

**The Growth in Electricity Demand in U.S. Households, 1981-2001:  
Implications for Carbon Emissions**  
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**ABSTRACT**

In 2003, energy used in housing units accounted for 22 percent of total U.S. energy consumption. In terms of carbon emissions, households were responsible for 21 percent of the energy-related carbon dioxide emissions—which is a significant amount of carbon emissions. Electricity use in households was responsible almost for 70 percent of household emissions. Despite its large impact on carbon emissions, the household sector does not receive as much attention in carbon emissions reduction programs, as do energy suppliers and larger consumers (e.g., manufacturers). Using data from the Energy Information Administration’s Residential Energy Consumption Surveys (RECS), this paper takes a look at the related carbon dioxide emissions over two decades, 1981 to 2001.

It is important to first examine trends in electricity consumption and then the related carbon emissions in households. Trend analysis is one tool that can assist in the design of an energy plan to reduce household electricity use and lower carbon emissions.

This paper first presents trends in electricity demand and the underlying factors affecting the trend such as population, size of housing, and income. Next, the implications for carbon emissions will be presented starting with the growth in carbon emissions between the 1981-2001 time periods. Finally the paper explores two measures of carbon-dioxide intensity.

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**INTRODUCTION**

According to the Energy Information Administration’s Annual Energy Outlook 2004 (AEO), household primary energy consumption<sup>2</sup> is projected to increase by 25 percent between 2002 and 2025. Electricity use is projected to account for about 76 percent of the growth in household energy use. According to the forecast, the upward trend in demand is projected to be influenced by increasing size of homes and housing growth in the South census region. Dampening the energy growth will be the increase in the use of more energy efficient appliances as well as technology advances.

There is a high correlation between energy consumption and carbon emissions. Electricity generation is the main source of carbon emissions, as coal is used to generate over half of the electricity. Therefore, households indirectly emit carbon by consuming electricity. Household’s electricity consumption is mainly as a result of demand for appliances followed by space cooling. In 2001, about 65 percent of household demand for electricity was for appliances.

The paper will first present the trend in electricity consumption by location of demand and show the growth in appliances, which is the main driver of household electricity demand. Next, the underlying factors are presented that affect the trend such as: population, size of home, and income. Following these trends are the implications for carbon emissions starting with the growth in carbon emissions between the 1981-2001 time periods—in both absolute numbers as well as carbon-intensity indicators. These intensity indicators include carbon per capita, and carbon per dollar of personal consumption expenditures.

## DATA USED

Most of the data used in this analysis are from the Energy Information Administration's (EIA) Residential Energy Consumption Surveys (RECS). The RECS collects energy consumption and expenditure data as well as related housing characteristic information from a sample of residential housing units. The estimated consumption data are based on the five main energy sources: natural gas, electricity, fuel oil, kerosene, and liquefied petroleum gas (LPG). Estimation of household carbon dioxide emissions is based on the carbon-emissions factors estimated by the EIA's International, Economic and Greenhouse Gases Division and used in *Emissions of Greenhouse Gas Emissions in the United States*.

