Why Is Electricity Use No Longer Growing?

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February 2014
An ACEEE White Paper

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Acknowledgments

Funding for this work was provided by the Kresge Foundation and the Tilia Fund. Ben Foster helped with the statistical analysis. We would like to thank Ahmed Faruqui, Marvin Horowitz, Karen Palmer, and Edward Vine for providing their expert feedback on a draft of this paper. Many thanks to ACEEE staff including Jim Barrett, Annie Downs, R. Neal Elliott, Maggie Molina, and Max Neubauer for reviewing the paper and to Fred Grossberg for editing it. To all of them we are grateful. Of course, all findings in this paper are ours and not necessarily those of the people who helped us.

Abstract

Prior to the 1970s energy crises, electricity sales in the United States were growing by more than 5% per year, and as recently as the early 1990s, electricity sales were growing more than 2% per year. In the past few years, growth has essentially stopped: retail electricity sales in 2012 were 1.9% lower than sales in 2007, the peak year. Some observers have attributed this stalled growth to the 2008 economic recession, while others have suggested a variety of other factors. In this paper, we undertake several analyses to consider which factors best explain changes in electricity use in recent years. Our hypothesis is that the recession alone cannot explain the recent stagnation in electricity consumption. We instead hypothesize that electricity savings from energy efficiency programs and from other efficiency efforts such as appliance standards and building codes are having a broad national impact on electricity consumption in the United States, possibly contributing significantly to the recent decline in electricity consumption.

Our various analyses suggest that energy efficiency has likely had a substantial impact on electricity use. Our analysis indicates that over the 1993-2012 period, changes in electricity use were most influenced by energy efficiency programs and policies, warmer weather, changes in gross domestic product (GDP), changes in electricity prices, and long-term trends. Over the more recent period of 2007-2012, savings from energy efficiency programs and policies and from warmer winter weather appear to be the most important contributors to declining electricity use. The impact of energy efficiency is statistically significant for the residential/commercial sectors but not for the industrial sector.

Further analysis and more data are needed to better understand the contribution of energy efficiency versus economic and other factors, particularly in the industrial sector. Also, for all sectors, it will be useful to repeat the analysis in a few years to see if the recent decline in electricity use, and the contribution of energy efficiency to this decline, continue.

The factors influencing electricity use are complex. Our analyses suggest that energy efficiency has become an important factor in U.S. electricity consumption.

Introduction

Electricity consumption has essentially stopped growing in the past few years. Retail electricity sales in 2012 were 1.9% lower than sales in 2007, the peak year. Some observers have attributed this stalled growth to the 2008 economic recession, while others have suggested a variety of other factors. In this paper, we undertake several analyses to consider which factors best explain changes in electricity use in recent years. Our hypothesis is that the recession alone cannot explain the recent drop in electricity consumption and that savings from energy efficiency programs and policies are also important contributors to declining electric sales. In particular, savings from energy efficiency programs and policies have increased substantially since about 2007, and even if energy efficiency did not have a large impact on sales prior to then, its impact is likely to have grown since 2007.

The rate of electricity demand growth in the United States has steadily declined over the last 50 years. Prior to the 1970s energy crises, U.S. electricity sales were growing by more than 5% per year. As recently as the early 1990s, growth was more than 2% per year. Figure 1 illustrates these trends along with Energy Information Administration (EIA) projections going forward.

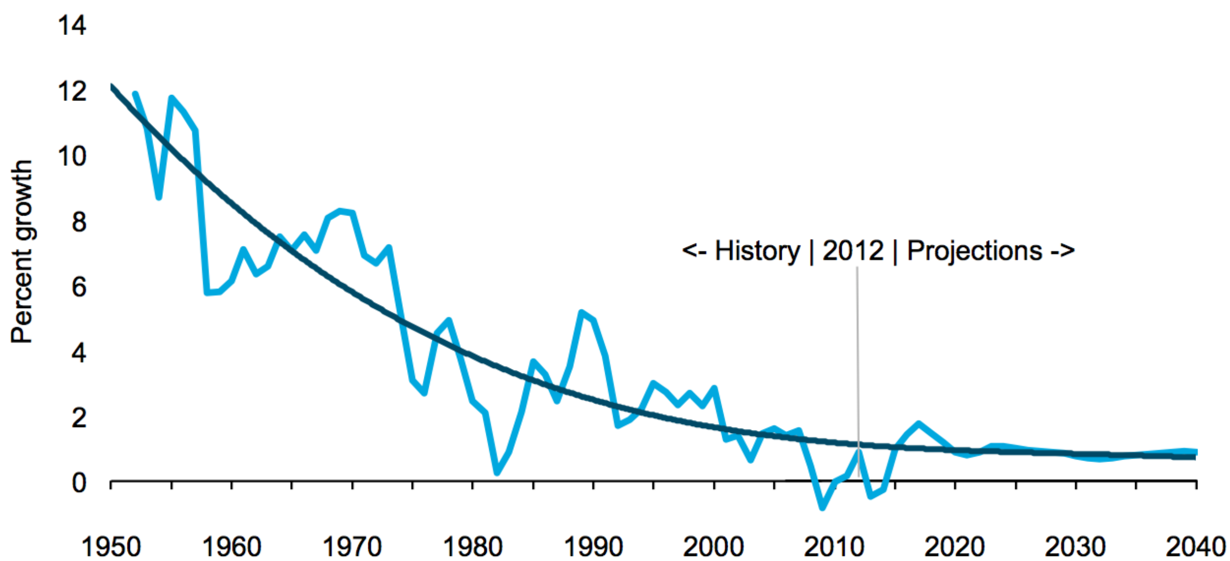

Figure 1. U.S. electricity demand growth, 1950-2035 (percent, 3-year moving average). Figures beyond 2012 are projections and not actual data. *Source:* EIA 2013e.

In the past few years, electricity growth has essentially stopped. As figure 2 shows, electricity sales peaked in 2007, declined significantly in 2008 and 2009 (the recession is likely an important factor), rebounded in 2010, and have trended downward since. Retail electric sales in 2012 were 1.9% less than sales in 2007. For the first ten months of 2013, retail sales were down 0.7% relative to the first ten months of 2012 (EIA 2013c).

