WHY THE SLOW DOWN IN U.S. GREENHOUSE GAS EMISSIONS GROWTH?

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Abstract

This paper addresses the following two questions regarding trends in U.S. greenhouse gas emissions:

- Total U.S. greenhouse gas emissions in 1998—as reported in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1998*—rose to 1,835 MMTCE[1] (11 percent above 1990 baseline levels). The single year increase in emissions from 1997 to 1998 was estimated at 0.4 percent. The average annual rate of increase for the 1990s, however, was 1.3 percent. What are some of the known factors leading to the slower growth in total U.S. emissions from 1997 to 1998 relative to the historical rate of the 1990s?
- What is the expected growth in U.S. greenhouse gas emissions from 1998 to 1999?

In 1998, a dominant factor leading to the slower growth in emissions was weather. Warm winter temperatures in 1998 resulted in a significant drop in residential, commercial, and industrial natural gas consumption for heating. Two factors that offset this drop in emissions from natural gas combustion were: 1) electric utility emissions, which increased in part due to a hot summer and its associated air conditioning demand; and 2) a continued steady increase in fuel consumption for transportation. If the demand for fossil fuels is adjusted as if normal[2] weather conditions had occurred, then the 1998 growth in emissions would have likely been about 1.3 percent—roughly equal to the average historical rate for the 1990s. However, given the rapid growth in the economy in 1998, it is surprising that greenhouse gas emissions did not grow at an even faster rate to keep up with the 4.2 percent increase in U.S. Gross Domestic Product.[3]

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[1] Million Metric Tons of Carbon Equivalents (MMTCE) is a measure of greenhouse gas emissions normalized to the temporally integrated global average radiative forcing impacts of carbon dioxide (CO_2). The Global Warming Potential (GWP) of each greenhouse gas is used as a weighting factor. For further information see *The Science of Climate Change Contribution of Working Group I to the Second Assessment of the Intergovernmental Panel on Climate Change*, <http://www.ipcc.ch/pub/reports.htm>.

[2] Normals are based on average population weighted degree day data from 1961 through 1990. Degree days are relative measurements of outdoor air temperature and are a proxy for estimating the amounts of energy required to maintain comfortable indoor temperature levels. Heating degree days are deviations of the mean daily temperature below 65°F, while cooling degree days are deviations of the mean daily temperature above 65°F. Excludes Alaska and Hawaii. Daily values are computed from each day's mean temperature (max + min/2). Degree day totals are derived from U.S. Census division-level population weighted data, and therefore are biased toward conditions existing in the more populous sections of the United States.

[3] Bureau of Economic Analysis, U.S. Department of Commerce, 10 May 2000, <http://www.bea.doc.gov/bea/dn/gdppch.htm>.

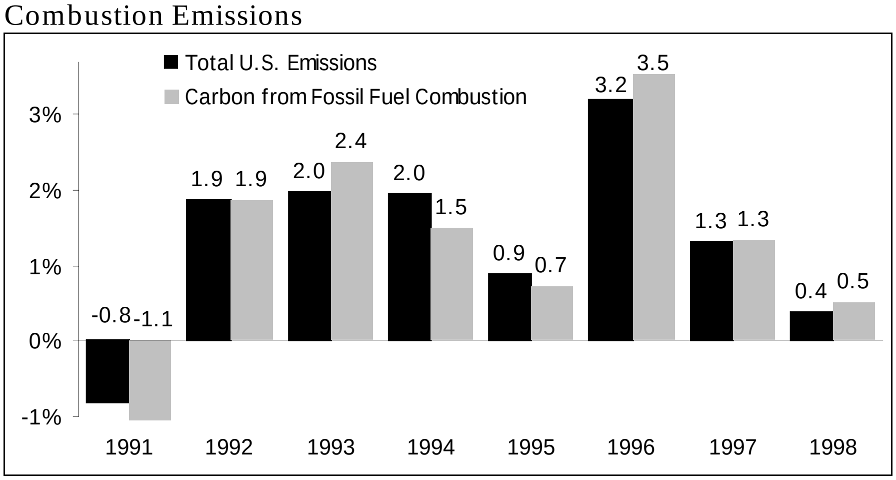
A preliminary estimate for the growth in total U.S. emissions from 1998 to 1999 shows that it will be in the range of 1.0 percent (confidence interval of 0.3 to 1.9 percent). This estimate is based on various fossil fuel consumption datasets from the Department of Energy's Energy Information Administration (EIA) and projections for emissions from other greenhouse gas source categories. Colder winter conditions in 1999 also appear to have altered fuel consumption patterns. Consumption of fuels for heating in 1999 appears to have increased because, although winter conditions were still significantly warmer than normal, they were colder than in 1998.

Before causal factors for year to year changes in overall greenhouse gas emissions trends are accepted, it is important for analysts to consider the sources of variability and uncertainty in energy data and other emissions data. In regards to the recent changes in U.S. greenhouse gas emissions, a longer time series of data and more detailed information on national scale energy efficiency patterns are needed before firm conclusions can be drawn regarding any dramatic shifts in long-term trends.

Introduction

As the largest source of U.S. greenhouse gas emissions, carbon dioxide (CO_2) from fossil fuel combustion accounted for a nearly constant 80 percent of global warming potential (GWP) weighted emissions throughout the 1990s.[4] Emissions from this source category have also dominated the annual trend in emissions during this period. On average CO_2 from fossil fuel combustion has been responsible for 86 percent of the change in emissions each year. The influence of other source categories on greenhouse emission trends has been significantly smaller.[5] Historically, changes in emissions from fossil fuel combustion have been the dominant factor affecting U.S. emission trends (see Figure 1).

Figure 1: Annual Percent Change in Total U.S. Greenhouse Gas and CO_2 from Fossil Fuel Combustion Emissions



Source: EPA (2000a)

[4] If a full accounting of emissions from fossil fuel combustion is made by including emissions from the combustion of international bunker fuels and CH_4 and N_2O emissions associated with fuel combustion, then this percentage increases to a constant 82 percent during the 1990s.

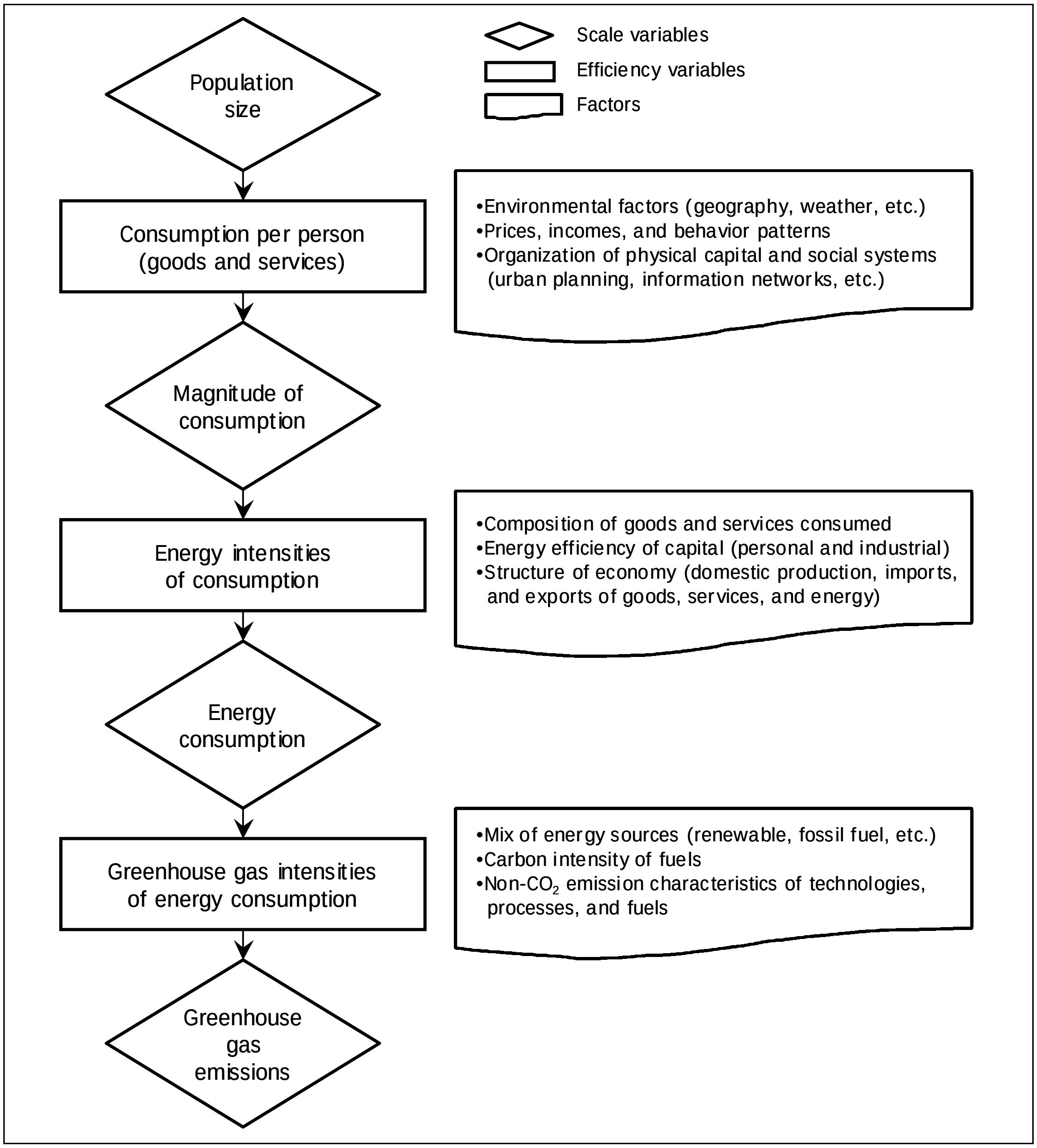
[5] In terms of the entire 1990s time series, the correlation coefficient between annual changes in total U.S. emissions and annual changes in CO_2 emissions from fossil fuel combustion was 0.98. The significant sources with the next highest correlation coefficients were CO_2 from cement manufacture and N_2O from agricultural soil management (0.41 and 0.32, respectively).