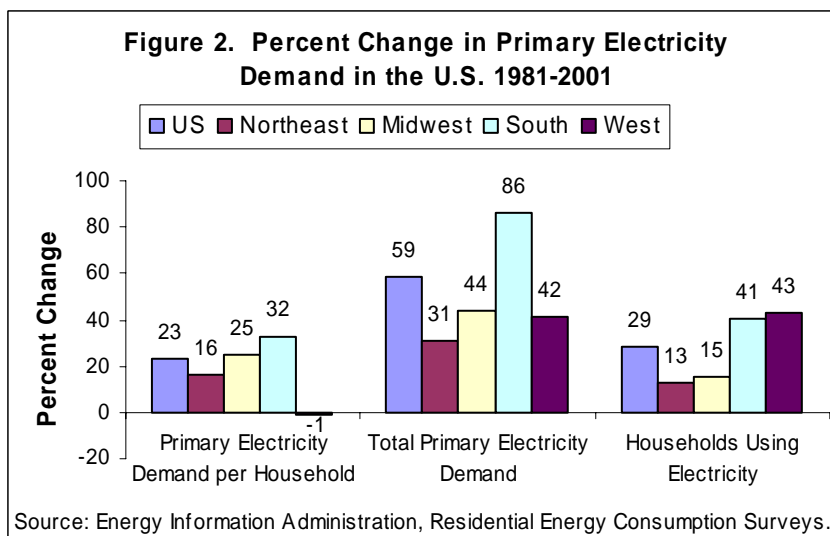
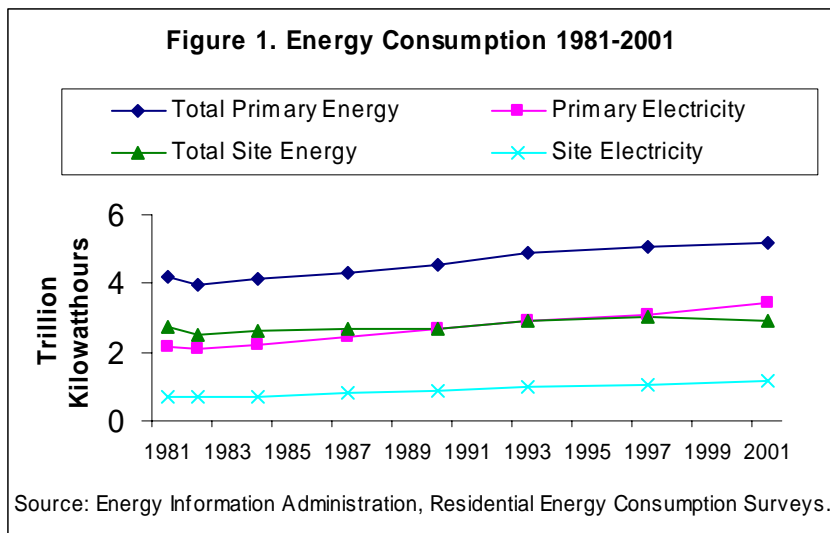
## GROWTH IN THE USE OF ELECTRICITY

### Total Electricity Demand

In 2001, U.S. households used 3,397 billion kilowatthours (KWh) of primary electricity, as estimated by RECS. This is about 36 percent of electricity used by all sectors--more than industrial demand of 29 percent (AER 2003). Electricity share's of total household energy consumption was 66 percent.<sup>3</sup> In 2001, about 69 percent of electricity was used in single-family household—63.1 million out of a total of about 107 million U.S. homes. There are variations by Census regions. About 38.9 million homes in the South region consumed 49 percent of electricity—where almost all new homes use central air conditioning.

Over the 20-year period demand for electricity in U.S. households continued to increase as demand for larger homes and consumer appliances increased. Between 1981 and 2001 the total amount of energy used by U.S. households increased by 24 percent, from 4,186 billion KWh in 1981 to 5,203 billion KWh in 2001 (Figure 1). In 2001, U.S. households used about 3,452 billion KWh of electricity-- about 66 percent of total energy used in the household sector.

Almost every household in the U.S. uses electricity. The number of homes increased by 29 percent between 1981 and 2001, but total electricity consumption increased by 59 percent. During the same time, electricity use per household increased by 23 percent—from 26,131 KWh in 1981 to 32,264 KWh in 2001.



From 1981 through 2001, total electricity demand increased in all regions—the South had the highest increase of 86 percent and the Northeast region experienced an increase of 31 percent (Figure 2). Average electricity consumption per household increased in all Census regions except for the West. Per household electricity demand in the West declined by 1 percent, while the number of households using electricity increased by 43 percent pushing up electricity demand by 42 percent. The electricity demand in West faced a supply crisis in 2001 which might have affected the per household electricity demand in the West.

## Electricity Use for End Uses

Unlike natural gas or fuel oil, for example, electricity has many uses in the household including heating, cooling, hot water, and the services of many appliances.<sup>4</sup> The type of appliances and the number of each type of appliances in households have grown rapidly. Not only are households purchasing new appliances, but they are getting multiple numbers of some. The largest use of electricity in the average U.S. households is for appliances. In 2001, two-thirds of all the electricity used in the household sector was used for appliances. In 2001, air-conditioning consumed the most electricity (16 percent of total), followed by refrigerators (14 percent), space heating (10 percent), water heating (9 percent), and lighting (8 percent).