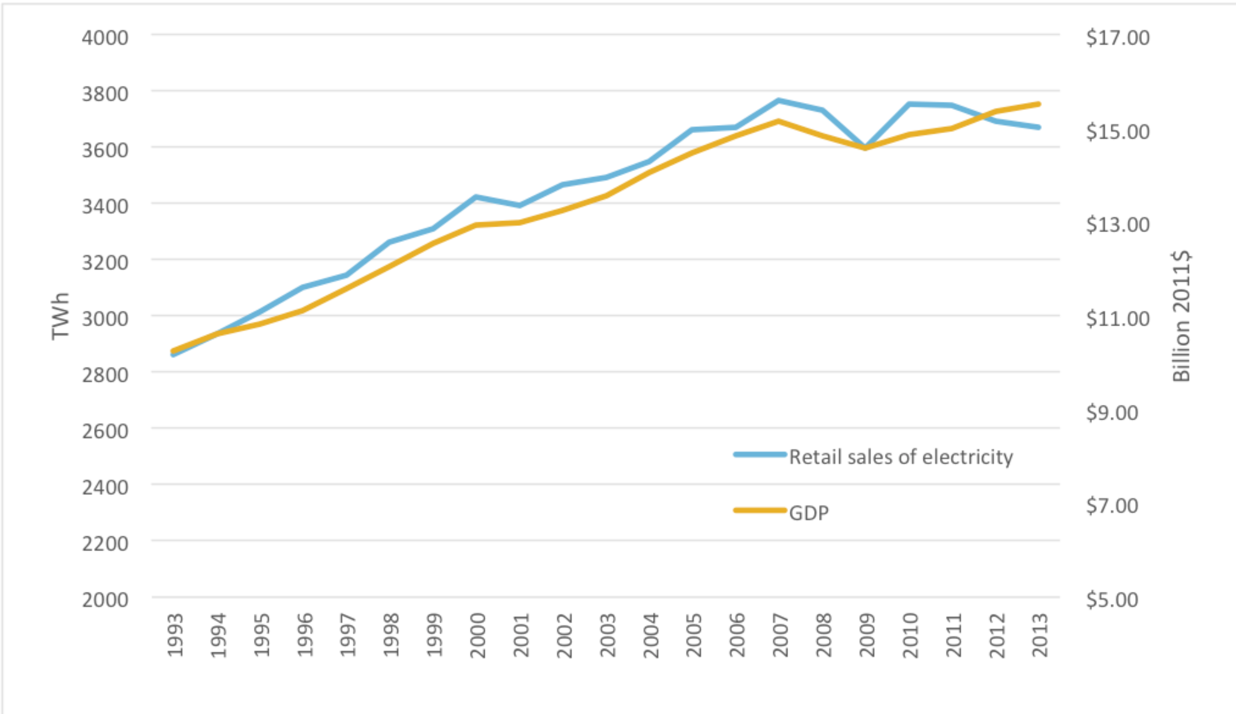

Figure 2. U.S. retail electric sales and GDP for past 20 years (1993-2013). Note: Bottom of graph is not zero on the y axis. 2013 data is annualized by taking use in 2012 and adjusting based on differences between the first ten months of 2012 and 2013. *Source:* Prepared by ACEEE from EIA 2013d and BEA 2013b.

Looking at the trends by sector, figure 3 below shows changes in electricity use in the residential, commercial, and industrial sectors over the 1990-2012 period. Commercial and industrial consumption both peaked in 2007. Commercial use has been modestly declining since then, while industrial use has gone down three years and up two years. Residential use peaked in 2010 and has declined in the two years since then.

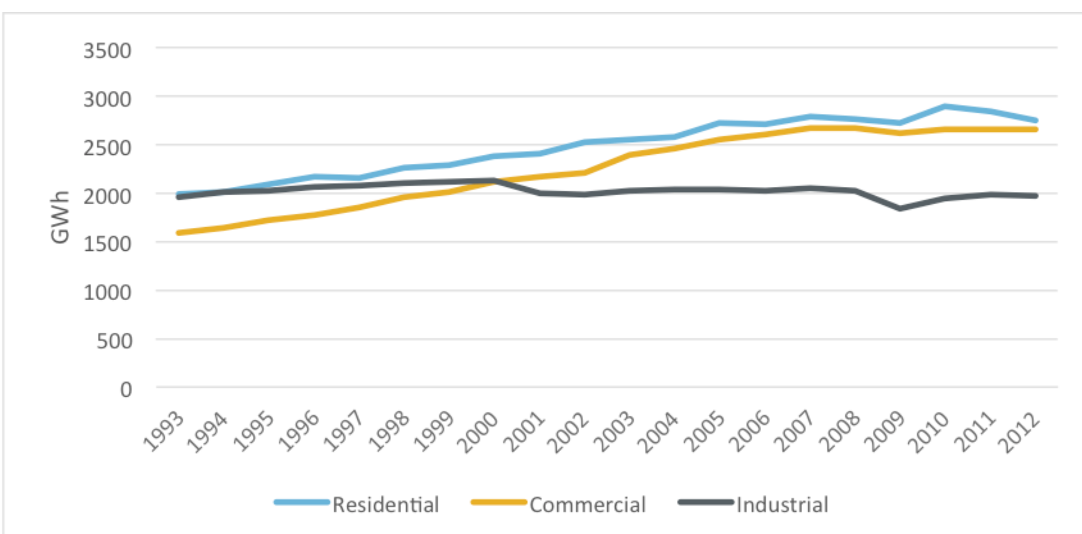

Figure 3. Changes in electricity consumption by sector and year

Previous writers have commented on the changes in electricity consumption and the economy over the second half of the twentieth century, finding that "there has been a strong correlation between the use of electricity and the size of the gross national product" and also that "there is a strong connection between electricity and productivity growth" (Committee on Electricity in Economic Growth 1986). However it is possible that this finding from the 1980s may not apply to recent years.

In the past year, several writers have noted the lack of demand growth and speculated on reasons for the change. For example, Rebecca Smith (2013), writing in the *Wall Street Journal,* ascribed it to the recent recession, more efficient appliances and lighting, and the erosion of manufacturing. Faruqui and Shultz (2012), writing in *Electric Utilities Fortnightly*, posited five explanations for low demand growth: a weak economy, utility demand-side management efforts, building codes and equipment efficiency standards, distributed generation, and fuel switching. They noted that the latter two factors may be small today but are likely to grow in the future. In the *Washington Post*, Plumer (2013), suggested that demand growth may have stalled because industry has yet to rebound from the recession, homes are using less electricity, office buildings are getting more efficient, and solar power and distributed generation are starting to catch on. Looking at broad trends, none of these recent writers has tried to examine data on which factors are most important and why, nor have they examined the various possible contributing factors in detail.

In this paper, we conducted five analyses to explore the likely causes of the decline in U.S. electricity use since 2007:

1. Plot of key variables
2. Simple correlations between electricity use and key variables
3. Review of energy efficiency and distributed generation data
4. Preliminary regression analysis of trends over the 1994-2012 period
5. Application of the regression equation to the 2007-2012 period

We discuss each of these analyses in turn in the sections below.

Analyses

PLOT OF KEY VARIABLES

Our first analysis was to identify key variables and plot changes in them over the 2007-2012 period. We looked separately at changes in residential/commercial electricity use and in manufacturing energy use, since different factors help drive consumption in these sectors. We got inconclusive results when we tried mixing the sectors in some initial analyses.

For the residential and commercial sectors, we chose the following key variables:

1. Non-manufacturing gross domestic product (GDP)
2. Average real electricity price for residential and commercial customers (in constant $, excluding the effects of inflation)
3. Residential and commercial savings from utility-sector energy efficiency programs and equipment standards
4. Cooling degree days (CDD) (a measure of weather that triggers a need for space cooling)

5. Heating degree days (HDD) (a measure of weather that triggers a need for space heating)

For the industrial sector we chose the following key variables:

1. Manufacturing GDP plus non-oil imports
2. Average real electricity price for industry
3. Industrial savings from utility-sector energy efficiency programs and equipment standards

An explanation of these variables, why they were chosen, and how they were measured can be found in Appendix A.

We plotted changes in sector electricity use and in each of these variables over the 2007-2012 period. To plot all variables on the same graph, we normalized the data so that the 2007 value for each variable is set to 1 and the relative change for each variable relative to 2007 is shown by a value above or below 1 (e.g., 1.2 or 0.9). This plot is shown in figure 4 for residential and commercial and in figure 5 for industry.