Annually, the overall demand for fossil fuels in the United States and other countries generally fluctuates in response to general economic conditions, energy prices, weather, and the availability of non-fossil alternatives. For example, a year with increased consumption of goods and services, low fuel prices, and severe summer and winter weather conditions would be expected to have proportionally greater energy consumption than a year with poor economic performance, high fuel prices, and mild temperatures.

Longer-term changes in energy consumption patterns, however, respond more to factors that affect the scale of consumption (e.g., population, number of cars, and size of houses), the efficiency with which energy is used in equipment (e.g., cars, power plants, steel mills, and light bulbs) and consumer behavior (e.g., living in the city and walking instead of suburban life and driving).

Energy-related CO_2 emissions are also a function of the type fuel or energy consumed and its carbon intensity. Producing heat or electricity using natural gas instead of coal, for example, can reduce the CO_2 emissions associated with energy consumption (see Figure 2).

Figure 2: Aggregate Measure Connections Between Human Activity and Energy-related Greenhouse Gas Emissions



Emission Trends

From 1997 to 1998, the increase in CO_2 emissions from fossil fuel combustion was only 0.5 percent—lower than the source's average annual rate of 1.3 percent during the 1990s. This slow down in the growth rate is due to a combination of all of the factors introduced above; however, certain factors appear to have dominated.

Except for 1991, economic growth in the United States during the 1990s was robust (e.g., U.S. gross domestic product increased by 4.2 percent in 1998) and energy prices through 1998 were generally low. Winter and summer temperatures across the United States, however, have fluctuated more significantly, with warmer winter temperatures reducing demand for heating fuels in 1998 and hotter summer temperatures stimulating electricity demand. Table 1 shows annual changes in CO_2 emissions from fossil fuel combustion during the last few years of the 1990s by fuel type and sector.

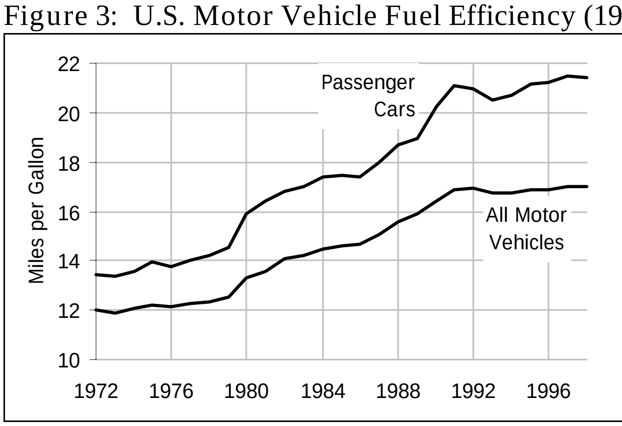
Table 1: Annual Change in CO_2 Emissions from Fossil Fuel Combustion for Selected Fuels and Sectors (MMTCE and percent)

Sector	Fuel Type	1995 to 1996		1996 to 1997		1997 to 1998	
Electric Utility	Coal	24.5	5.7%	14.3	3.1%	5.5	1.2%
Electric Utility	Petroleum	1.4	10.0%	2.4	14.4%	7.3	41.6%
Electric Utility	Natural Gas	-6.9	-14.6%	3.3	8.1%	4.2	9.8%
Transportation[a]	Petroleum	13.8	3.3%	1.1	0.2%	7.3	1.7%
Residential	Natural Gas	5.8	8.1%	-3.8	-4.9%	-7.4	-10.0%
Commercial	Natural Gas	1.9	4.2%	0.9	1.9%	-2.7	-5.7%
Industrial	Natural Gas	4.7	3.4%	-1.4	-1.0%	-2.9	-2.0%
Industrial	Petroleum	5.9	6.0%	2.4	2.3%	-4.0	-3.8%
All Sectors[b]	**All Fuels[b]**	**49.3**	**3.5%**	**19.4**	**1.3%**	**7.5**	**0.5%**

[a] Excludes emissions from International Bunker Fuels.
[b] Includes fuels and sectors not shown in table. The sectors and fuels not shown accounted for less than 4 percent of CO_2 emissions from fossil fuel combustion in 1998.
Source: EPA (2000a)

From 1995 to 1996 emissions increased significantly due, primarily, to two factors. First, electric utilities shifted from natural gas to more carbon intensive coal as colder winter conditions in 1996—and the associated rise in demand for natural gas from residential, commercial and industrial customers for heating—caused gas prices to rise sharply. Second, the consumption of petroleum fuels for transportation continued to rise as people traveled more and automotive fuel economy stagnated (see Figure 3).

Figure 3: U.S. Motor Vehicle Fuel Efficiency (1972-1998)



Source: FHWA (1999)

Milder summer and winter weather conditions moderated the growth in emissions in 1997; however, the shutdown of several nuclear power plants lead electric utilities to increase their fossil fuel consumption to offset the lost nuclear capacity.[6]

In 1998, warm winter temperatures resulted in a significant drop in residential, commercial, and industrial natural gas consumption. This drop in emissions from natural gas used for heating

[6] The cause of the slow down in petroleum consumption in the transportation sector is unclear. Vehicle miles traveled (VMT) data for 1997 show a 1.9 percent increase.

was primarily offset by: 1) electric utility emissions, especially from petroleum, which increased in part due to a hot summer and its associated air conditioning demand; and 2) further increases in petroleum consumption for transportation.[7]

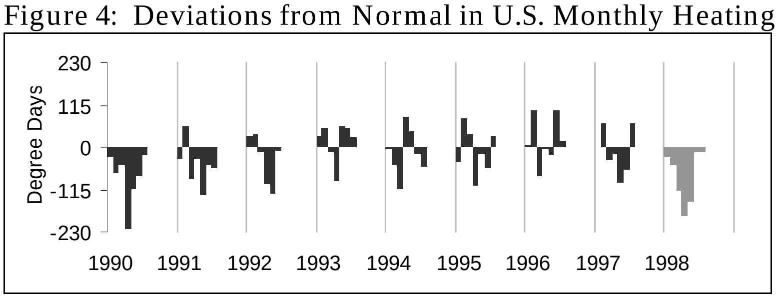
Variability and Uncertainty

Despite the discussion and information presented above, in reality there is a significant amount of variability and uncertainty in U.S. estimates of energy-related greenhouse gas emissions. Weather patterns, obviously, play a large role in shaping changes in energy consumption from year to year. Other factors, though, such as fluctuations in industrial output and the availability of non-fossil fuel power sources can also have a significant influence. The magnitude of these variations and uncertainties are actually small relative to overall estimates of U.S. energy-related greenhouse gas emissions; however, they have a far greater impact on the statistical significance of small differences in annual rates of growth.

Weather

Unlike in other major end-use sectors, emissions from the residential and commercial sectors did not decline during the economic downturn in 1991, but instead decreased in 1994, 1997, and 1998. This difference in these pattern of energy consumption compared to other end-use sectors is because energy consumption in residences and commercial buildings is affected proportionately more by the weather than by prevailing economic conditions. In 1998, the winter conditions in the United States were extremely warm—with heating degree days 12 percent below normal—leading to an estimated 10 and 6 percent drop in natural gas consumption by the residential and commercial sectors, respectively.[8] (See Figure 4, Figure 5, and Figure 6)

Figure 4: Deviations from Normal in U.S. Monthly Heating Degree Days During Winter

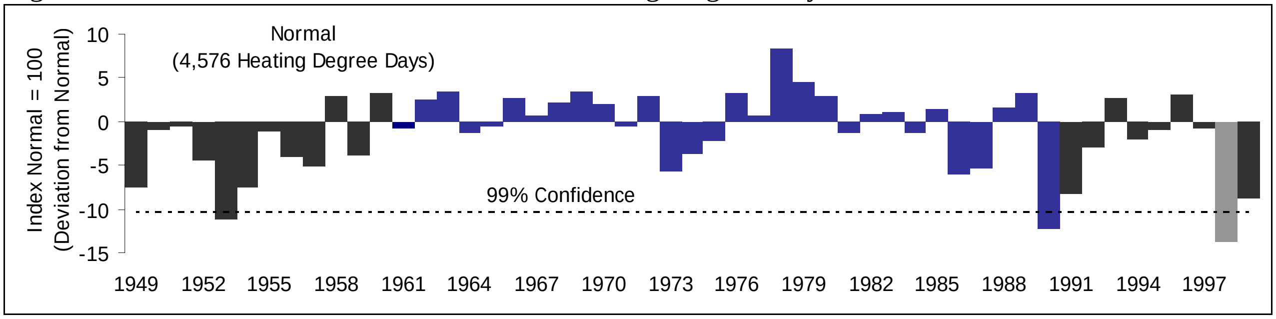


Note: 1998 Data is highlighted. Order of winter months within each calendar year for display purposes is October, November, December, January, February, March, and April.
Source: NOAA (2000a), EIA (1999a)

[7] The real price of crude oil paid by refiners in 1998 dropped to its lowest level since 1972. Although the short-term price elasticity of demand for petroleum in the transportation sector is probably small, electric utilities are far more sensitive to price fluctuations and capable of switching between fuels.