Table 1 shows the penetration of selected electrical equipment and appliances in the U.S. households. In 1981 only 17 percent of households were using microwave ovens. By 2001, 86 percent of households were using a microwave oven, an increase of more than 400 percent. The use of dishwashers increased from 37 percent of all households in 1981 to 53 percent in 2001. Personal computers, which

**Table 1. Growth of Electrical Equipment and Appliances, 1981-2001(Percent of Households)**

	Survey Years							
	1981	1982	1984	1987	1990	1993	1997	2001
Refrigerator (One)	87	86	88	86	84	85	85	83
Refrigerator (Two or More)	13	13	12	14	15	15	15	17
Central Air Conditioning	27	28	30	36	39	44	47	54
Room Air Conditioning	31	30	30	30	29	27	25	22
Water Heating	32	32	34	35	37	38	40	38
Main Space Heating	17	16	17	19	23	26	29	29
Color Television	82	88	88	93	96	98	99	99
Black and White Television	48	47	43	36	31	20	NA	NA
Clothes Dryer	45	45	46	51	53	57	55	57
Freezer	38	37	37	34	35	35	33	32
Microwave Oven	17	21	34	61	79	84	83	86
Dishwasher	37	36	38	43	45	45	50	53
Personal Computer	NA	NA	NA	NA	16	23	35	56

Source: Energy Information Administration, Energy Consumption Surveys.

were virtually nonexistent in households in 1981, were found in only 16 percent of the U.S. housing units in 1990.<sup>5</sup> By 2001, the percent of households with a personal computer increased to 56 percent. In 2001, about 15 percent of households used more than one personal computer at home. During the same time period, the number of households using two or more refrigerators, increased from 13 percent to 17 percent. Similarly, the consumer demand for large screen televisions and multiple color televisions and other communication equipment grew over this time period.

Air-conditioning equipment has continuously increased its penetration in the U.S. housing stock over the two decades. In 1981, 58 percent of households used air (space) conditioners of some kind, compared with 76 percent in 2001. The overall increase was the result of significant increases in the use of central air conditioning which offset a decline in the use of window/wall units. The percent of

households using window/wall air conditioning decreased from 31 percent in 1981 to 23 percent in 2001. By 2001, 55 percent of households were using central air conditioning, compared with 27 percent in 1981.

These trends are related to income growth affecting a change in lifestyles resulting in increases in electricity demand despite energy-efficiency improvements in the equipment. In the following paragraphs the growth in electricity demand for appliances, air-conditioning, space heating, and water heating are explored.

**Appliances.** As mentioned earlier, the most important use of electricity in the average U.S. household is for appliances. Over the 1981-2001 period, the energy consumption for appliances rose by 2.5 percent a year. The average annual growth rate was higher in the South (3.5 percent) and lower in the Northeast (1.6 percent). Electricity consumption attributed to appliances increased from 16,424 KWh per housing unit in 1981 to 26,842 KWh. By 2001, the average household in the South consumed 33,948 KWh of electricity for appliances, compared with 19,530 KWh in the Northeast region. Relative to 1981, consumption of electricity for appliances by households located in the South and the Northeast census regions increased by 99 percent and 36 percent, respectively. The difference between the South and the West is mainly due to the high growth in the number of housing, size of housing and population in the South. During the same time period, population increased by 29 percent in the South and decreased by 4 percent in the Northeast.

**Air-Conditioning.** Despite improvement in the energy efficiency of cooling units, the increased demand for space cooling pushed the electricity consumption attributed to air-conditioning upward. As expected, the South consistently had the highest percentage of households using central air-conditioning. Air conditioning was used the least in the West.

Since 1981, air-conditioning related electricity consumption has grown by 3.1 percent annually. The total electricity consumption for space cooling increased by 83 percent, from 303 billion KWh in 1981 to 554 billion KWh in 2001 as the result of the increase in the number of housing units as population grew particularly in the South. The overall increase in air conditioning was due to a very large increase in demand for central air conditioning as the use of room air conditioning fell.

Between 1981 and 2001, the use of electricity by central air conditioning increased by 127 percent, while that of wall/window units decreased by 20 percent. Homes with central air-conditioning, all other things being equal, use more energy for cooling than homes with individual room conditioners. In 2001, average households that cooled with central air used 5,435 KWh more than households that cooled with window units.

**Space Heating.** Natural gas continues to be the major heating fuel in the U.S. homes. However, the proportion of households using electricity as a main space heating fuel has increased from 17 percent in 1981 to 29 percent in 2001—a reflection of significant increase in use of electricity as the main space heating especially in the South census region. One-third of all housing units in 2001 that used electricity as the main heating fuel used a heat pump;<sup>6</sup> the corresponding figure for the South was 41 percent. One of the factors that may influence the use of electricity for space heating is the unavailability of natural gas. About 59 percent of housing units that used electricity as main heating fuel, in 2001, did not have access to natural gas.