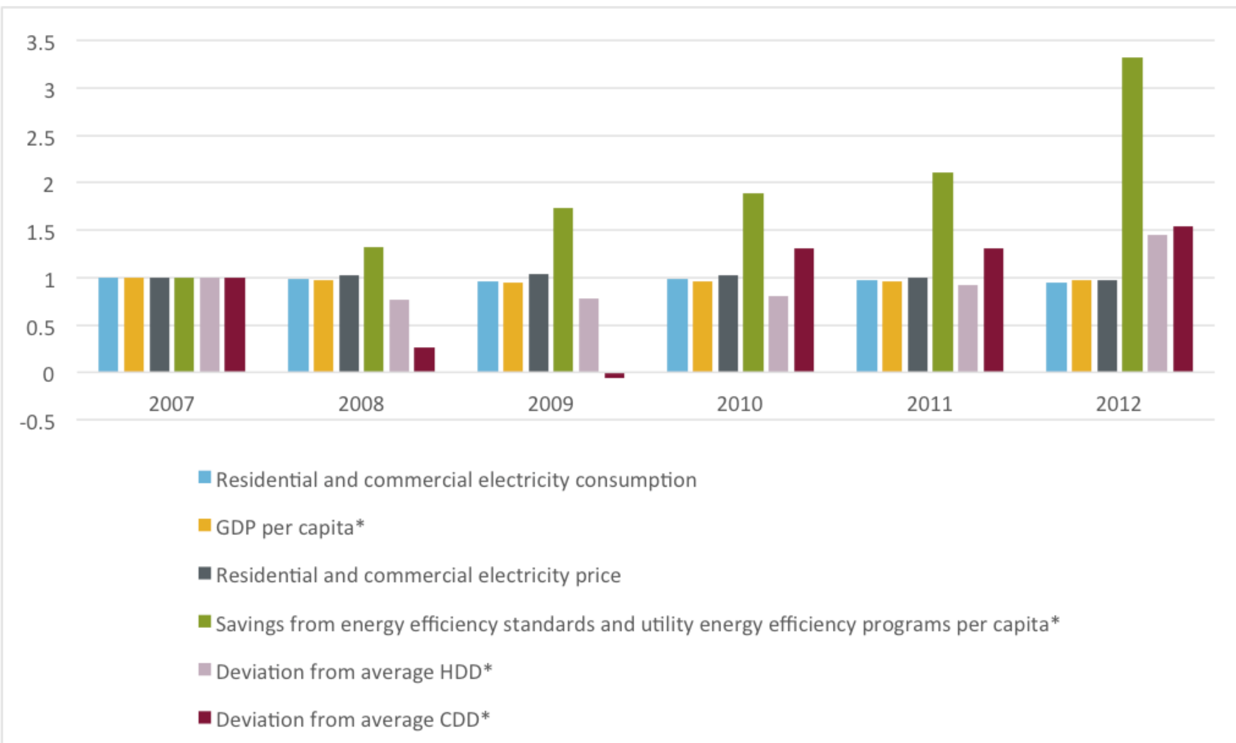

Figure 4. Normalized plot of each variable over the 2007-2012 period for residential and commercial sectors. For each variable, the 2007 value is set equal to 1 and subsequent values are a multiple of the 2007 value. Asterisked variables are statistically significant per an analysis discussed later in this paper. *Source:* 2012 energy efficiency savings are from EIA (2013b) Form 861; other years are from the ACEEE *State Energy Efficiency Scorecard*.

This analysis shows a dramatic rise in energy efficiency savings in the residential and commercial sectors since 2007. Heating and cooling degree days also change substantially from year to year.

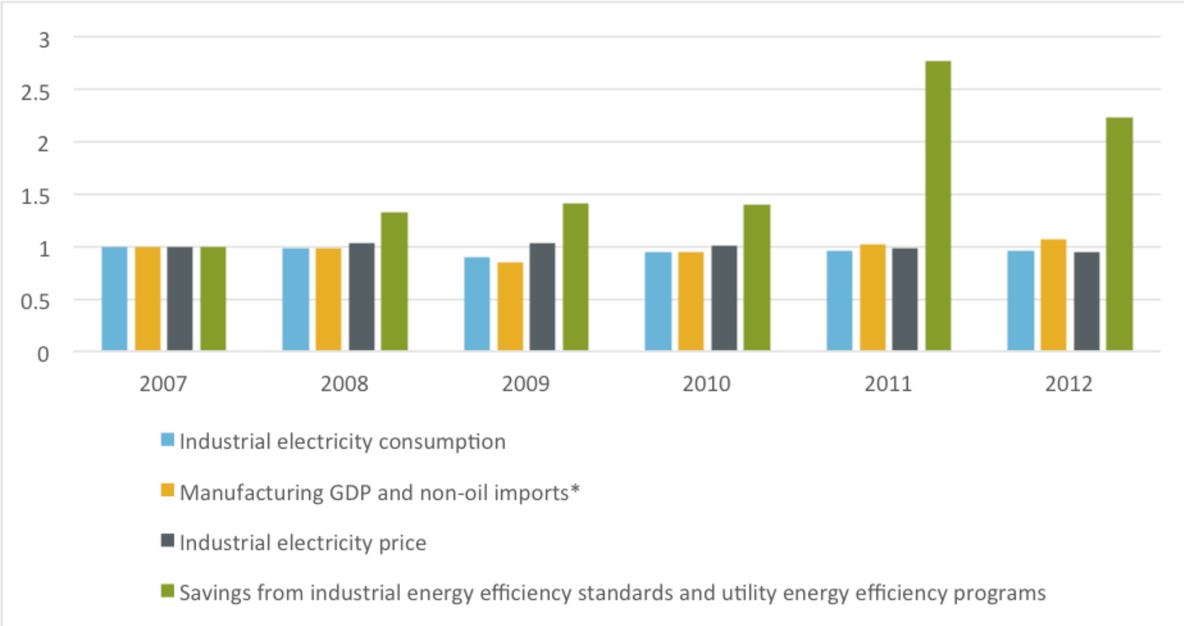

Figure 5. Normalized plot of each variable over the 2007-2012 period for the industrial sector. For each variable, the 2007 value is set equal to 1 and subsequent values are a multiple of the 2007 value. Asterisked variables are statistically significant per an analysis discussed later in this paper. *Source:* 2012 energy efficiency savings are from EIA (2013b) Form 861; other years are from the ACEEE *State Energy Efficiency Scorecard*.

In the industrial analysis, GDP plus imports declines substantially in 2009 and then steadily increases through 2012. Industrial energy efficiency savings rise substantially in 2012 but then decline modestly in 2012. The decline in 2012 is because EIA (the source of the data we used to separate the sectors) estimates that only 13% of utility energy efficiency savings in that year were in industry, while the figure was 23% in 2011 (EIA 2013b). (We are not sure of the accuracy of this part of the EIA analysis.) The other variables in both equations change by modest amounts over this period. By 2012, manufacturing GDP plus imports is somewhat higher than in 2007.

Interestingly, manufacturing GDP increased by 14.5% from 2010 to 2012 while industrial electricity use increased by 1.5%. This is a surprising result, and one of our colleagues has speculated that it could be due to increased production from efficient factories and decreased production from inefficient factories coming out of the recession (R.N. Elliott, pers comm., 2014). Further analysis on this issue is needed, particularly as data for additional years become available.

SIMPLE CORRELATIONS

Next we calculated simple statistical correlations over the 1993-2012 period between residential and commercial electricity use per capita and our residential/commercial variables, and between industrial electricity use and our industrial variables. We used per capita use for the residential and commercial sectors to eliminate the effects of population growth. We had to extend our analysis to 1993 in order to include enough data points to get reasonable statistical explanatory power. We started in 1993 because that is the first year for which we have good data on energy efficiency savings. These analyses are shown in Tables 1 and 2.

Table 1. Correlation between residential and commercial electricity consumption per capita and five variables

	Pearson correlation coefficient	Significance (2-tailed)
Non-manufacturing GDP/population	0.556*	0.011
Residential and commercial electricity price	- 0.258	0.273
Savings from residential and commercial efficiency standards and utility programs/population	- 0.645**	0.002
Deviation from long-term average HDD	0.223	0.344
Deviation from long-term average CDD	0.105	0.661

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

For the residential/commercial analysis, two variables are statistically significant: energy efficiency savings and non-manufacturing GDP. With energy efficiency savings, there is a 99% chance that as energy efficiency savings go up, electricity use goes down. Likewise, there is a 95% chance that as non-manufacturing GDP goes up, so do residential and commercial electricity use.

Table 2. Correlation between manufacturing electricity consumption and three variables

	Pearson correlation Coefficient	Significance (2-tailed)
Manufacturing GDP and non-oil imports	0.866**	0.000
Industrial electricity price	- 0.393	0.087
Savings from industrial efficiency standards and utility programs	- 0.131	0.581

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

For the industrial analysis, there is a 99% chance that manufacturing GDP is positively correlated with industrial electricity use.