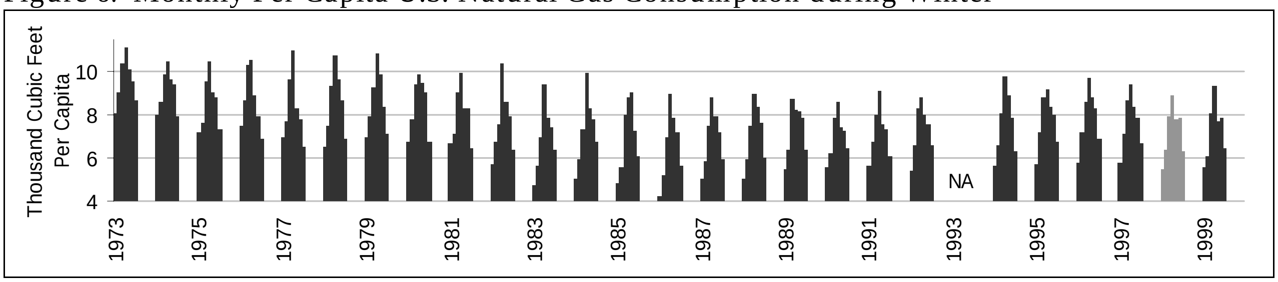
[8] Normals are based on average population weighted degree day data from 1961 through 1990. Degree days are relative measurements of outdoor air temperature and are a proxy for estimating the amounts of energy required to maintain comfortable indoor temperature levels. Heating degree days are deviations of the mean daily temperature below 65°F, while cooling degree days are deviations of the mean daily temperature above 65°F. Excludes Alaska and Hawaii. Daily values are computed from each day's mean temperature (max + min / 2). Degree day totals are derived from U.S. Census division-level population weighted data, and therefore are biased toward conditions existing in the more populous sections of the United States.

Figure 5: Annual Deviations from Normal Heating Degree Days for the United States



Note: 1998 and climatological normal data is highlighted. Statistical confidence interval for "normal" climatology period of 1961 through 1990.
Source: NOAA (2000a) and EIA (1999a)

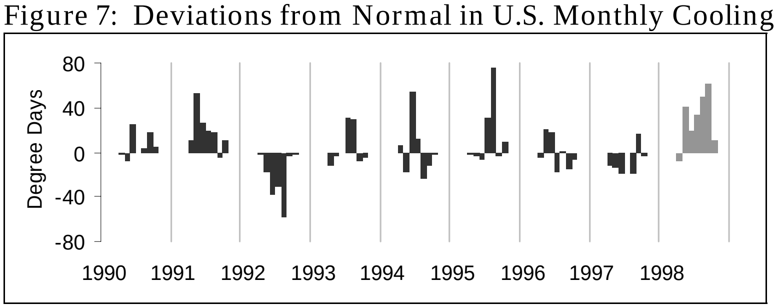
Figure 6: Monthly Per Capita U.S. Natural Gas Consumption during Winter



Note: 1998 Data is highlighted. Order of winter months within each calendar year for display purposes is October, November, December, January, February, March, and April. Data for 1993 was not available.
Source: EIA (2000a)

In 1998, retail sales by electric utilities increased in all end-use sectors due largely to robust economic growth and the year's summer weather conditions. The summer of 1998 for the United States was exceptionally warm, with cooling degree days 14 percent above normal.[9] The resulting increased electricity demand for air conditioning was likely a significant factor in the 3.2 percent increase in CO_2 emissions from electric utilities from 1997 to 1998. (See Figure 7, Figure 8, and Figure 9)

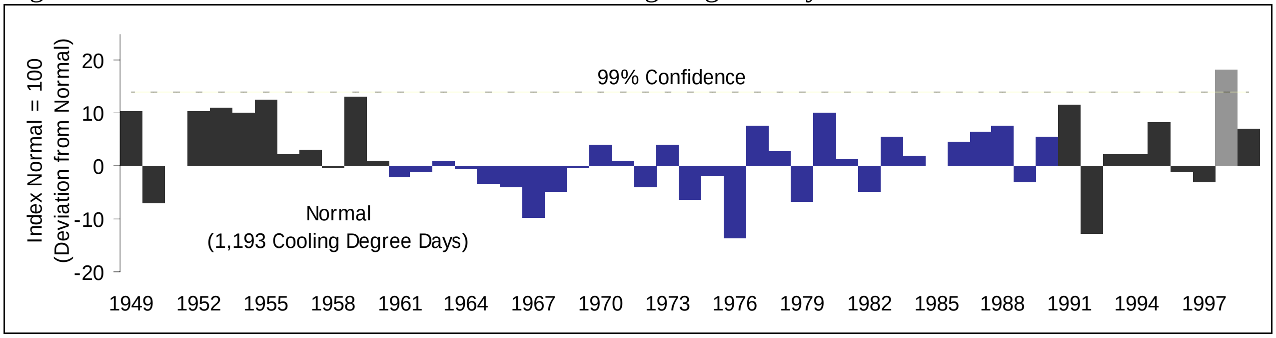
Figure 7: Deviations from Normal in U.S. Monthly Cooling Degree Days during Summer



Note: 1998 Data is highlighted. Order of summer months within each calendar year is April, May, June, July, August, September, and October.
Source: NOAA (2000b) and EIA (1999a)

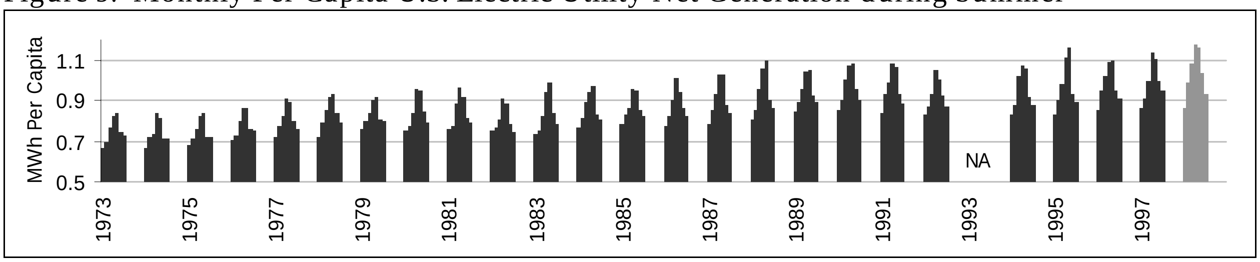
[9] Cooling degree days in 1998 were approximately 3 standard deviations above the normal value (i.e., average of 1961 to 1990). These higher summer temperatures were especially predominant in the Southwest.

Figure 8: Annual Deviations from Normal Cooling Degree Days for the United States



Note: 1998 and climatological normal data is highlighted. Statistical confidence interval for "normal" climatology period of 1961 through 1990.
Source: NOAA (2000b) and EIA (1999a)

Figure 9: Monthly Per Capita U.S. Electric Utility Net Generation during Summer

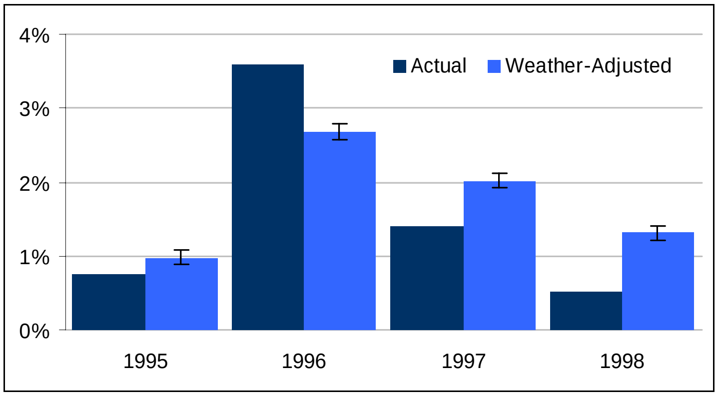


Note: 1998 Data is highlighted. Order of summer months within each calendar year is April, May, June, July, August, September, and October. Monthly data for nonutilities was not available. Data for 1993 was not available.
Source: EIA (2000a)

An analysis was performed by the Energy Information Administration (EIA) to examine the effects of weather conditions on U.S. fuel consumption patterns. The analysis—using the EIA's Short-Term Integrated Forecasting System (STIFS)—found that if normal weather conditions had existed in 1998, overall CO_2 emissions from fossil fuel combustion would have increased by about 1.2 to 1.4 percent above weather-adjusted emissions in 1997, instead of the actual 0.5 percent increase (see Figure 10).[10] It should also be noted that the EIA has actually incorporated into its short-term forecasts an assumption for the gradual increase of summer and winter temperatures in the United States that is consistent with a three-decade long warming trend identified by the National Oceanographic and Atmospheric Administration (NOAA). Their analysis found that these temperature changes were leading to overestimates of winter heating fuel demand and underestimates of fuel demand for summer cooling. In other words, EIA's short-term forecasts are no longer based on historical average (i.e., normal) temperatures, but instead on slow rate of increasing temperatures nationally (Morris 1999).