Between 1981 and 2001, the growth in space heating electricity consumption averaged 2.1 percent per year. As expected, the average annual growth rate was higher in the South (3.6 percent) and lower in the Northeast (0.3 percent). As the number of housing units increased, the amount of electricity that was used for space heating increased from 217 billion KWh in 1981 to 330 billion KWh in 2001, an increase of 52 percent.

Although the proportion of households using electricity for main space heating increased the intensity of electricity usage for space heating decreased. Over this time period, the average consumption of electricity among households that used it as main heating fuel declined from 5,909 KWh in 1981 per housing unit to 4,449 KWh—a 25 percent reduction. Among households that use electricity for heating,

the weather-adjusted average heating intensity per thousand square foot (KWh/HDTSQ) declined by 25 percent from 3.17 (KWh/HDTSQ) in 1981 to 2.54 (KWh/HDDTSQ) in 2001.

**Water Heating.** Electricity was the water-heating fuel of choice in 32 percent of homes in 1981. By 2001, 38 percent of households used electricity for heating water. During this period, electricity consumption attributed to water heating grew by 0.7 percent a year. Electricity use was 271 billion KWh in 1981, compared with 315 billion KWh in 2001, an increase of 17 percent. However, it varied by the Census regions. Electricity use to heat water in the South and the West regions experienced an increase of 36 percent and 6 percent, respectively. Electricity use declined by 10 percent in the Northeast and by 4 percent in the Midwest. A better indicator for measuring the change in water heating electricity use is the amount of electricity used per person. Between 1981 through 2001 electricity used for water heating per person decreased by 13 percent, from 3,647 KWh in 1981 to 3,173 KWh in 2001. The West experienced the greatest decline (29 percent) followed by the Northeast (18 percent).

As shown in Table 1, the proportions of households using electricity for space heating, water heating, and central air-conditioning increased between 1981 and 2001. During this period the energy efficiency of the appliance stock improved as less efficient older units were replaced by new, more efficient ones. This overall improvement in efficiency was a factor in the reduction of the average electricity consumption, contributing to the observed decrease in electricity intensity. In addition, variation in weather, population growth, larger homes are other factors that have also affected the level of consumption. The effects of these factors are discussed below.

## FACTORS AFFECTING THE GROWTH OF ELECTRICITY CONSUMPTION

The amount of electricity used in U.S. households is affected by many social and structural factors such as: income, age of householders, size of home, population, age of home and equipment. In addition, weather, appliance energy standards, and energy-saving programs influence the use of electricity.<sup>7</sup> This section will look at the trends in some of these factors between 1981 and 2001.

**Growth in Population and Housing.** Changes in population size, the size of homes, and the number of housing units affects the amount of electricity that is consumed at home. During the 1981-2001 period, electricity consumption by U.S. households has grown faster than population growth and the increase in the number of housing units. During the same time, primary electricity rose by 2.3 percent per year, number of housing units by 1.3 percent, and population by 0.8 percent per year.

Over the period, due to faster growth in electricity consumption than population, per capita use of electricity has increased. In 1981 an average household used 26,131 KWh of electricity, compared with 32,264 KWh in 2001. However, the increase in per capita use of electricity was less than per household. In 2001, the average household member used 12,589 KWh of electricity compared to 9,310 KWh in 1981.

Although total population grew over this period, the average size of households declined from 2.8 in 1981 to 2.5 in 2001. Regardless of household size, per capita consumption is higher in 2001 than in 1981. The intensity per member is lower for larger size households in both years. The energy intensity per household for an average one person household was 10,000 KWh in 1981 and 21,000 KWh in 2001. This measure for household of size three was 9,000 KWh and 12,000 KWh in 1981 and 2001, respectively.

Electricity use also is affected by the size of the homes—which is mostly affected by income as will be explained next. Over the years the average size of U.S. homes has grown, increasing the amount of electricity used. In 2001, an average two-person household in a less than 1,000 square feet unit used 23,000 KWh of electricity. This is 31 percent less than a household living in a 1,000 to 2,000 square feet home and 51 percent less than a household living in a more than 2000 square feet home. If the growth in these factors continue, it is more likely that the demand for electricity increases.