Review of Energy Efficiency and Distributed Generation Data

Third, we examined several trends over the 2007-2012 period to look for additional insights. Over this period, electricity consumption in the U.S. declined by 1.9%, an average of 0.37% per year. Population grew by an average of 0.92% per year, while electricity use per capita declined by 1.21% per year.[1] According to Lawrence Berkeley National Lab (LBL) data, savings from energy efficiency standards averaged 0.61% per year over this period (Myers 2014). Savings from utility energy efficiency programs averaged 0.42% per year according to our data set (Eldridge et al. 2008, 2009; Molina et al. 2010; Sciortino et al. 2011; Foster et al. 2012; Downs et al. 2013). An analysis by Aroonruengsawat, Auffhammer, and Sanstad (2012) of residential building codes over the 1970-2006 period estimated that these codes reduced electricity use by about 0.1% per year. This study did not examine commercial building codes, but in our experience, savings from commercial codes are similar to and often a little higher than savings from residential codes.[2]

In addition, the increase in distributed electricity generation in the residential, commercial, and industrial sectors over the 2007-2012 period has averaged about 0.09% per year. Nearly half this increase was in 2012 alone, with the increase in customer generation accounting for 0.2% of 2012 electricity sales. Data on customer generation are shown in table 3. As the data show, electricity generation in the residential sector has been steadily increasing, generation in the commercial sector has been increasing modestly, and industrial generation goes up and down.

Table 3. Electricity generated in industrial, commercial, and residential sectors, 2007-2012 (TWh)

					Change	
	Industrial	Commercial	Residential	Total	From prior year	From 2007
2007	143.1	8.3	7.0	158.4	-4.6	-
2008	137.1	7.9	8.1	153.1	-5.3	-5.3
2009	132.3	8.2	9.1	149.6	-3.5	-8.8
2010	144.1	8.6	11.7	164.4	14.8	6.0
2011	141.9	10.1	15.8	167.8	3.4	9.3
2012	145.2	10.6	19.9	175.7	7.9	17.2

Source: EIA Monthly Energy Review 2013d; industrial and commercial data from table 8.2d; residential data derived by ACEEE from tables 10.2a and A6.

Taken together, the savings from utility energy efficiency programs (about 0.4% per year), appliance and equipment efficiency standards (0. 6% per year), and building codes (0.2% per year) total about 1.2% per year. This figure is similar to the decline in electricity use per capita and more than explains the 0.37% per year decline in electricity sales.[3] Changes in other factors could have offset some of these effects. For example, a regression analysis we conducted (discussed later) found that modest increases in manufacturing GDP and non-energy imports and modest decreases in industrial electricity price contributed to slightly higher electricity use,

[1] ACEEE analysis of data from EIA 2013a and U.S. Census Bureau 2012a.

[2] For example, in a recent analysis of building code provisions from pending legislation, Young et al. (2013) found that commercial code savings are about a third higher than residential code savings.

[3] The fact that energy efficiency savings are greater than the sales decline could be due to a variety of factors, including high correlations between energy efficiency savings and some of our other independent variables, inaccuracies in estimates of energy efficiency savings, impacts of other variables not examined, a less than 100% realization of expected energy savings, and/or some type of rebound effect.

offsetting a portion of the energy efficiency savings. This summation is approximate and should not be viewed as definitive; each of these estimates is subject to substantial uncertainty.

PRELIMINARY REGRESSION ANALYSIS OF TRENDS OVER THE 1993-2012 PERIOD

Fourth, to better gauge the relative impact of the different factors discussed in the sections above, we conducted an initial statistical analysis, drawing on national data over the 1993-2012 period, to try to tease out the relative impact of the economy, weather, energy efficiency programs, and other factors on electricity use. We are not statisticians or econometricians, so this analysis should be considered preliminary; we leave it to researchers with more skills in these areas to conduct more definitive analyses. Appendix A presents the details of the regressions we ran. We prepared separate equations for residential/commercial and industrial electricity use, using the variables discussed above in the section called Simple Correlations. Statistical measures for the equations are provided in tables 4 through 7. We discuss each equation separately.

For the residential and commercial analysis (tables 4 and 5), four of the independent variables are statistically significant with a 95% probability: HDD, CDD, non-manufacturing GDP, and energy efficiency savings. Only electricity price is not statistically significant, and this variable does not move in the expected direction. In standard economic theory, when price goes up, consumption should go down. Our analysis found a modest trend in the other direction. In multiple regression analyses, when variables are not statistically significant, signs are sometimes wrong, which appears to be the case here. Furthermore, real electricity price barely changed during this period. When a variable barely changes, it is more likely the sign will be wrong since there is little change to work with.

Table 4. Regression statistics for residential and commercial equation

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
(Constant)	1.123	0.209		5.363	0
Non-manufacturing GDP/population	249.894	92.541	0.452	2.7	0.017
Residential and commercial electricity price	0.141	0.161	0.111	0.875	0.396
Savings from residential and commercial efficiency standards and utility programs/population	-15.689	4.256	-0.573	-3.686	0.002
Deviation from long-term average HDD	5.936	1.346	0.747	4.411	0.001
Deviation from long-term average CDD	3.859	0.796	0.759	4.849	0

B is the coefficient in front of each variable in the equation. Standard error is the plus or minus value around this coefficient with about 2/3's probability. "t" is the result of t-test statistical analysis for each variable. The larger the t, regardless of whether it is positive or negative, the greater the statistical significance. Sig. is the statistical significance, indicating in each case the chance that the explanatory power of that variable is due to random chance. Statisticians typically look for a Sig. value of .05 or less, meaning there is less than a 5% chance that random chance would explain a result. Sometimes a Sig. value of .10 or less is used.

Table 5. Summary statistics for residential and commercial equation

R	R^2	Adjusted R^2	Std. error of the estimate
.916	0.839	0.781	0.16508

Adjusted R^2 is a modification of R^2 that adjusts for the number of terms. Since R^2 increases when a new term is added, the adjusted R^2 accounts for this and only increases the R^2 if a new variable improves the model.

Table 6. Regression statistics for industrial equation

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
(Constant)	-0.025	0.011		-2.235	0.04
Manufacturing GDP and non-oil imports	0.251	0.035	0.819	7.268	0
Industrial electricity price	-0.058	0.031	-0.213	-1.882	0.078
Savings from industrial efficiency standards and utility programs	-0.008	0.009	-0.093	-0.84	0.413

See notes to table 4.

Table 7. Summary statistics for industrial equation

R	R^2	Adjusted R^2	Std. error of the estimate
.898	0.806	0.769	0.0306

See notes to table 5.

One way to get a rough approximation of the importance of each variable is to look at the standardized coefficients for each of them. The standardized coefficients are a standard output of statistical software and adjust for the scale used for each variable and the distribution of each variable. By standardizing the variables based on their standard deviation, all of them are put on the same scale, so that their variances are one. This makes it easier to compare the magnitude of the coefficients to see which one has more of an effect. The standardized coefficients for the residential and commercial equation are shown in figure 6.

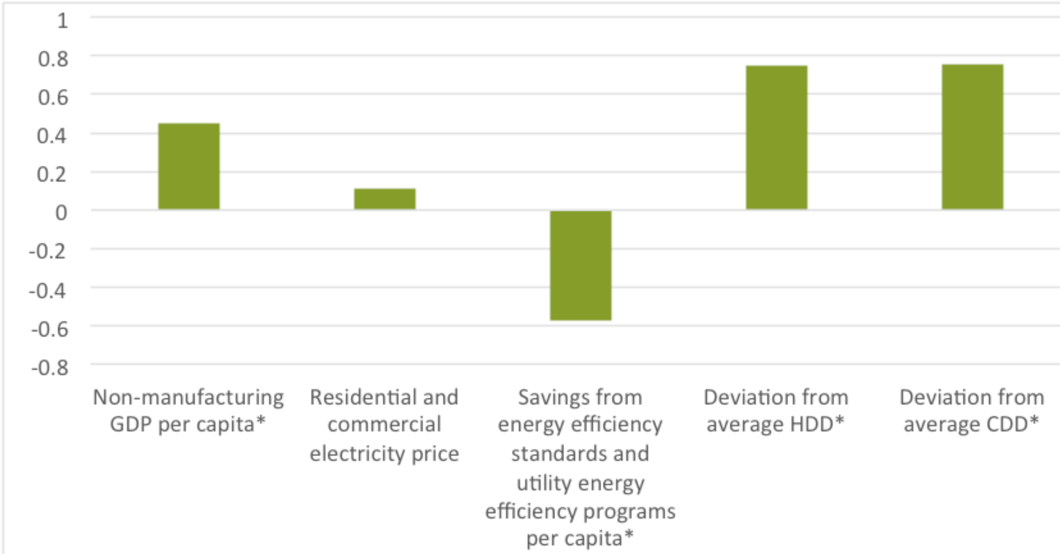

Figure 6. Standardized Beta for residential and commercial equation. Asterisked variables are statistically significant.