[10] The economic growth rate in EIA's weather adjusted model is actually the average annual growth rate between 1990 and 1998. The EIA goes on to state that given the high rate of economic growth in 1998, the increase in weather adjusted emissions between 1997 and 1998 would likely have been even greater. (EIA 1999b)

Figure 10: Annual Percent Change in Actual and Weather-Adjusted CO_2 Emissions from Fossil Fuel Combustion



Note: Error bars span the range of values obtained by adjusting STIFS data to be consistent with actual emissions data, but do not indicate the overall uncertainty.
Source: EPA (2000a) and EIA (2000f)

The EIA study also confirmed that weather fluctuations have historically affected consumption of winter heating fuel consumption more significantly than summer electricity consumption. In other words, a unit change in U.S. winter heating degree days will have a greater impact on energy consumption than a comparable change in summer cooling degree days (Morris 1999).

Industrial Sector

The industrial sector—as operationally defined in the EIA's energy statistics—includes manufacturing, mining, construction, agriculture, and nonutility electricity generators. Manufacturing industries have accounted for a majority of this sector's energy consumption and CO_2 emissions from fossil fuel consumption (see Figure 11). Nonutilities, however, are a growing portion of the industrial sector as deregulation of the electric power industry progresses. In contrast to electric utilities, which generate a majority of their electricity with coal, natural gas is the fuel of choice for nonutilities. In 1997 and 1998, these nonutility generators accounted for a quarter of the industrial sector's consumption of natural gas (EIA 1999d and EIA 2000a).[11]

Table 2 presents the same data as was presented in Table 1 above, but separates out the nonutility portion of industrial sector natural gas consumption. The remainder of the industrial sector (i.e., "Other Industrial") exhibits an even more dramatic decline in emissions from natural gas consumption in both 1997 and 1998.[12]

[11] Roughly 40 percent of the energy in the industrial end-use sector was supplied by natural gas in the 1990s, while 14 percent of was in the form of electricity.

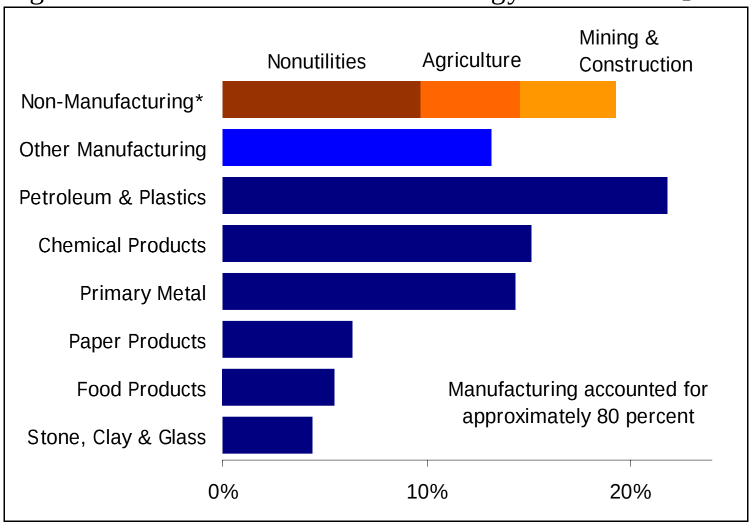
[12] Approximately 47 percent of the energy-related CO_2 emissions from the industrial sector in 1988 resulted from natural gas combustion (EPA 2000a). In 1994, 37 percent of energy for manufacturing in the industrial sector was provided by natural gas (EIA 1997b).

Table 2: Annual Change in CO_2 Emissions from Natural Gas Combustion for the Industrial Sector (MMTCE and percent)*

Category	1996 to 1997		1997 to 1998	
Non-Utility Generators	1.4	4.7%	4.6	14.6%
Other Industrial	-2.8	-2.5%	-7.5	-6.7%
Industrial Sector	**-1.4**	**-1.0%**	**-2.9**	**-2.0%**

* Preliminary estimates.
Source: EPA (2000a) and DOE/EPA (1999)

Figure 11: U.S. Industrial Sector Energy-Related CO_2 emissions in 1994*



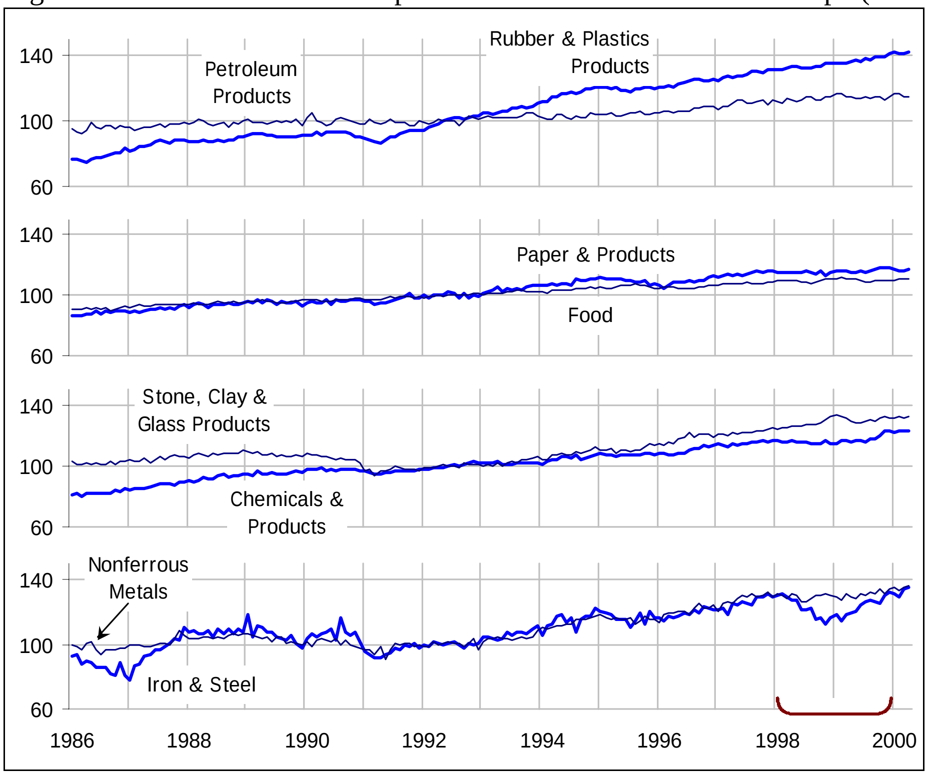
* Preliminary estimates.
Note: Includes indirect emissions from electricity consumption and oxidized portion of fossil fuel feedstocks for nonfuel purposes. Excludes other by-product process emissions (e.g., calcination of $CaCO_3$ during cement manufacture). Approximately 95 percent of primary metal energy consumption is associated with iron and steel manufacturing.
Source: EPA (2000a), EIA (1997b), DOE/EPA (1999), EIA (2000a), USDA (2000), EIA (1999b)

The reason for this even more dramatic decline in the remaining portion of the industrial sector is not entirely clear; however, weather was actually likely to have played an important role. In general, energy-related emissions from the industrial sector are more sensitive to weather fluctuations than is often appreciated, especially for certain activities within the sector such as heating of buildings and agriculture.

Part of the reason for this sensitivity to weather is an artifact of how sectoral definitions are made. The EIA allocates consumption of natural gas, and some petroleum products, according to the price paid by consumers (i.e., rate schedules). Rate schedules for the industrial sector, though, can unintentionally include some large commercial and residential consumers who have successfully negotiated a rate equivalent to an industrial consumer. Similarly some small industrial consumers may actually end up categorized as commercial (EIA 1997a). The upshot is that care should be taken in assuming that only the residential and commercial sectors are sensitive to weather or that a drop in fuel consumption by the industrial sector can only be associated with changes in output or improvements in energy efficiency.