**Income Growth.** The most important factor affecting electricity demand is household income. Between 1981 and 2001 household real disposable income increased by 49 percent from \$17,217 to \$25,698.<sup>8</sup> As income increased so did the demand for larger homes and new appliances which in turn increased the

demand for electricity. In 2001, an average household with income of less than \$20,000 used about 24,000 KWh of electricity, compared with 42,000 KWh for those with income of more than \$50,000.

**Weather.** Weather is a major cause of the variation in household electricity use for space cooling and heating. Examination of the trend in electricity consumption and weather shows a direct relationship between weather and electricity consumption for space heating and space cooling. When undertaking trend analysis, the affects of weather need to be considered.

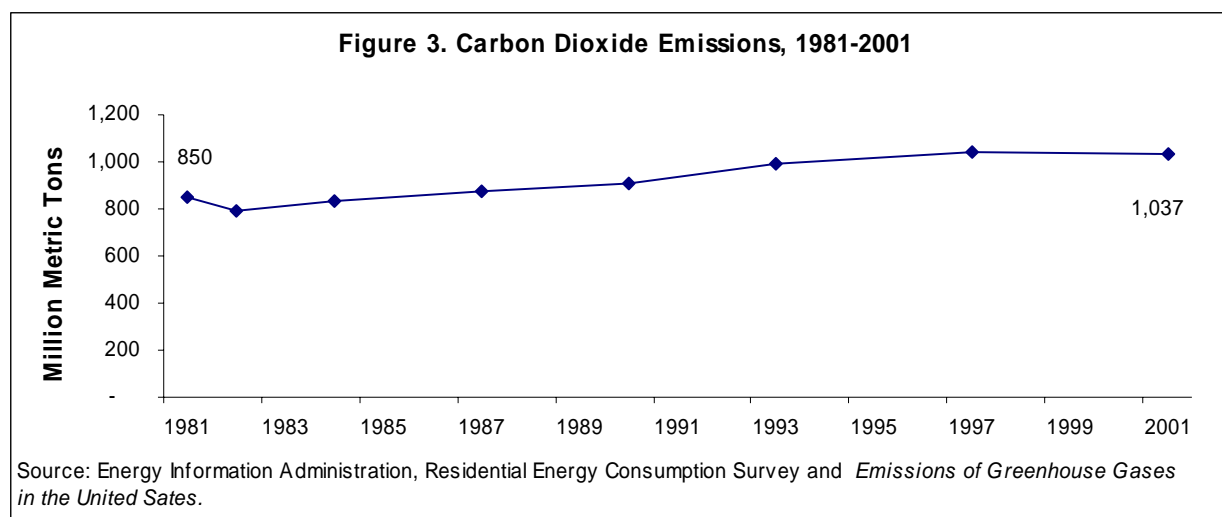
These factors have also affected the amount of carbon dioxide emissions. In the following section the trends in carbon dioxide during 1981 and 2001 are examined.

## TRENDS IN CARBON DIOXIDE EMISSIONS

Both the mix of energy sources used and the uses of energy affect carbon emissions. Year to year variation in energy consumption can affect carbon dioxide emissions. In the short run the amount of carbon dioxide emitted varies due to variation in weather, power generation fuel mix, and economic growth (EIA 2004). However, in the long run variation in carbon dioxide emissions is driven by factors such as population growth, income, and household choice of energy using equipment (EIA 2005). The carbon emissions occur where the electricity is generated, rather than at home. Therefore, primary energy consumption should be used when estimating the emissions.