For the residential and commercial analysis, over the 1993-2012 period, weather (heating and cooling degree days) and the energy efficiency variable (energy efficiency savings per capita) account for the largest amount of variance, followed by the economy (non-manufacturing GDP per capita) and electricity price. As shown in table 4, all of these variables except for price are statistically significant with 95% confidence. However there are high correlations between a few of our variables that could affect these results. Using a Pearson correlation test, we found correlations between change in heating degree days and change in cooling degree days (two-sided probability of 99%), between non-manufacturing GDP and energy efficiency (95% probability), and between energy efficiency and change in cooling degree days (90% probability). These correlations mean that while the overall equation may be robust, the predictive power of these variables when examined individually is subject to uncertainty. As an example, since cooling degree days and energy efficiency are correlated, some of the impact attributed to cooling degree days could in fact be due to energy efficiency, or vice versa.

The standardized coefficients for our industrial equation are shown in figure 7.

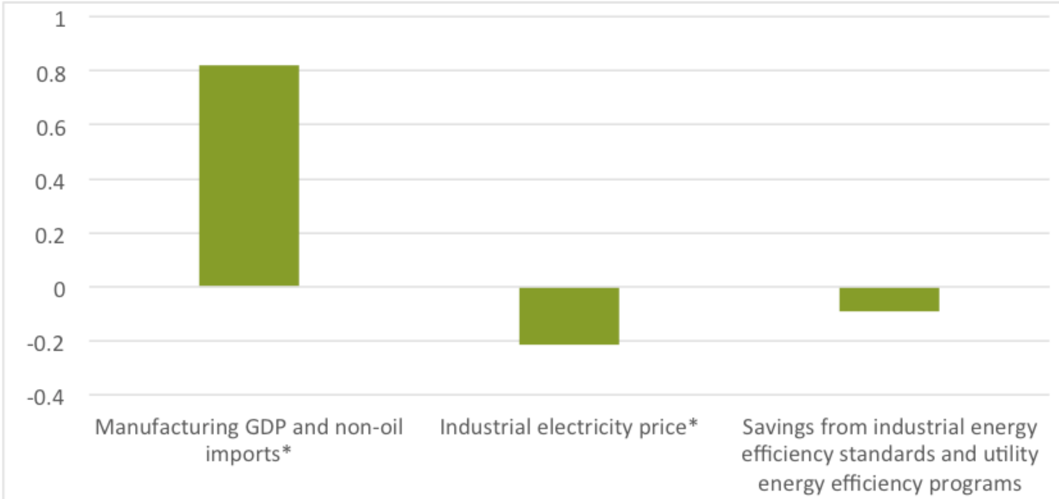

Figure 7. Standardized Beta for industrial equation. Asterisked variables are statistically significant.

For the industrial analysis, change in manufacturing GDP and non-oil imports explains the largest amount of variance, followed by change in electricity price. Both of these are statistically significant, with 99% and 90% confidence respectively, as shown in table 6. Energy efficiency explains the least variance and is not statistically significant.

APPLYING THE EQUATION AND DATA TO THE 2007-2012 PERIOD

Since a major purpose of this study was to look at contributors to the decline in electricity use in recent years, for our final analysis we applied the results of our regression analysis to this recent period. We used our regression equations to compare the impact of each independent variable on the dependent variable over the 2007-2012 period. We looked at the difference between 2012 and 2007 and thus the change over this entire period, ignoring the up and down changes in the intervening years. This analysis is shown in figure 8 (residential and commercial) and figure 9 (industrial). In reviewing these figures, please recall that only the variables with an asterisk are statistically significant and also that several of the variables are correlated with each other. Thus the analysis should be considered indicative and not definitive.

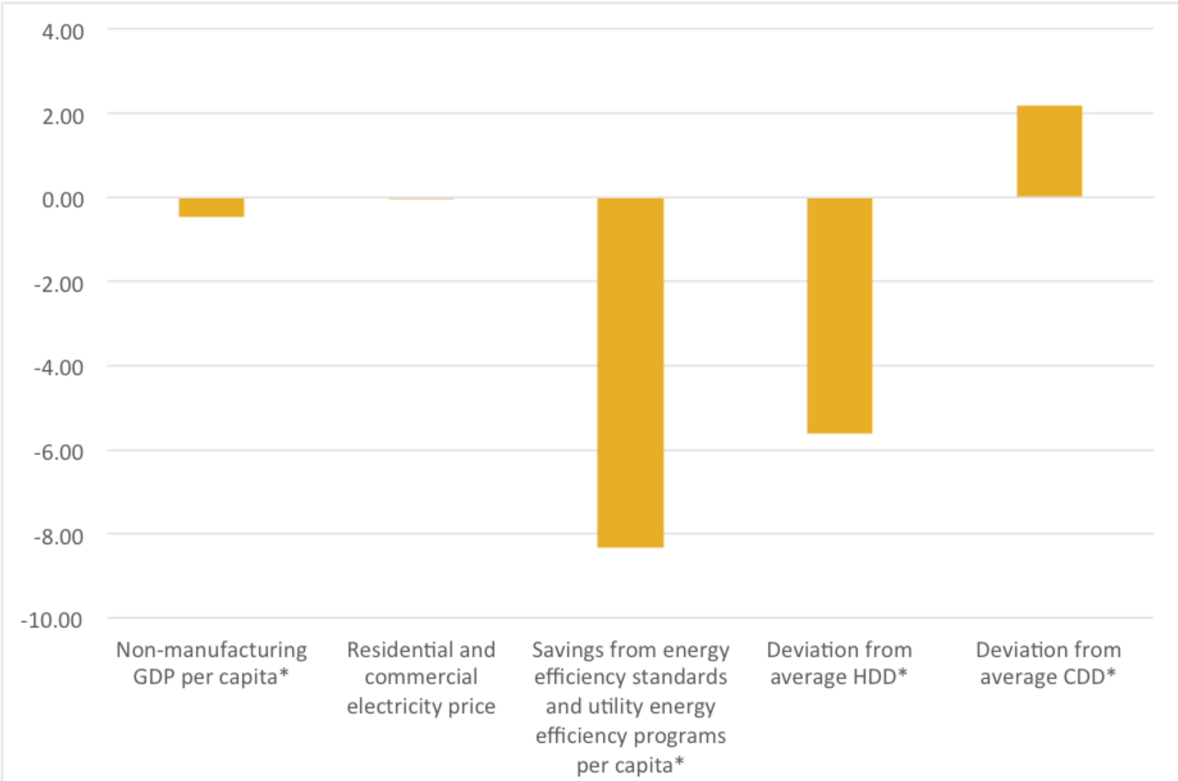

Figure 8. Contribution of each independent variable to change in dependent variable between 2007 and 2012 for residential and commercial sectors. Asterisked variables are statistically significant with 90% confidence in our regression analysis.

For the residential and commercial sectors, our analysis indicates that energy efficiency is the largest cause of the decline in electricity use, followed by warmer weather. (The decline in heating electricity use during warmer winters is partly offset by an increase in cooling electricity use during warmer summers.) Change in non-manufacturing GDP per capita and the trend variable are much smaller contributors. Over the 2008-2012 period, annual heating degree days were an average of 19% below the 30-year average, while annual cooling degree days were an average of 11% above the 30-year average. Our analysis period did not include the very cold winter of 2013-2014, as data are not yet available to analyze these months.