In 1998, though, the iron and steel industry actually did experience a significant drop in output. The recent Asian financial crisis led to a sharp reduction in the region's demand for iron and steel and a global depression in commodity prices. As a result of both the drop in prices and 49 percent increase in imports, pig iron production in the United States dropped by approximately 3 percent in 1998 (USGS 1999 and FRS 2000). This recent drop in iron and steel output can be seen clearly in Figure 12, as can the more general economic recession in 1991. The 1998 drop in output of pig iron is estimated to have resulted in a roughly 0.5 to 1.0 MMTCE drop in industrial sector CO_2 emissions because of the overall reduced consumption of natural gas and coking coal by the iron and steel industry.

Figure 12: U.S. Industrial Output Index for Select Market Groups (Index 1992 = 100)



Note: Seasonally adjusted.
Source: FRS (2000)

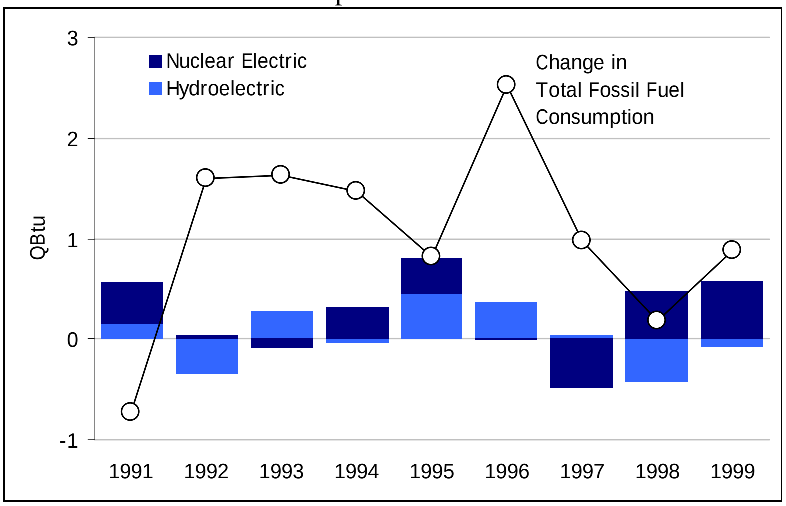
It is quite likely, that a portion of the decline in energy-related CO_2 emissions from the industrial sector is the result of efficiency improvements. Unfortunately, though, adequately detailed energy statistics are not yet available to thoroughly assess the various factors influencing recent trends in industrial sector energy consumption. Near the end of this year, however, data from the EIA's most recent survey of manufacturing energy consumption for 1998 should be available. These data should help to shed some light on changes in manufacturing energy efficiency.

Availability of Non-Fossil-Fuel Energy

Variations in energy consumed from hydroelectric and nuclear sources can also have a significant effect on U.S. fossil fuel consumption, and therefore on U.S. greenhouse gas emissions. This effect is because electricity generated by hydroelectric and nuclear plants—which have no CO_2

emissions directly associated with them—generally displaces fossil fuel consumption by electric utilities. Figure 13 illustrates that the magnitude of shifts in electricity generated by hydroelectric and nuclear plants is significant relative to changes in total U.S. fossil fuel consumption.[13] During the 1990s, aggregate output by hydroelectric plants has varied by as much as 15 percent from year to year, while output from nuclear plants has varied output by as much as 8 percent. Output from hydroelectric plants is primarily affected by changes in annual precipitation patterns, while output from nuclear plants tends to be affected by maintenance and regulatory issues.

Figure 13: Annual Change in Energy Consumption from Nuclear and Hydroelectric Power and Total Fossil Fuel Consumption



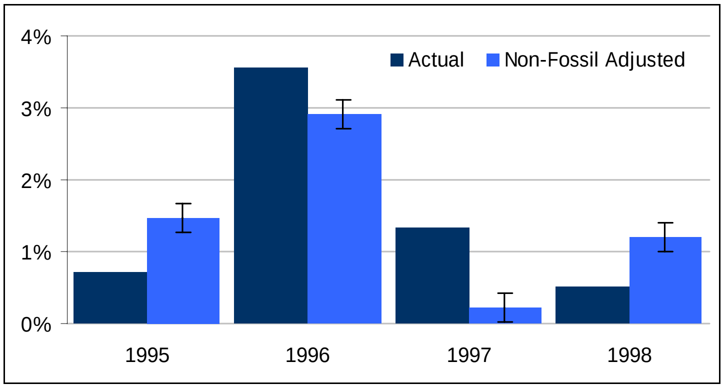
Note: Hydroelectric energy consumption based on average heat rate for fossil-fueled steam-electric plant generation.
Source: EIA (2000a)

Nuclear and hydroelectric sources account for, on average, 7.6 and 3.8 percent of U.S. energy consumption. They also account for the majority of non-fossil energy sources (75 percent) in the United States. The remaining quarter of non-fossil energy is primarily provided by biomass fuels, which tend to have lower inter-annual variability. (EIA 1999a)

Figure 14 provides an estimate of U.S. CO_2 emissions from fossil fuel combustion adjusted to remove the inter-annual variation in energy output from hydroelectric and nuclear sources. Like those for weather presented above, these adjustments can have a significant effect upon the interpretation of year to year emission trends.

[13] Figure 13 is not intended to imply or quantify complete causality, but instead simply to illustrate the scale of variability of energy availability from the major nonfossil fuel energy sources.

Figure 14: Annual Percent Change in Actual and Non-Fossil Adjusted* CO_2 Emissions from Fossil Fuel Combustion



* Adjustments include only the variation in energy consumption from hydroelectric and nuclear power sources.
Note: Error bars span the range of carbon intensities for the substitution of fossil fuels (e.g., natural gas, petroleum, and coal) for nuclear and hydroelectric sources, but do not indicate the overall uncertainty. Hydroelectric energy consumption based on average heat rate for fossil-fueled steam-electric plant generation.
Source: EPA (2000a) and EIA (2000a)

Uncertainty

Although it is not often treated thoroughly by most policy analysts, uncertainty is an essential factor to consider when manipulating data or drawing conclusions. Random errors—in addition to systematic biases—are an unavoidable part most energy statistics and greenhouse gas emissions data. The frequency with which more contemporaneous EIA statistics tend to be revised is one indication of these errors and the noble efforts by EIA staff to minimize them.

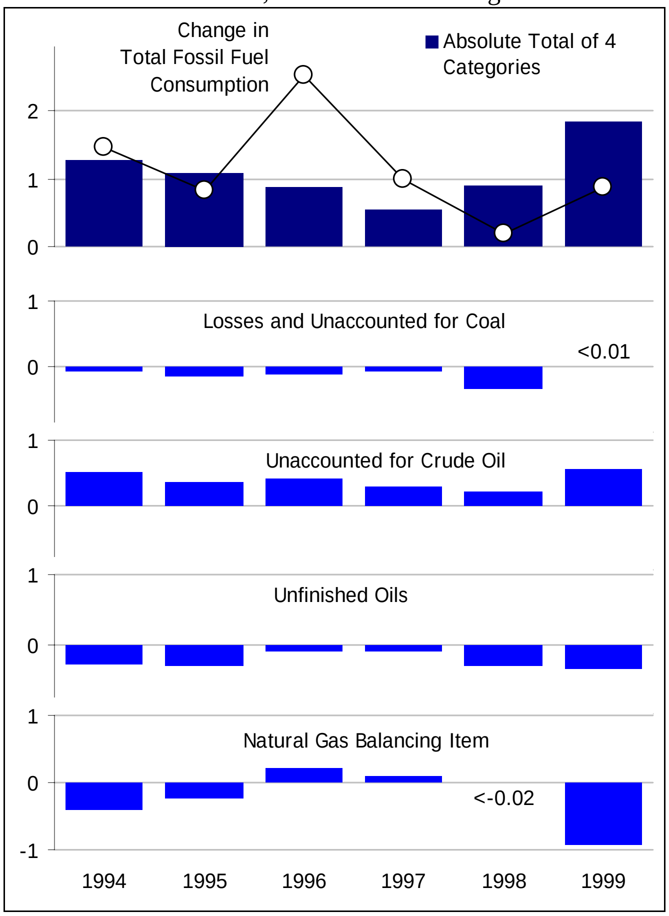
In general, though, the uncertainty in aggregate measures—such as total petroleum consumption—have a lower level of uncertainty than more disaggregated data—such as distillate fuel oil consumption in the industrial sector. It has been estimated that uncertainties of 10 percent for the sectoral allocation of energy consumption for OECD countries are not unusual (Schipper, et al. 1999).

The maximum random error in annual estimates of energy-related CO_2 emissions in the United States was subjectively estimated by EIA to be roughly ±0.4 percent, or at current emission levels about ±7 MMTCE (EIA 1999b).[14] Given the scale of the quantity being estimated—total annual fossil fuel consumption in the United States—this error is impressively small. However, even small random errors can have important implications for the statistical significance of small differences in emissions from year to year. Applying these subjective random error estimates to the calculation of a year to year trend produces an uncertainty value of roughly ±10 MMTCE. Between 1997 and 1998, the 0.5 percent increase in U.S. CO_2 emissions from fossil fuel combustion was equivalent to about 8 MMTCE. The influence of these random errors can be illustrated by examining some of the fuel type-specific accounting discrepancies in U.S. energy statistics.