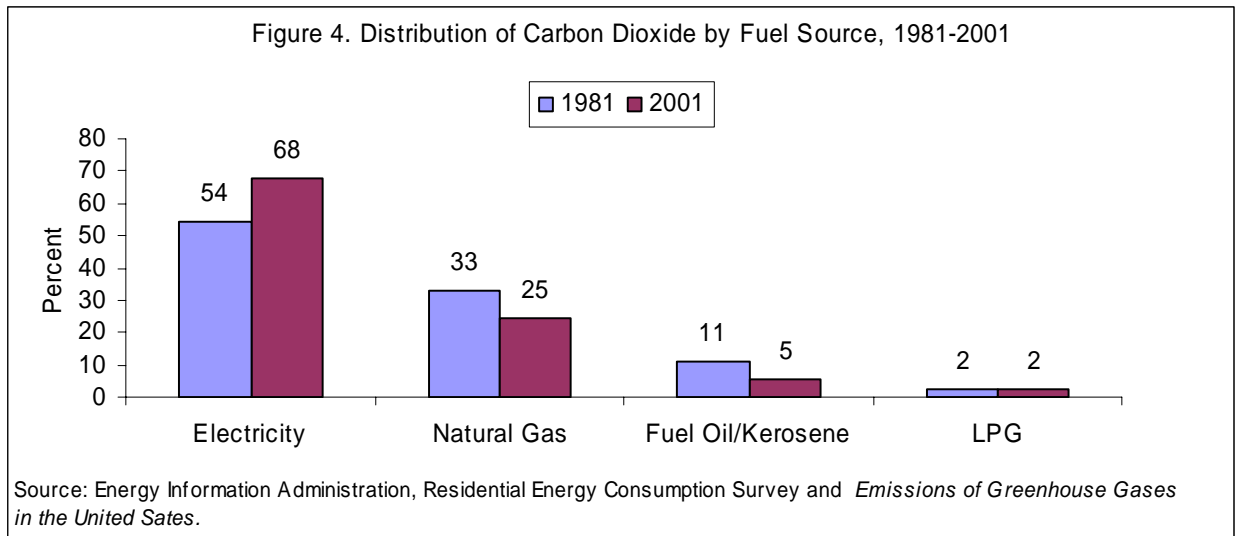
In 2002, carbon dioxide accounted for 84 percent of total greenhouse gas emissions in the U.S. Households were responsible for 21 percent of the energy-related carbon dioxide emissions (AEO 2005). According to the 2004 AEO, carbon dioxide emissions from energy consumption in the household sector are projected to increase by 1.1 percent per year from 2002 to 2025.

Figure 3 illustrate trends in household carbon dioxide emissions.<sup>9</sup> Over the 20-year period from