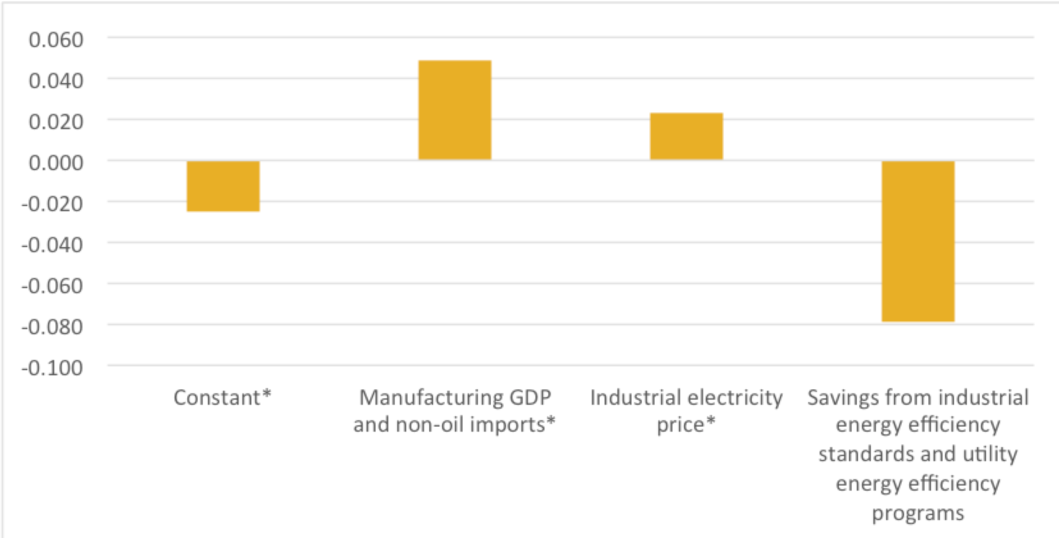

Figure 9. Contribution of each independent variable to change in dependent variable 2007 to 2012 for industrial sector. Asterisked variables are statistically significant with 90% confidence in our regression analysis.

The biggest impact on industrial electricity use over the 2007-2012 period was energy efficiency. However, as noted earlier, the energy efficiency coefficient is not statistically significant, and therefore this result is subject to substantial uncertainty. The next largest impact was changes in manufacturing GDP and non-oil imports, which caused industrial sector electricity use to *increase* over this period. Third in impact was the constant term, indicating a steady and long-term decline in electricity use *after controlling for the other factors*. Electricity price modestly decreased over this period, causing a modest *increase* in electricity use. GDP plus imports, price, and the constant term are statistically significant.

More in-depth analysis on industrial electricity use and factors contributing to changes in use is needed. We note that a recent analysis by Horowitz (2014) looked at overall industrial energy use and electricity use in depth and found that "market persuasion programs" (his term) reduced industrial electricity use by 5.4% over the 2002-2010 period after controlling for changes in output, other production inputs, and economic conditions. This result is broadly consistent with our findings.

Discussion and Conclusions

Our various analyses suggest that energy efficiency has likely had an impact on electricity use. Over the 1993-2012 period, changes in electricity use were most influenced by energy efficiency programs and policies, warmer weather, changes in GDP, changes in electricity prices and long-term trends. Given differences between the residential/commercial and industrial sectors and correlations between independent variables, it is difficult to separate out the exact contribution of each of these individual variables. We should also note that our regression analysis only explains about 75% of the variance in electricity use, so additional factors are influencing the results. Further work is needed to identify and analyze these variables, and we would expect that as new variables are added, the results will change somewhat, particularly for variables that are highly correlated with other variables.

Over the more recent period of 2007-2012, savings from energy efficiency programs and policies and warmer winter weather appear to be the most important contributors to declining electricity use. Over this period, savings from equipment efficiency standards and utility-sector energy efficiency programs have increased substantially, and these effects were statistically significant for the residential/commercial sectors but not for the industrial sector. The other variables we examined, such as GDP, non-energy imports, and electricity prices, have not changed as much. Furthermore (while outside of our regression analysis), the effects of building codes also add to the energy efficiency savings, and customer generation of electricity increased substantially in 2012.

We also note that our results are consistent with a recent regression analysis by Afsah and Salcito (2013) who found that energy efficiency and conservation measures were the primary cause of reduced CO_2 emissions in the United States in 2012. These authors estimate that nearly 75% of the decline in emissions was due to reduced energy demand, primarily attributable to energy efficiency but with a helping hand from the mild winter in the first quarter of 2012. The remaining emissions reductions were due to a shift toward natural gas in the electric power sector. Our findings are also broadly consistent with two econometric studies by Horowitz (2007 and 2012). In the earlier study he found that over the 1973-2003 period, "those states that have moderate to strong commitment to energy efficiency programs reduce electricity intensity relative to what it would have been with weak program commitment." In the more recent study he finds that over the 2006-2010 period, energy efficiency programs and policies in California reduced California electricity use by 7.3%.

In conclusion, our analysis suggests that increased energy efficiency is likely a major contributor to decreased electricity growth rates over the 2007-2012 period. Further analysis is needed to better understand the contribution of energy efficiency as opposed to economic and other factors, particularly in the industrial sector where energy efficiency data are less complete, manufacturing GDP and electricity use trends have recently diverged, and non-oil imports are positively correlated with industrial electricity use. Also, for all sectors, it will be useful to repeat the analysis in a few years to see if the recent decline in electricity use and the contribution of energy efficiency to this decline continue, or if the last few years have merely been an aberration in long-term trends.

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Appendix A: Description of the Regression Analysis

In this analysis, ACEEE considered several economic indicators that affect electricity consumption and ran a series of linear regression analyses to determine the relative impact of each variable. We collected national-level data for the residential, commercial, and industrial sectors as well as the economy as a whole. We began the analysis by looking at total electricity consumption as the dependent variable and several national independent variables including total energy efficiency from utility programs and appliance standards, total gross domestic product (GDP), manufacturing GDP, and others. The results from these analyses were inconclusive. Based on feedback from experts, we decided that there were too many differences between sectors to do a good combined analysis, and so we split up electricity consumption and created two equations, one for the residential and commercial sectors and one for industry. Below we lay out each variable for our two equations, our assumptions, our data sources, and some changes we made to the variables during the analysis.

VARIABLES

All the data used in the analysis are national-level data between 1993 and 2012. We started the analysis in 1993 because that was the first year for which we had estimates of energy efficiency savings. Although energy efficiency programs existed in earlier years, we do not have good data for them. (We do know enough about these programs to say it would be wrong to assume they achieved zero savings.[4]) In the end we had 20 total data points for each variable. We tried several iterations of each of the variables to derive the most explanatory power from the linear regression analysis. The final equations for our analysis are as follows.

The residential and commercial sector electricity use regression equation is:

$$E = \alpha + \beta_1 G + \beta_2 P + \beta_3 S + \beta_4 H + \beta_5 C$$

where:
E = Δ (Residential and commercial electricity consumption/Population)
G = Δ (Non-manufacturing GDP/Population)
P = Δ (Residential and commercial electricity price)
S = (Savings from residential and commercial efficiency standards and utility programs)/Population
H = Deviation from average heating degree days (HDD)
C = Deviation from average cooling degree days (CDD)

The industrial-sector electricity use regression equation is:

$$E = \alpha + \beta_1 G + \beta_2 P + \beta_3 S$$

where:
E = Δ (Industrial electricity consumption)
G = Δ (Manufacturing GDP and non-oil imports)

[4] Although limited data from this earlier period do exist (see for example Hirst 1994 and Hirst 1991), their definitions and methods appear to be different from more recent methodology. We were not able to get older and more recent estimates of savings in the early 1990s to line up.

P = Δ (Industrial electricity price)
S = Savings from industrial efficiency standards and utility programs

All of the variables are the change in the metric from the previous year. We take the difference between each year of the data to better understand what a unit of increase in energy efficiency or GDP has on a unit change in electricity consumption. Differencing the data allows us look at the change in the independent variables between each year and make some determination about the change in electricity consumption. This method is particularly helpful when the variables all tend to grow over time, a tendency that can show autocorrelation rather than the true relationship between the variables.

