that a high correlation exists between heating degree-days and residential heating fuel consumption. Simple regressions confined to a small area where data for residential heating fuel consumption was obtained had observed correlation coefficients around 0.9 (Qualye & Diaz, 1980, pp. 242). As this analysis was performed in a small area, other variability that may contribute to variations in heating fuel consumption was likely held constant. However, as the majority function of heating fuels on the residential level is defined through modifying temperatures within a household, this study is logically consistent with the definition.

Reasons for Higher Specificity Analysis

While national monthly data is available for energy related climate change analysis, the implications of climate change for the energy sector are heavily dependent on higher specificity variables, such as region-specific variables, infrastructure, socioeconomic, and energy use profiles (Amato, Ruth, Kirshen, & Horwitz, 2005, pp. 175). While the method discussed allows for the disaggregation of heating fuel consumption down to the state level, the disaggregation method is more accurate at the regional level because the percentage difference observed in the year-to-year values of state yearly energy consumption when grouped by region is smaller than the percentage difference observed in the year-to-year values of state yearly energy consumption when just using the state.

Regional division

As heating fuels are a type of petroleum product, the Petroleum Administration for Defense Districts (PADD) represent a logical division of the states into regions. PADDs were originally created during World War II under the Petroleum Administration for War Act to aid in the allocation of fuels derived from petroleum products (U.S. Energy Information Administration, Independent Statistics and Analysis, n.d., PADD). These districts were abolished in 1946 and then reinstated during the Korean War (U.S. Energy Information Administration, Independent Statistics and Analysis, n.d., PADD). Today the districts are used for data collection.

Data

This section explains the specific data sets used in the development of the method discussed later in the paper.

Energy Information Administration (EIA) State Energy Data Systems (SEDS) Data

The specific data series used in this paper was the Energy Information Administration's (EIA's) State Energy Data Systems (SEDS) online database residential consumption for all states in British Thermal Units (BTU). Note as the computations involving this data result in percent values, only the units across states must be standard for each type of heating fuel observed.

The state yearly data used to calculate the percent yearly consumption for each state was queried through the Energy Information Administration's (EIA) State Energy Data Systems (SEDS). As state-level consumption data and end-use consumption data are not available for the three primary heating fuels (distillate fuel, liquefied petroleum gas, and kerosene), the EIA estimates state yearly consumption. The state-level residential consumption estimate for each type heating fuel is based on the two primary assumption: [1] each state consumes a specific type of heating fuel in proportion to the amount of sales to that state, and [2] each end-use sector in a state consumes a specific type of heating fuel in proportion to the amount of sales to that end-use sector (U.S. Energy Information Administration, Independent Statistics and Analysis, 2009, State Energy, pp. 34, 44, 47). Hence, for each type of heating fuel, the total U.S. consumption of that fuel is apportioned into state-level consumption via [1] and then end-use consumption via [2] (U.S. Energy Information Administration, Independent Statistics and Analysis, 2009, State Energy, pp. 34, 44, 47).

Residential distillate fuel consumption, coded DFRCP*ZZ* (*ZZ* represents the unique state abbreviation), is estimated based on the sales of distillate fuel into or within each state, which is published in the Energy Information Administration's (EIA) *Fuel Oil and Kerosene Sales Report* (U.S. Energy Information Administration, Independent Statistics and Analysis, 2009, State Energy, pp. 32). Distillate fuels sales to the residential sector include uses for space heating, water heating, and cooking, excluding farm houses (U.S. Energy Information Administration, Independent Statistics and Analysis, 2009, State Energy, pp. 33).

Residential liquefied petroleum gas consumption, coded LGRCP*ZZ* (*ZZ* represents the unique state abbreviation), is estimated based on the sales of liquefied petroleum gas into or within each state, which is published in the Energy Information Administration's (EIA) *Petroleum Supply Annual* (U.S. Energy Information Administration, Independent Statistics and Analysis, 2009, State Energy, pp. 51). LPG sales for residential use include uses by nonfarm private households for space heating, cooking, water heating, and other household uses, such as clothes drying and incineration (U.S. Energy Information Administration, Independent Statistics and Analysis, 2009, State Energy, pp. 47).

Residential kerosene consumption, coded KSRCP*ZZ* (*ZZ* represents the unique state abbreviation), is estimated based on the sales of kerosene into or within each state, which is published in the Energy Information Administration's (EIA) *Fuel Oil and Kerosene Sales Report* (U.S. Energy Information Administration, Independent Statistics and Analysis, 2009, State Energy, pp. 47). Kerosene sales for residential use include uses only for heating (U.S. Energy Information Administration, Independent Statistics and Analysis, 2009, State Energy, pp. 44).

Energy Information Administration (EIA) Monthly Energy Review (MER)

The national monthly residential consumption data that is proportionately disaggregated among the regions is published in the Energy Information Administration's (EIA) Monthly Energy Review (MER). The EIA estimates the national monthly values as direct consumption data is not available. Residential consumption data for each of the three main types of heating fuel is computed similarly: [1] historical estimates are computed by allocating the annual estimates into months via each month's share of the year's sales (U.S. Energy Information Administration, Independent Statistics and Analysis, 2010, Petroleum: Monthly Energy Review, pp. 3); and [2] estimates for each month of the current year are based off the consumption increase from same month in the previous year by using the percent increase in that month's sales as compared to the previous year (Amato, Ruth, Kirshen, & Horwitz, 2005).