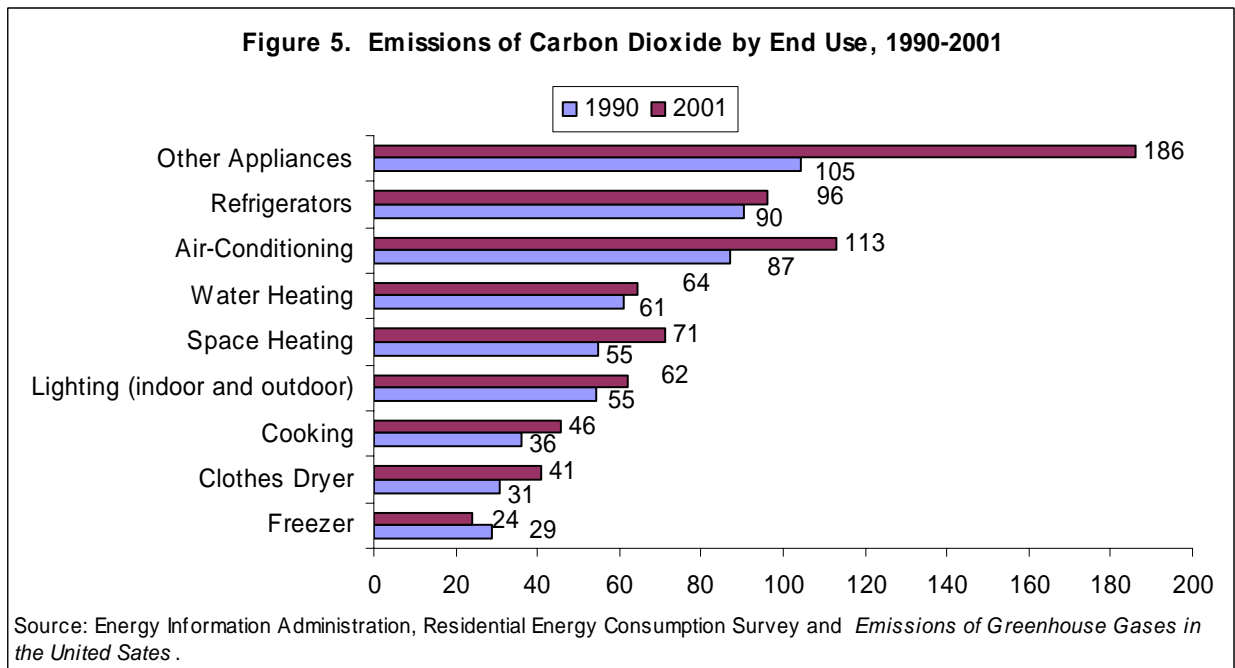


1981 to 2001, household carbon dioxide emissions increased by one percent annually, from 850 million metric tons of carbon (MMT) to 1,037 MMT, or an increase of 22 percent. Electricity-related carbon dioxide emissions grew faster than total household carbon emissions. During the same time period, carbon dioxide emissions attributed to electricity consumption rose by 2.15 percent per year, from 460 MMT in 1981 to 704 MMT in 2001, or an increase of 53 percent. This is a reflection of combined increase in electricity demand and increase in the use of more carbon-intensive fuel in generating electricity which can affect the carbon emissions factors (EIA 2004). Figure 4 shows the trends in carbon dioxide emissions by four major energy sources (electricity, natural gas, fuel oil/kerosene, and liquefied natural gas). While the share of electricity in residential carbon emissions rose, between 1981 and 2001,

those of other energy sources fell. In 1981, 54 percent of carbon dioxide emissions were accounted by electricity. By 2001, electricity's share of emissions was 68 percent.

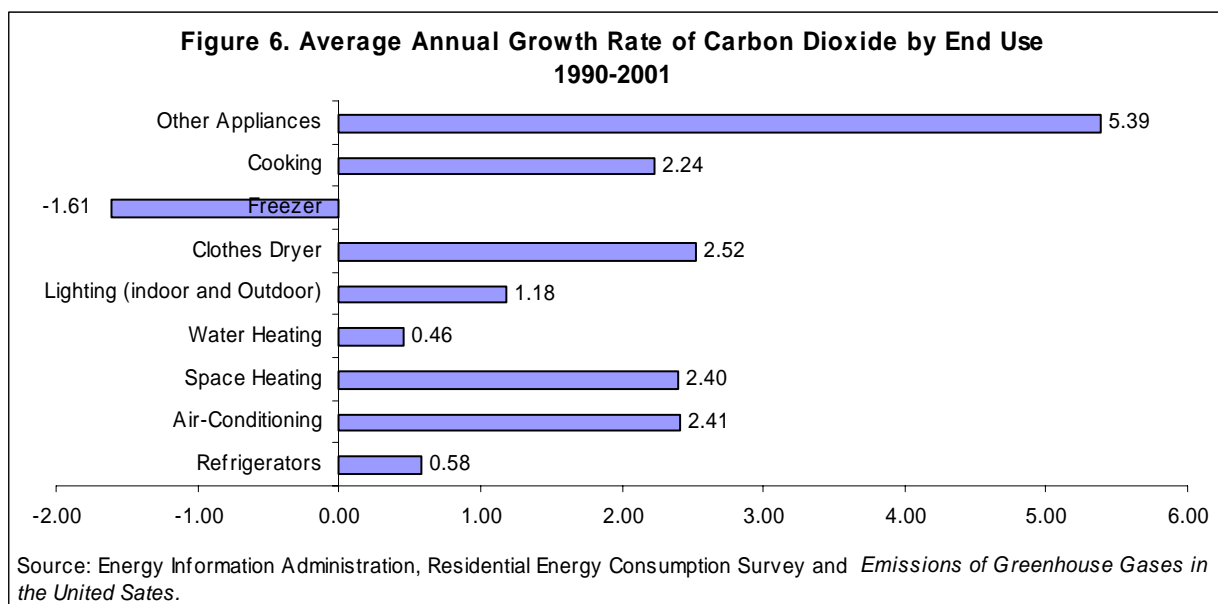


As mentioned earlier, electricity use is the main source of residential carbon dioxide. To better understand the source of carbon emissions attributed to electrical equipment, we examine the growth in carbon dioxide emissions by end use. This is helpful for designing future energy efficiency and energy



saving programs (Koomey 1996). As shown in Figure 5 “Other Appliances” are the major source of carbon dioxide followed by refrigerators, air-conditioning, water heating, space heating, and lighting in 1990<sup>10</sup> and 2001. Figure 6 shows the annual average growth rate of carbon dioxide by end use between 1990 and 2001. During the same time, population rose by 1.02 percent and housing by 1.18 percent annually. The annual average growth rate of carbon dioxide emissions was higher than population and housing for all the end uses, except for refrigerators, water heaters, and freezers. Other appliances had the highest growth rate of carbon dioxide emissions, 5.39 percent per year. This suggests that refrigerators,

water heater, and freezers have received more attention with respect to energy-efficiency standards than other end uses. Energy-reducing technology research needs to focus now on other appliances including color televisions, furnace fans, personal computers, waterbed heaters, clothes dryers, pool filters/pumps, and fax machines.