[14] The EIA provides separate estimates for the random errors and biases in fuel consumption statistics. Based on the data provided, the overall the random error in fossil fuel consumption statistics is estimated to be roughly ±0.3 percent. Other energy data is likely to have less error (e.g., nuclear plant generation), while some data is likely to have greater error (e.g., biomass consumption). The larger error in overall CO_2 emissions is a result of incorporating the uncertainties in carbon dioxide emission factors.

Petroleum consumption in the United States is estimated from records of the volume of petroleum products shipped from primary storage facilities. Coverage of crude oil inputs and refinery outputs by EIA surveys is generally complete. However, significant reporting anomalies are still found in U.S. petroleum data, as well as data for other fuels. (EIA 1999b) These reporting anomalies also have significant variations in magnitude from year to year (see Figure 15)

Figure 15: Natural Gas Balancing Item, Unfinished Oils, Unaccounted for Crude Oil, Losses and Unaccounted for Coal, and Annual Change in Total U.S. Fossil Fuel Consumption (QBtu)



Note: Data for 1999 is preliminary.
Source: EIA (2000a), EIA (2000b), EIA (2000c), EIA (2000e), EPA (2000a), and EIA (1999b) unpublished data.

Each year in U.S. petroleum statistics, more crude oil is reported as being delivered to refineries than is accounted for by data on oil production, imports, and stock changes. This discrepancy is referred to as unaccounted for crude oil.[15] In 1998 it accounted for less than one

[15] Unaccounted for Crude Oil represents the difference between crude oil supply and disposition. Crude oil supply is the sum of field production and imports. Crude oil disposition is the sum of stock change, losses, refinery inputs, exports, and products supplied. A positive result indicates that refiners and exporters reported use of more crude oil than was reported to have been available to them. (This occurs, for example, when imports are undercounted due to late reporting or other problems.) A negative result indicates that more crude oil was reported to have been supplied to refiners and exporters than they reported to have used. (EIA 1999f)

percent of refinery supply. Unaccounted for crude oil is likely due to imprecise records of crude oil production, imports, and stock changes. (EIA 1999b)

In addition to the unaccounted crude oil, each year more unfinished oils are delivered to refineries than can be accounted for by sales and imports.[16] The EIA states that this unfinished oil discrepancy is probably the result of asymmetric treatment of sales between refineries. For example, a buyer likely knows that the intended use of these oils is for motor gasoline or distillate fuel. However a seller simply identifies them as unfinished oils. The implication is that there is some discrepancy in the allocation of petroleum consumption across specific petroleum products. This discrepancy is accounted for through an adjustment to the "other oils" category in the EIA's consumption statistics. In 1998, the unfinished oils adjustment accounted for less than one percent of U.S. petroleum supply. However, despite its relatively small magnitude, almost the entire drop in industrial petroleum consumption from 1997 to 1998 can be attributed to the large increase in the unfinished oils adjustment (see Table 1 and Figure 15).

In natural gas statistics a balancing item is necessary to account for the difference between estimates of natural gas supply and disposition. On average this natural gas balancing item has been equivalent to 2 to 3 percent of consumption, with reported consumption usually smaller than reported production. It was believed that this error represented a systematic source of unreported consumption and quantities lost. Unreported consumption can result from flow meter measurement errors or differences between billing cycles and calendar periods (EIA 2000b). In 1996 and 1997, however the EIA's statistics showed consumption being greater than supply by as much as 1 percent, thereby casting doubt on the earlier explanation. In 1998, the natural gas balancing item was less than 0.1 percent of total U.S consumption, with the data again showing a greater supply than consumption (see Figure 15).[17]

Analogous to petroleum and natural gas, an adjustment item in coal statistics—referred to as losses and unaccounted for coal—is also used to account for discrepancy between production, imports, exports, stock changes, and consumption (EIA 2000e). In 1998, this discrepancy was equivalent to just less than 2 percent of coal consumption, with consumption consistently greater than supply (see Figure 15).

Some other energy-related uncertainties specific to greenhouse gas emission estimates include the adjustments made to separate out consumption of international bunker fuels, carbon emitted from the oxidation of non-energy fossil fuel feedstocks (e.g., plastics), and emissions from U.S. territories. Because of the limited quality of data on these categories, each involves greater uncertainties than those for overall fossil fuel consumption statistics.

In terms of systematic biases, it is more likely the U.S. energy statistics underestimate fossil fuel consumption than overestimate. This case is more probable due to the difficulty in obtaining complete survey coverage. In general, though, biases will cancel out because they are correlated between years, and therefore, they have minimal impact on the interpretation of trends. It is also possible, however, that the bias in U.S. energy statistics may not be as consistent from year to year as might be hoped. The deregulation of natural gas industry, the ongoing deregulation of the electric

[16] Unfinished oils include all oils requiring further processing, except those requiring only mechanical blending (naphtha and lighter oils, kerosene and light gas oils, heavy gas oils, and residuum). (EIA 1999f)

[17] Although based on preliminary data, the reader should also note the large rise in the natural gas balancing item for 1999.

power industry, and restructuring in the petroleum industry have all resulted in new difficulties in the collection of energy data.[18]

For example, following the restructuring of the interstate natural gas transportation system in the 1980s, many industrial firms have began purchasing gas from marketers and other alternatives to traditional distribution companies (EIA 1999d). These changes have made it more difficult to maintain accurate consumption data and identify the sector (e.g., commercial or industrial) of final disposition. Recently, State regulators have also begun to offer residential and small commercial customers a choice of off-system providers of natural gas (EIA 1999d).[19]

This discussion on uncertainty and the calling out of the four categories of adjustments to EIA statistics—and comparison with changes in total fossil fuel consumption—is not meant to imply that U.S. energy statistics are unacceptably ridden with errors. The supply and consumption statistics produced by the EIA are, in contrast, of exceptionally high quality. Unfortunately, though, given the scale of their task, errors and uncertainties are unavoidable. Similar to the factors causing year to year variations in U.S. energy consumption, analysts should also take care to consider the uncertainty in the data used to estimate U.S. greenhouse gas emissions, especially when assessing short-term trends.

The EPA is currently collaborating with the EIA on a project to better assess and quantify these and other uncertainties using Monte Carlo techniques and a detailed assessment of the quality of input data used for the U.S. greenhouse gas inventory.

A Preliminary 1999 Emissions Estimate

Given the discussion and caveats above—and at the risk of being hypocritical—a preliminary estimate for the increase in U.S. greenhouse gas emissions from 1998 to 1999 has been developed using various datasets from EIA and preliminary estimates for other gases and source categories. Using fossil fuel consumption data at various levels of disaggregation and from both the Monthly Energy Review and the Short-Term Energy Outlook, the range in values for the increase in emissions in 1999 was estimated to be between 0.9 and 1.3 percent, with a best guess value of about 1.0 percent.[20] Using a the STIFS modeling framework, the weather-adjusted growth rate in CO_2 emissions from fossil fuel combustion and in total U.S. greenhouse gas emissions was estimated to be roughly 1.2 percent (see Figure 16). Separately, Figure 17 illustrates the effect of adjusting for changes in output by nuclear and hydroelectric plants in 1994 through 1999. Figure 18 combines the adjustments for both weather and variations in nuclear and hydroelectric output.

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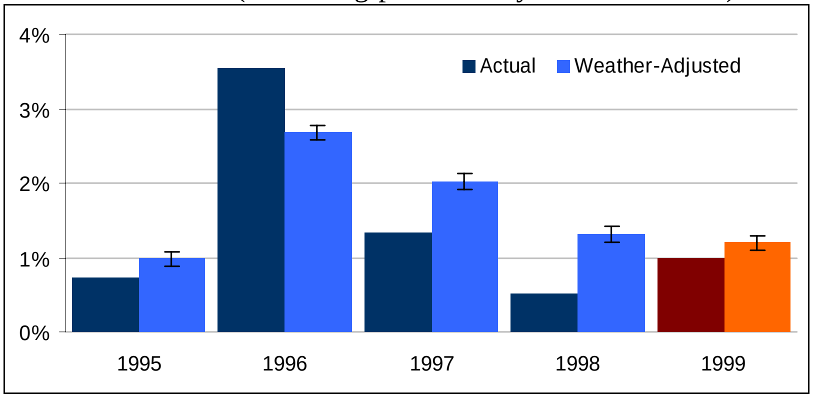
[18] The EIA has initiated a project—called Next Generation * Natural Gas (NG)2—to redesign their natural gas information collection system in response to the restructuring of the natural gas industry. The project includes addressing supply, demand and price developments in the industry, the competitiveness of the industry, and determinants of long-term demand. As final information requirements are established, the EIA plans to implement new and revised data collection and information programs. The project’s goal is the incremental implementation of revised natural gas surveys and publication systems with completion of the redesign by the end of 2002. See <http://www.eia.doe.gov/oil_gas/natural_gas/ng2/ng2main.html>, or for their information requirements report see <http://www.eia.doe.gov/oil_gas/natural_gas/ng2/ng2ir.html>.