Dependent Variable

We chose electricity consumption as the dependent variable for this study because the hypothesis we seek to prove is that the recent decline in electricity consumption in the United States is in part due to an increase in end-use energy efficiency. Therefore we explore the relative impact of a variety of economic and energy indicators on electricity consumption.

For the residential and commercial equation, we gathered the annual retail sales of electricity data in terawatt hours (TWh)[5] between 1993 and 2012 for the residential and commercial sectors from EIA (2013a). We summed the sales of the two sectors and divided the total by the population of the United States (TWh per million people). Population data came from the U.S. Census Bureau (U.S. Census Bureau 2012a; U.S. Census Bureau 2012b). We tried both electricity use adjusted for population and electricity use alone as dependent variables (with population as an independent variable in the electricity-use-only case). Using electricity use adjusted for population as the dependent variable resulted in an equation that explained more of the variance. For the industrial equation, we gathered data from EIA 2013a and used industry sector sales for industrial electricity consumption. We subtracted each year from the previous year to get the difference data.

Independent Variables

Independent variables are also known as predictor variables or explanatory variables. They are the variables that are expected to affect the dependent variable. We used five independent variables for the residential/commercial analysis as follows.

NON-MANUFACTURING GDP/POPULATION

Total GDP is from the Bureau of Economic Analysis (BEA 2013b). We converted the data from nominal to real dollars using the BEA national GDP deflator (BEA 2013a). We then subtracted manufacturing GDP from the total GDP to get the non-manufacturing GDP number. Manufacturing is an energy-intensive economic activity, and as the manufacturing sector grows, so generally does electricity consumption. "Manufacturing" is defined by North American Industry Classification System (NAICS) codes and includes durable and nondurable goods (U.S. Census Bureau 2013a). The data for manufacturing GDP between 1993 and 2012 also are from BEA 2013a. We converted the data from nominal to real 2011 dollars using the BEA national GDP deflator (2013c). Population data come from the U.S. Census Bureau (U.S.

[5] A TWh is a billion kilowatt hours (kWh).

Census Bureau 2012a; U.S. Census Bureau 2012b). We calculated the difference between each year.

PRICE OF ELECTRICITY FOR THE RESIDENTIAL AND COMMERCIAL SECTORS

In classical economics, as the price of a good decreases (or increases), all other things being equal, consumption of that good will increase (or decrease). Therefore, changes in electricity price are expected to affect electricity consumption. The national annual price of electricity for the residential and commercial sectors between 1993 and 2012 comes from EIA Annual Energy Review (EIA 2013c). We used the retail price for all sectors, converted from nominal dollars to real 2011 dollars using the Consumer Price Index from the Bureau of Labor Statistics (BLS) (BLS 2013).6 To get an accurate average of the price of electricity in the residential and commercial sectors, we weighted the price in each sector by the percentage of electricity it consumed. Electricity consumption by sector comes from EIA (2013a). Once we calculated the average weighted price of electricity, we took the difference between each year. We ran our regressions using the price for the same year as we used for consumption, but also lagging price or calculating price as a two- or three-year rolling average. We used these alternative calculations to look at whether price has a delayed or gradual effect on electricity consumption. We found the highest R^2 when we used the price for the same year as for consumption, so that is how we modeled price in our final equation.[7]

SAVINGS FROM RESIDENTIAL AND COMMERCIAL ENERGY EFFICIENCY UTILITY PROGRAMS AND STANDARDS/POPULATION

As consumers and businesses adopt energy efficiency measures, they use less electricity per unit of service. In recent years, many electric utilities have ramped up their efforts to encourage and help their consumers to improve energy efficiency (Downs et al. 2013). The United States has also made strides in improving minimum efficiency requirements for appliances and other energy-using equipment, substantially reducing energy use in homes and commercial facilities. These efforts are likely a contributor to changes in electricity consumption.

The best variable for energy efficiency savings we could find was estimates of the savings from utility programs and equipment efficiency standards. These were only estimates, and thus the regression equation can help capture how much of these savings were actually realized and how much of the savings might be due to efficiency programs and policies and not to other factors. As discussed in the body of the paper, the actual savings may differ from the estimated savings for many reasons. We also note that while our equation assumes that energy efficiency programs and policies affect sales, the reverse is also possible: the volume of sales may affect the amount of savings achieved. In our view, such effects would be small enough in our period of analysis that they would not make much difference.[8] However if efficiency savings continue to grow while electricity sales decline, future analyses will need to address such feedback effects.

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[6] We used the CPI because our analysis focused on the residential and commercial sectors. The CPI better reflects inflation for these sectors than the economy-wide GDP deflator compiled by the BEA.

[7] "R squared" denotes the explanatory power of an equation. It can range from 0, where the equation has no explanatory power, to 1, where the equation fully explains changes in the dependent variable.

[8] For example, if a 2% decline in electricity sales causes a 2% decline in energy efficiency savings, this impact is much smaller than the imprecision in our energy efficiency data.

For the energy efficiency variable, we used reported savings from utility-run energy efficiency programs and appliance/equipment standards. The data for savings from utility efficiency programs between 2006 and 2012 come from the annual ACEEE *State Energy Efficiency Scorecard* for 2007 through 2013 (Eldridge et al. 2007, 2008, 2009; Molina et al. 2010; Sciortino et al. 2011; Foster et al. 2012; Downs et al. 2013). We converted savings given in MWh to savings in TWh. The savings data for each year in the *Scorecard* are based on that year's EIA *Annual Electric Power Industry Report* supplemented with data from a survey of state utility commissions and independent statewide utility program administrators. It is important to note that states use different methodologies to determine energy savings from efficiency programs and that these various evaluation, measurement, and verification (EM&V) processes have an impact on the savings reported.

To arrive at the national savings, we summed the reported state savings from the *State Scorecard*. Electric savings from energy efficiency for 1992 to 2005 were pulled directly from the EIA *Annual Electric Power Industry Report*, form 861 (EIA 2013b) and summed to get the national totals. All the annual savings data are incremental, that is, they represent savings from programs and measures adopted in that year and not compounded over the life of efficiency measures implemented in prior years. We lagged the data by one year because many of the efficiency measures are not installed until the middle or end of the year, and therefore the full annual savings are not realized until the following year. We then split the savings by sector as follows: using EIA energy efficiency/energy savings data (2013d), we calculated the percentage of energy saved in the industrial sector in each year and subtracted that from the total to get residential and commercial savings. The data we used in our analysis are summarized in Appendix B.

Savings from appliance standards are from Lawrence Berkeley National Lab (LBL) (Myers 2014). They model cumulative annual savings from equipment standards as they are implemented. To ensure that savings from appliance standards were comparable to the incremental utility efficiency savings, we subtracted the LBL data from the previous year to get incremental savings. To split the savings by sector, we assumed that savings from electric motor standards were predominantly in the industrial sector and the rest of the savings were in the residential and commercial sectors. In actuality some motor savings are in the residential and commercial sectors and some limited savings from other equipment are in the industrial sector, but we assumed that these exceptions cancel each other out.

For the residential and commercial analysis, we summed the savings from utility programs and standards and then divided by the population (million people). Population data come from the U.S. Census Bureau (U.S. Census Bureau 2012a; U.S. Census Bureau 2012b). Since these data represent incremental annual savings, we did not calculate the difference from the previous year, as only a single year of incremental savings is included in our figures. The data are summarized in Appendix B.

ADJUSTED COOLING DEGREE DAYS (CDD)

Higher summer temperatures increase the use of air conditioning. Cooling degree days are a measure of the impact of weather on the need for space cooling at a specific location for a particular period.[9] Annual cooling degree days (CDD) between 1993 and 2012 come from the National Oceanic and Atmospheric Administration (NOAA) (NOAA 2013a). We then calculated the percentage by which each year deviated from the national 30-year average. The 30-year average data come from NOAA (2013c).