Population-Weighted Heating Degree-Days Data

The daily minimum and maximum temperature data used for the computation of the mean temperature for the calculation of heating degree-days was obtained through the National Climatic Data Center's (NCDC) TD-3200 U.S. Cooperative Summary of the Day (1890(1948)-cont) database, which includes station data from the National Weather Service (NWS), the Federal Aviation Administration (FAA), the National Park Service (NPS), the Bureau of Land Management (BLM), the U.S. Forest Service (USFC), the U.S. Geological Survey (USGS), the Tennessee Valley Authority (TVA), and several of the stations at Air Force and Navy bases (National Science Foundation, Community Data Portal, n.d.). The stations used are located in the contiguous U.S. and passed the Menne and Williams statistical homogeneity tests.

The population-weighting was added via 2000 census data for each station coded. As stations are coded and each code involves a numeric representation for each state, the population-weighted values for the stations in each state were then summed to get the state total population-weighted HDD.

Regional Data Analysis

As the purpose behind the creation of the Petroleum Administration for Defense Districts (PADDs) was the allocation of petroleum-based fuel products, similarities exist pertaining to the consumption and pricing within each district. Hence, the data was divided with this same construction when exploring regional analysis.

TABLE 1
PETROLEUM ADMINISTRATION DEFENSE DISTRICTS
(U.S. Energy Information Administration, Independent Statistics and Analysis, n.d., PADD)

PADD I (East Coast)	PADD IA (New England): Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont.
	PADD IB (Central Atlantic): Delaware, District of Columbia, Maryland, New Jersey, New York, Pennsylvania.
	PADD IC (Lower Atlantic): Florida, Georgia, North Carolina, South Carolina, Virginia, West Virginia
PADD II (Midwest)	Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, Oklahoma, South Dakota, Tennessee, Wisconsin
PADD III (Gulf Coast)	Alabama, Arkansas, Louisiana, Mississippi, New Mexico, Texas
PADD IV (Rocky Mountain)	Colorado, Idaho, Montana, Utah, Wyoming
PADD V (West Coast)	Alaska (North Slope and Other Mainland), Arizona, California, Hawaii, Nevada, Oregon, Washington

METHOD DEVELOPED

Process to Derive Data Set

To recap the data used in the development of this method included state yearly residential heating fuel consumption for distillate fuel oil, liquefied petroleum gas, and kerosene; national monthly residential heating fuel consumption for distillate fuel oil, liquefied petroleum gas, and kerosene; and state monthly population-weighted heating degree days.

To obtain current estimates of monthly residential heating fuel consumption data for a higher specificity area (i.e., state-level or regional-level), the following process was developed.

In the structure of the equations, an area refers to a state or region. The sum of all the areas a_i is equal to the "nation" N:

$$N = \sum_{i=1}^{n_a} a_i$$

where $i=1,\ldots,n_a$ is the number of areas in the nation

The time t is in months, and the end computation is for a single month, which is noted as the "current" month at time (i.e.,$t=0$).

The first step is to calculate that area's percent yearly consumption with respect to the national yearly consumption:

$$\%\left(c_a^f\right) = \frac{c_a^f}{\sum_{i=1}^{n_a} c_i^f}$$

where $\%(c^f_a)$ is area a's percent yearly consumption of a type of heating fuel f with respect to the national yearly consumption.

The second step is to calculate the area's percent population-weighted heating degree-days (HDD) for that month with respect to the sum of the area's total population-weighted HDD for the current past year:

$$\%(hdd_{a,t}) = \frac{hdd_{a,t}}{\sum_{k=0}^{11} hdd_{a,t-k}}$$

where $\%(hdd_{a,t})$ is area a's percent population-weighted HDD for the current past year from time t.

The third step is to multiply step [1] times step [2]:

$$\%(c_a^f \times hdd_{a,t}) = \%(c_a^f) \times \%(hdd_{a,t})$$

where $\%(c^f_a \times hdd_{a,t})$ is area a's percent yearly consumption of a type of heating fuel f with respect to the national yearly consumption times area a's percent population-weighted HDD for the current past year from time t.

The fourth step is to divide step [3] by the summation of the [3]'s for each of the areas composing the nation:

$$\%(C_{a,t}^f) = \frac{\%(c_a^f \times hdd_{a,t})}{\sum_{i=1}^{n_a} \%(c_a^f \times hdd_{a,t})}$$

where $\%(C^f_{a,t})$ is percent area a's monthly consumption of a type of heating fuel f with respect to the national monthly consumption.

The fifth step is to multiply step [4] times the national monthly consumption for that month, which equals the area's monthly consumption for that month:

$$C_{a,t}^f = \%(C_{a,t}^f) \times C_{N,t}^f$$

where $C^f_{a,t}$ is heating fuel f consumption for area a for time t and $C^f_{N,t}$ is heating fuel f consumption for the "nation" N for time t.

RESTRICTIONS OF THE DATA SET

The primary limitation of the data set stems from the necessary inclusion of heating degree-day (HDD) in the computational process, which adds endogeneity to analysis involving temperature components. The data set also assumes that all other uses for heating fuels outside of the heating homes involve negligible consumption.

When using data from the previous year to estimate the disaggregation for the current year, the regional-level disaggregation is more accurate than state-level disaggregation due to the greater variability in the percentage distribution of the higher specificity values when lags in the state yearly data are compared from year-to-year. Hence, the national monthly data should only be disaggregated to the state monthly level after state yearly data becomes available for that year.

CONCLUSION

The resulting method of disaggregation of heating fuel consumption outlined in this paper provides researchers with a stable process for computing higher specificity data that can be used to further analyze the affects of climate variations on residential energy consumption and values. While the resulting data has strict limitations, the higher specificity values are still useful to gain insight into the relationship between heating fuel consumption and alternate factors. This includes allowing the researcher to assess a data set that could be combined with other readily available higher specificity data sets for dynamic panel data analysis as well as a model for more in-depth exploration into additional economic variables.

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