[19] In the industry this level of deregulation is often referred to as "retail unbundling."

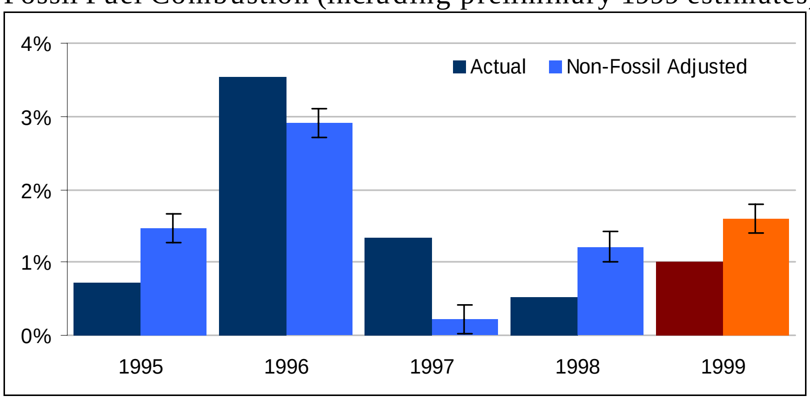
[20] The full 95 percent confidence interval for the growth in 1999 emissions, considering only the random error in CO_2 emissions from fossil fuel combustion, is estimated to be 0.3 to 1.9 percent.

Figure 16: Annual Percent Change in Actual and Weather-Adjusted CO_2 Emissions from Fossil Fuel Combustion (including preliminary 1999 estimates)



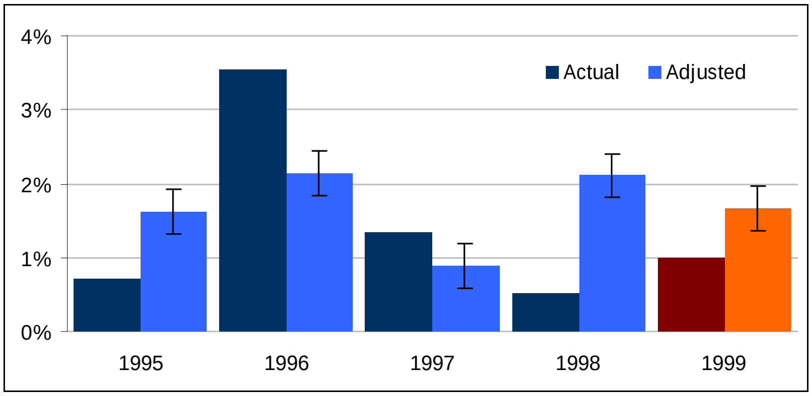
Note: Data for 1999 is preliminary. Error bars span the range of values obtained by adjusting STIFS data to be consistent with actual emissions data, but do not indicate the overall uncertainty.
Source: EPA (2000a), EIA (2000f), and preliminary estimates by author.

Figure 17: Annual Percent Change in Actual and Non-Fossil Adjusted* CO_2 Emissions from Fossil Fuel Combustion (including preliminary 1999 estimates)



* Adjustments include only the variation in energy consumption from hydroelectric and nuclear power sources.
Note: Data for 1999 is preliminary. Error bars span the range of carbon intensities for the substitution of fossil fuels (e.g., natural gas, petroleum, and coal) for nuclear and hydroelectric sources, but do not indicate the overall uncertainty.
Source: EPA (2000a), EIA (2000a), and preliminary estimates by author.

Figure 18: Annual Percent Change in Actual and Adjusted* CO_2 Emissions from Fossil Fuel Combustion



* Includes adjustments for heating degree days, cooling degree days, changes in hydroelectric output, and nuclear electric output.

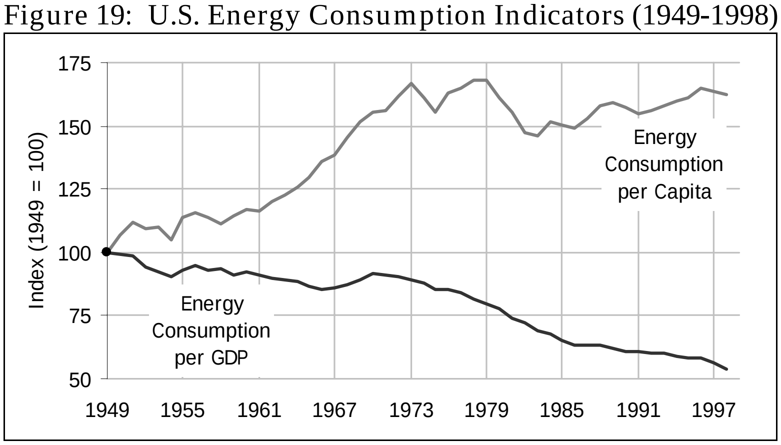
Note: Data for 1999 is preliminary. See Figure 10 and Figure 14 for an explanation of error bars. Non-fossil energy consumption estimates do not include feedbacks for weather induced electricity demand changes.

Source: (see Figure 10 and Figure 14)

Economic Growth and Energy Intensity

The U.S. economy—as measured by the gross domestic product (GDP)—has steadily become less energy intensive since 1949, signaling long-term structural changes[21] and improvements in energy efficiency. However, except for the oil crisis period beginning in the late 1970s, energy consumption per capita in the United States has generally increased, implying that these structural changes and productivity gains have been mostly offset by increased economic activity. (See Figure 19)

Figure 19: U.S. Energy Consumption Indicators (1949-1998)



Source: EIA (1999a) and BEA (2000)

Note: GDP in 1996 real dollars.

[21] Structural changes occur as the composition of an economy changes over time due to shifts in share attributable to its various sectors and industries. Some of these structural changes may have also resulted in a growth bias in GNP and GDP measures as previously existing activities (e.g., child care) have entered the market and become monetized.

It appears that the incremental boost in economic growth from 1997 to 1999 has been largely driven by the goods and services associated with information and computer technologies. The goods and services associated with these technologies are generally less energy intensive compared to more traditional manufacturing industries. This boost in economic growth has apparently enlarged the denominator in the energy intensity per unit GDP equation (see Equation 1) and reduced the fraction of the U.S. economy that is composed of energy intensive industries.[22] However, it is not clear that these new technologies have actually shrunk the numerator in the energy intensity equation by improving energy efficiencies throughout the economy, although the potential for such improvements using emerging information technologies and more traditional energy efficient technologies appears to be large.[23]

$$Energy\ Intensity = \frac{Total\ Energy\ Consumption}{GDP} \quad \text{Equation 1}$$

As of yet, though, the data on energy consumption does not clearly indicate that anything exceptional has occurred with regards to energy consumption (see Figure 20 and Figure 21). However, the economic and climatological data does suggest that some atypical trends are emerging with regards to overall economic growth (i.e., faster on the margin) and the weather (i.e., warmer nights and winters).

Of course whether the recent data on energy consumption and greenhouse gas emissions appears to be charting a new trend also depends on the historical baseline used. Because of the highly aggregated nature of total energy consumption and GDP, some analysts have suggested that the resulting ratio "does not really measure anything" (Shipper et al. 1999). Instead they advocate disaggregated energy and carbon intensity measures on a much more detailed sectoral and sub-sectoral basis. As GDP attempts to quantify many diverse activities, it cannot reliably be used to measure changes in macroeconomic energy efficiency.[24] Measuring efficiency is much more difficult than just measuring aggregate energy consumption and GDP.[25]

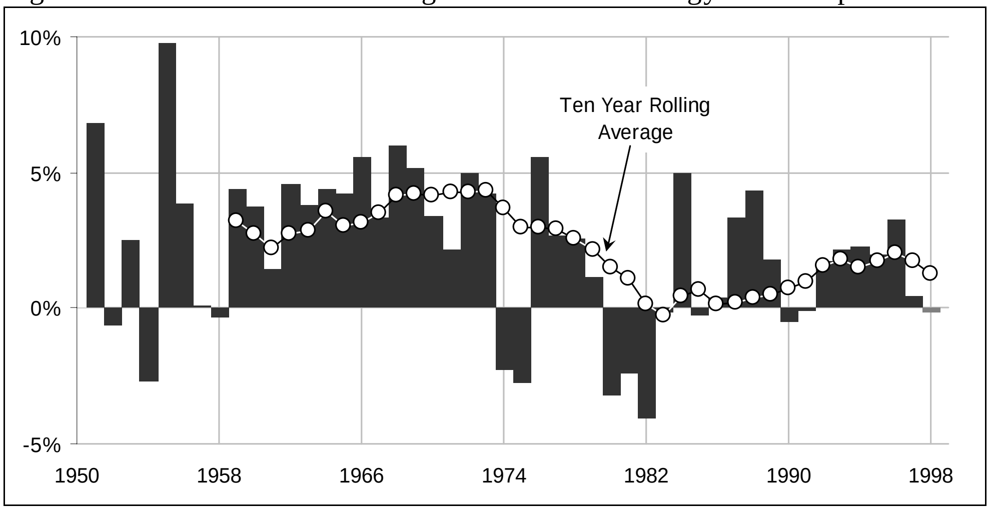
[22] Growth in the information technology industry was estimated to be responsible for about one-third of the overall economic growth in then United States in 1997 and 1998 (DOC 1999).