ADJUSTED HEATING DEGREE DAYS (HDD)

Colder winter temperatures increase the use of space heating systems. Heating degree days are a measure of the impact of weather on the need for space heating at a specific location for a particular period.[10] The annual total heating degree days (HDD) for each year come from the National Oceanic and Atmospheric Administration (NOAA) (NOAA 2013b). We then calculated the percentage by which each year deviated from the national 30-year average. The 30-year average data come from NOAA (2013c).

For the industrial equation, we used three independent variables.

MANUFACTURING GDP PLUS NON-OIL IMPORTS

Manufacturing GDP is the value added by manufacturing to the economy of a country. Manufacturing is an energy-intensive economic activity, and as the manufacturing sector grows so generally does electricity consumption. "Manufacturing" is defined by North American Industry Classification System (NAICS) codes and includes durable and nondurable goods (U.S. Census Bureau 2013a). The data for manufacturing GDP between 1993 and 2012 come from BEA (BEA 2013a). We converted the data from nominal to real 2011 dollars using the BEA national GDP deflator (2013c). We subtracted each year from the previous year to get the difference data.

We originally included non-oil imports as a separate independent variable, but we found that this variable was highly correlated with manufacturing GDP. (The Pearson correlation coefficient showed a correlation with 99.9% certainty.) The correlation between these two variables is illustrated in figure A1 which shows how industrial electricity use, manufacturing GDP, and non-oil imports change in tandem. We also tried using total GDP (manufacturing and non-manufacturing), thinking that non-manufacturing GDP might have an impact on demand for manufactured products. However we got the best fit when we combined non-manufacturing GDP and non-oil imports. It appears that these two variables measure slightly different aspects of the economy, both of which affect energy use. We recognize that this is an unusual combination, and we see a need for additional analysis on why increased non-oil imports appear to lead to increased electricity use. We would expect that as imports increase, domestic production and domestic electricity use might decrease.

To get the total non-oil imports, we pulled historical goods and services import data from the U.S. Census Bureau U.S. Trade in Goods and Services (U.S. Census Bureau 2013c). We then subtracted total U.S. Imports of Crude Oil (U.S. Census Bureau 2013b). We converted imports

[9] Specifically, for a location, the difference between the average temperature that day and 65 degrees F is the number of cooling degree days for that day (e.g., if the average temperature is 85 degrees F, then 20 cooling degree days accrue that day). These daily figures can be added to obtain CDD in a month or year for a location.

[10] Specifically, for a location, the difference between the average temperature that day and 65 degrees F is the number of heating degree days for that day (e.g., if the average temperature is 30 degrees F, then 35 heating degree days accrue that day). These daily figures can be added to obtain HDD in a month or year for a location.

from nominal dollars to real 2011 dollars using the BEA national GDP deflator (2013c). We then summed manufacturing GDP and non-oil imports and calculated the difference between each year.

PRICE OF ELECTRICITY FOR THE INDUSTRIAL SECTOR

The national annual price of electricity for the industrial sector between 1993 and 2012 comes from the EIA *Annual Energy Review* (EIA 2013c). We used the retail price for all sectors, converted from nominal dollars to real 2011 dollars using the CPI (BLS 2013). We then calculated the difference between each year.

SAVINGS FROM INDUSTRIAL ENERGY EFFICIENCY UTILITY PROGRAMS AND STANDARDS

We used the same method and data to calculate these savings as for residential and commercial sector savings. We did not normalize the industrial savings over population, as the unadjusted data provided a better fit.

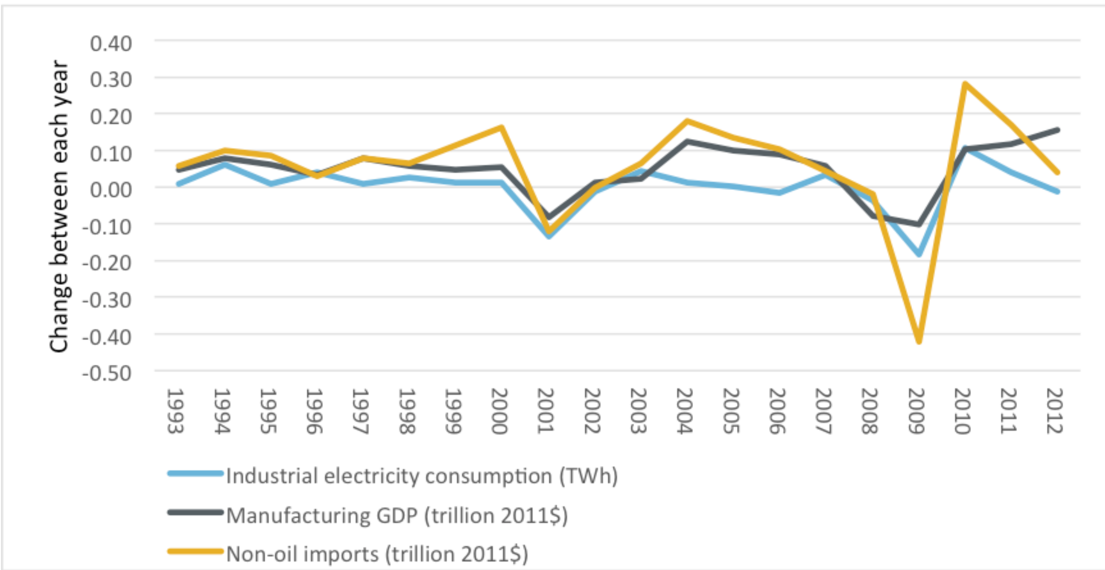

Figure A1. Trends in industrial electricity use, manufacturing GDP, and non-energy imports

Based on the various regressions we ran, we chose the best equations for the residential/commercial and industrial sectors. The best residential and commercial sector electricity use regression equation was:

$$E = 1.123 + 249.894G + 0.141P - 15.689S + 5.936H + 3.859C$$

The best industrial-sector electricity use regression equation was:

$$E = -0.025 + 0.251G - 0.058P - 0.008S$$

We chose these equations because they had the highest R^2 and the most statistical significance for our independent variables. Statistical measures for the equations are provided in tables 4 through 7 in the body of the paper.

Appendix B: Energy Savings Data by Sector and Year

Year	Industrial incremental EE standards (kWh)	Residential and commercial incremental EE standards (kWh)	Utility industry EE (TWh)	Utility residential and commercial EE (TWh)	Total industrial EE (TWh)	Total residential and commercial EE (TWh)
1993	-	0.0005	0.25	1.29	0.00	0.02
1994	-	0.0008	0.31	1.60	0.25	1.29
1995	-	0.0008	0.29	1.51	0.31	1.60
1996	-	0.0010	0.33	1.28	0.29	1.51
1997	0.0008	0.0010	0.37	1.05	0.33	1.28
1998	0.0008	0.0010	0.25	0.87	0.37	1.05
1999	0.0007	0.0011	0.16	0.69	0.25	0.87
2000	0.0007	0.0010	0.93	2.15	0.16	0.69
2001	0.0005	0.0011	0.54	2.79	0.93	2.15
2002	0.0006	0.0009	0.65	3.79	0.54	2.79
2003	0.0005	0.0009	0.73	3.04	0.65	3.79
2004	0.0006	0.0010	0.74	2.25	0.73	3.04
2005	0.0006	0.0009	0.90	3.67	0.74	2.25
2006	0.0008	0.0014	1.08	4.85	0.90	3.67
2007	0.0008	0.0013	1.44	6.42	1.08	4.85
2008	0.0007	0.0018	1.52	8.40	1.44	6.42
2009	-0.0002	0.0018	1.51	9.12	1.52	8.40
2010	0.0001	0.0015	2.98	10.22	1.51	9.12
2011	0.0000	0.0017	2.41	16.08	2.98	10.22
2012	0.0002	0.0041	3.37	18.75	2.41	16.08

The totals lag utility savings by one year.

The decline in industrial savings from standards in 2009 is likely due to the fact that some motors installed in the prior decade were replaced. The new motors were also efficient, but by 2009 more efficient motors were part of the business-as-usual base case. Savings increased in some subsequent years due to new motor standards.