## Carbon Dioxide Intensity

Total emissions are important to consider—but intensities also are an important measure. However, one intensity measure may not be enough. In this section two intensities are discussed—showing that intensities can move in different directions. One is carbon emissions per capita. Another is carbon emissions per dollar of personal consumption expenditures (PCE),<sup>11</sup> as a measure of economic growth. Over the 1981 to 2001 per capita carbon dioxide emissions continued to increase at an annual average of 1.25 percent, or an increase of 28 percent. This is the result of faster annual growth of carbon dioxide (2.15 percent) than population growth (0.80 percent).

During the same period, because of economic prosperity, personal consumption expenditures grew faster (3.58 percent a year) than carbon dioxide emissions (2.15 percent a year). Therefore, electricity related carbon dioxide emissions per unit of PCE (carbon/PCE) fell at an annual average rate of 1.45 percent, or 25 percent lower in 2001 compared with 1981. To explain the trends in the intensity of carbon/PCE, we examine the electricity use per unit of PCE (electricity/PCE) and carbon dioxide emissions per unit of electricity (carbon/electricity) consumed. Between 1981 and 2001, electricity/PCE fell by 1.19 percent per year and carbon/electricity fell by 0.27 percent—which affected the decline in the intensity of carbon emitted from consumption of electricity per unit of personal consumption expenditures.

In the future, demand for electricity is likely to continue to increase in U.S. housing, and the electricity's share of energy will likely to increase. To avoid increasing carbon emissions, household electricity intensity must decline and/or less carbon-intensive fuel should be used for electricity generation.



## SUMMARY

Electricity demand in U.S. household is more than one third of electricity used by all sectors. The household sector also accounts for about one fifth of the energy-related carbon dioxide emissions.

Using the available data from the RECS, this paper examines the trend in electricity consumption and carbon dioxide emissions between 1981 and 2001. While total electricity demand increased in all regions, the South had the highest growth. U.S. households use most of the electricity for appliances. The growth in electricity demand is affected by many factors such as population growth, income, weather, and energy efficiency standards and other energy saving programs.

There is a high correlation between electricity use and carbon dioxide emissions. Carbon dioxide is the main component of total greenhouse gas emissions in the U.S. During 1981 to 2001, electricity related carbon dioxide emissions grew faster than total household carbon dioxide emissions.

Energy efficiency standards and energy saving programs have improved the energy efficiency of various household appliances over the period. However, examination of carbon dioxide emissions by end use indicates that one of the major sources of carbon emissions is the other appliances that are not under appliance standards. Over the 1981 to 2001 per capita carbon dioxide emissions increased, while the intensity of electricity related carbon dioxide emissions per unit of personal consumption expenditures continued to fall.

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## ENDNOTES

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<sup>1</sup> Dr. Hojjati and Ms. Battles are energy analysts in the Energy Consumption Division (ECD) within the Energy Information Administration. The opinions expressed in this paper are those of the authors and do not necessarily reflect the views of the Energy Information Administration or the U.S. Department of Energy.

<sup>2</sup> Energy consumption can be expressed as the amount of energy used within the housing unit (site energy) or it can also include the energy used in generating and transmitting electricity (primary energy). Since carbon emissions are closely related with primary energy use, primary energy is reported in this paper.

<sup>3</sup> The distribution of total energy consumption by fuel is notably different if site electricity, rather than primary electricity, is measured. By this measure, natural gas, not electricity, is the predominate energy source. In 1981, 26 percent of total site energy was electricity, compared with 39 percent in 2001.

<sup>4</sup> Appliances exclude space heating, space cooling, and water heating equipment.

<sup>5</sup> The first Residential Energy Consumption Survey that collected information on personal computers.

<sup>6</sup> A heat pump is a year round combined heating and air-conditioning system in which refrigeration equipment transfers both heating and cooling through ducts leading to an individual room. Heat pumps are operated by electricity only.

<sup>7</sup> For a discussion of energy efficiency standards and energy saving programs see Battles and Hojjati, 2005.

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<sup>8</sup> Real disposable income is measured in 2000 chained dollars.

<sup>9</sup> Estimation of household carbon dioxide emissions is based on four major energy sources (electricity, natural gas, fuel oil/kerosene, and liquefied natural gas).

<sup>10</sup> Detailed data by end use were not estimated by earlier RECS.

<sup>11</sup> Real personal consumption expenditures is measured in 2000 chained dollars.