[23] For a detailed—but somewhat anecdotal—discussion on the internet's potential benefits and costs for greenhouse gas emissions see Romm (1999). For a briefer discussion of the general environmental benefits and costs of the internet see Cohen (1999) and Kelly (1999). The increased used of networked computers appears to be a powerful tool to improve productivity and energy efficiency; however, like any new technology diffused widely, there are also likely to be areas where energy and resource demands will increase.

[24] Not addressed here are the uncertainties in the GDP measure itself, although they are likely to be significant.

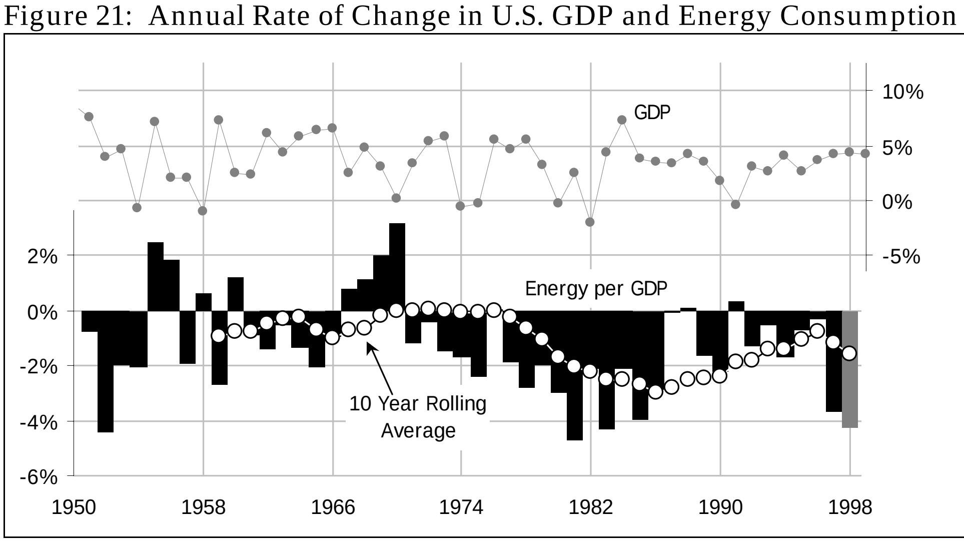
[25] Again the upcoming data on manufacturing energy consumption from the EIA should add some light on this discussion, although that data will only cover the years 1991, 1994, and 1998.

Figure 20: Annual Rate of Change in Total U.S. Energy Consumption



Note: 1998 data is highlighted.
Source: EIA (1999a)

Figure 21: Annual Rate of Change in U.S. GDP and Energy Consumption per GDP

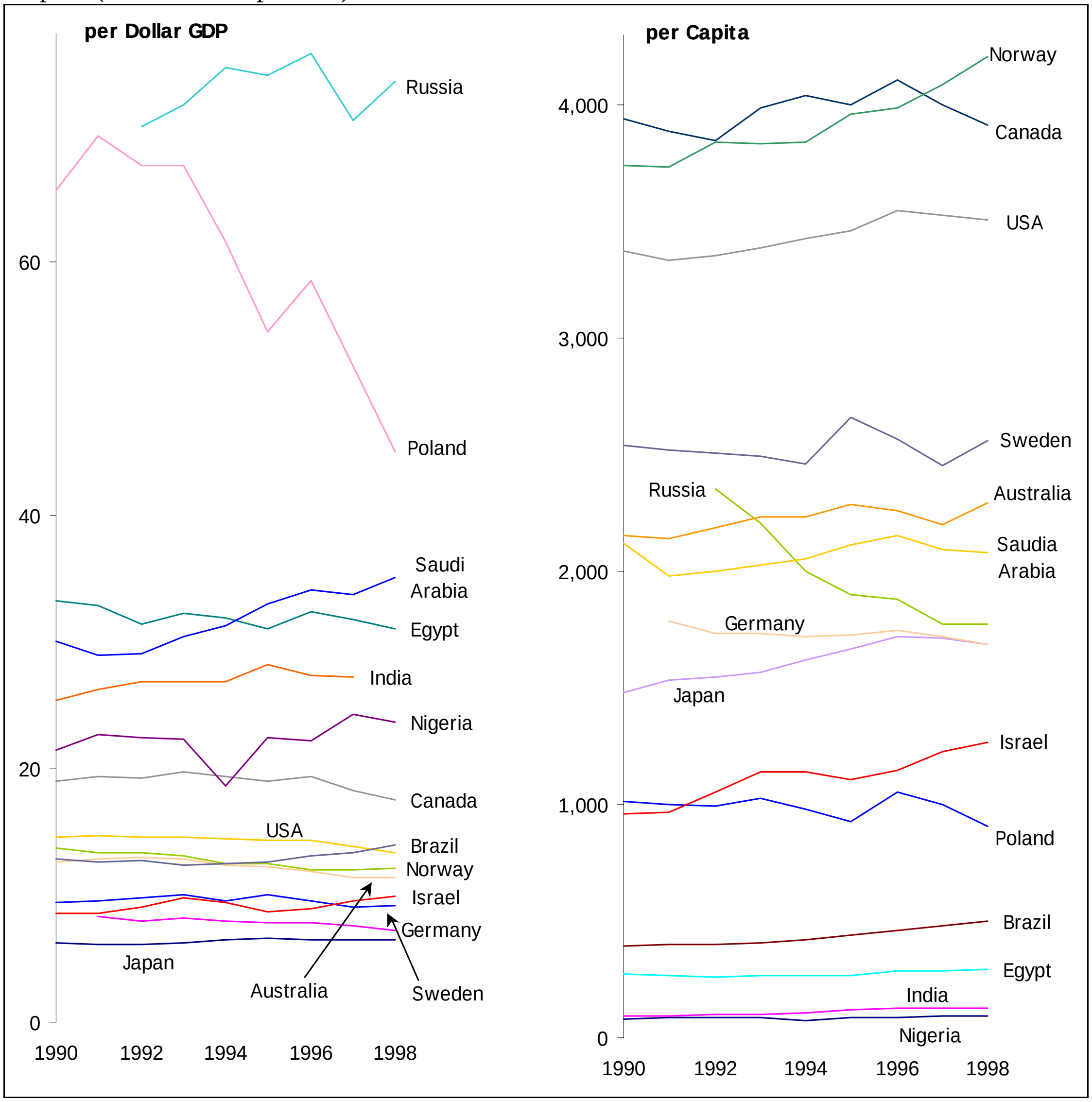


Note: 1998 data is highlighted. GDP in 1996 real dollars.
Source: EIA (1999a) and BEA (2000)

A comparison of energy intensity across countries illustrates some of the stark differences and factors that can influence such aggregate measures (see Figure 22). For example Norway exhibits a high level of energy consumption per capita both because its economy is more reliant on energy intensive industries—such as pulp and paper and primary metals production—and its relatively cold climate. Energy intensity, however, does not always translate into carbon intensity (i.e., CO_2 emissions). Again, Norway obtains much of its energy from hydroelectric sources.

In general, differences in energy intensity per unit GDP and per capita are for reasons that are a function of a collection of factors, including but not limited to: the mix of energy sources, structure of economy (e.g., extent of heavy industry), weather (e.g., Canada versus Australia), geography, and organization of physical capital and social systems. They may also differ, obviously, because of actual differences in overall energy efficiency.

Figure 22: Intensity of Energy Consumption per Dollar GDP (Thousand Btu / Dollar) and per Capita (Billion Btu / person) for Select Countries



Note: GDP in 1990 real dollars. Not adjusted for purchasing power parity.
Source: EIA (1999c)

Conclusion

Much of the slow down in the growth rate of U.S. greenhouse gas emissions recently can be explained by changes in weather patterns, the variability in energy consumption from non-fossil fuel sources, and the uncertainty induced by random errors—and possibly a growing negative bias—in national energy statistics.

The increasing diffusion of information technology is certainly producing structural changes in the U.S. economy; however, it is unclear from the available data whether it has yet resulted in significant energy efficiency gains on a national scale. Although the beginning of more fundamental changes may be on the horizon due to more drastic structural changes such as those some predict to be associated with the internet and e-commerce, the data necessary to determine if such shifts in energy consumption patterns are occurring, are not yet available.

Overall, the central point is that given the uncertainty and variability in the system for estimating U.S. greenhouse gas emissions, it is unlikely that any statistically significant trends can be discerned from only two year's worth of data. Instead of rushing to conclusions, the efforts of analysts are probably better directed at improving the quality of energy and greenhouse gas emissions data.

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