Explaining and Understanding Declines in U.S. CO_2 Emissions

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Seven key factors, combined with the impacts of a prolonged economic slowdown, have led U.S. CO_2 emissions to fall to 1996 levels, approaching even the long-abandoned Kyoto Protocol target. Is it conceivable that U.S. CO_2 emissions may actually have peaked?

U.S. carbon dioxide (CO_2) emissions have fallen nearly 12 percent over the past five years, and are currently down to 1996 levels. While some reduction is attributable to the economic downturn between 2008 and 2010, the continuing decline up to present suggests that additional and more persistent factors are at work.

A close examination of energy use in different sectors suggests that the transition from coal to natural gas for electricity generation has probably been the single largest contributor to the decline, but a combination of many other factors accounts for the majority of reductions. These include people driving less and flying less, driving more fuel-efficient cars, a large increase wind generation, and less electricity and other forms of energy used for industrial activities. Some of those factors also stem from the economic slowdown, but all combined these factors have produced a dramatic, persistent, and largely unexpected decline in U.S. CO_2 emissions.

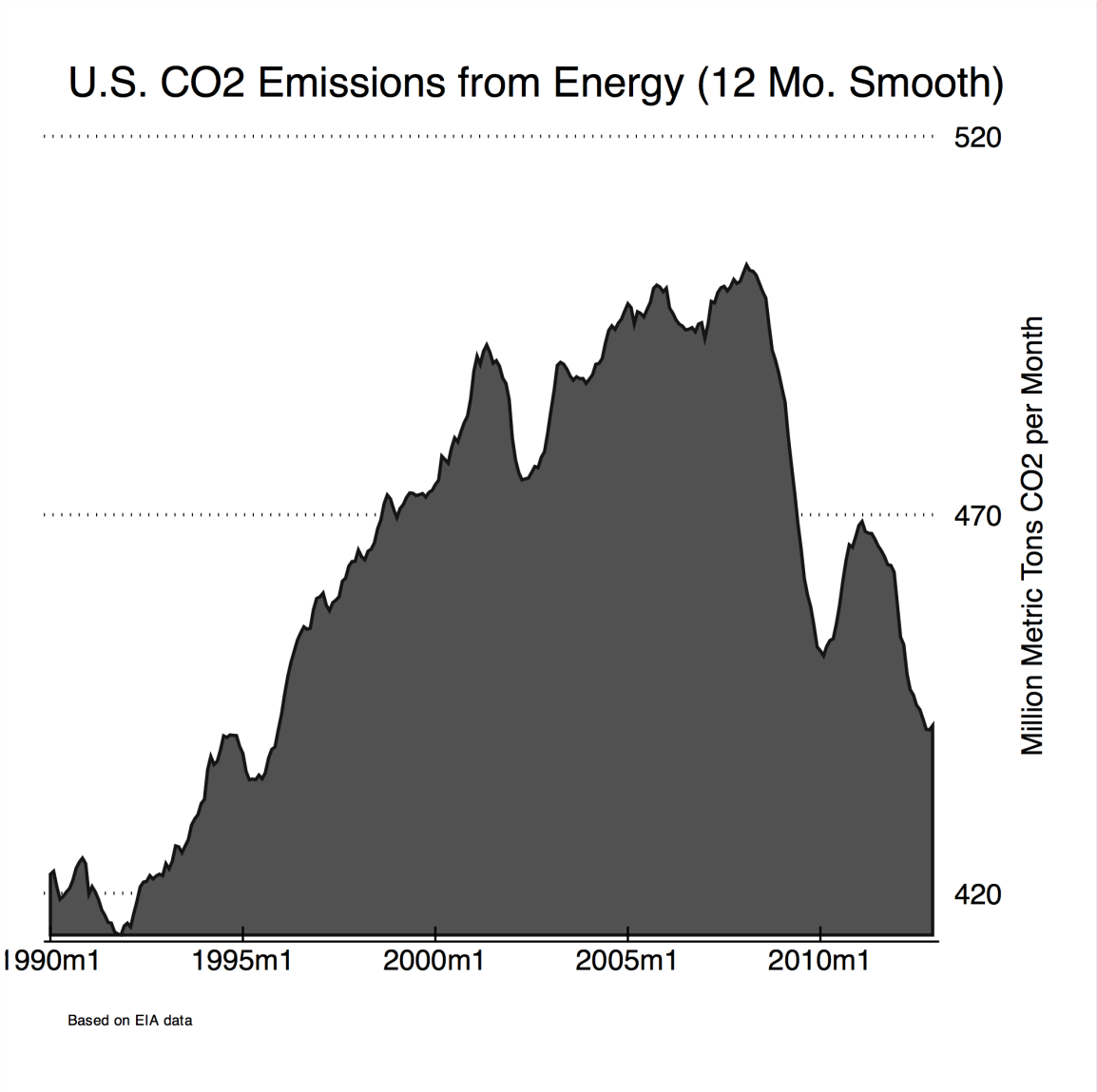

Figure 1: U.S. monthly CO_2 emissions from energy, January 1990 through December 2012 with a 12-month lagging average applied to remove seasonal cycles. Note that the y-axis begins at 415 million metric tons (MMT).

U.S. carbon emissions have declined at an impressive rate given the absence of any cohesive federal climate change policy. The U.S. has actually managed to come within striking distance of long-abandoned Kyoto Protocol targets to reduce emissions 7 percent below 1990 levels.

It is important to note, however, that this analysis concerns itself only with CO_2 from energy, and not with CO_2 emissions from land use changes or other greenhouse gases. However, as CO_2 emissions from energy comprise upwards of 90 percent of total greenhouse gas emissions, and emissions from most non-CO2 greenhouse gases have also been declining in recent years, a more thorough assessment of all sources of greenhouse gases over the past decade would likely lead to similar results. This analysis does not look at CO2 emissions embodied in trade, and some

declines (particularly in the industrial sector) may be offset by increases in other countries due to the offshoring of production.

To understand how these CO_2 emission reductions have come about, we first review just how energy is used in the U.S.

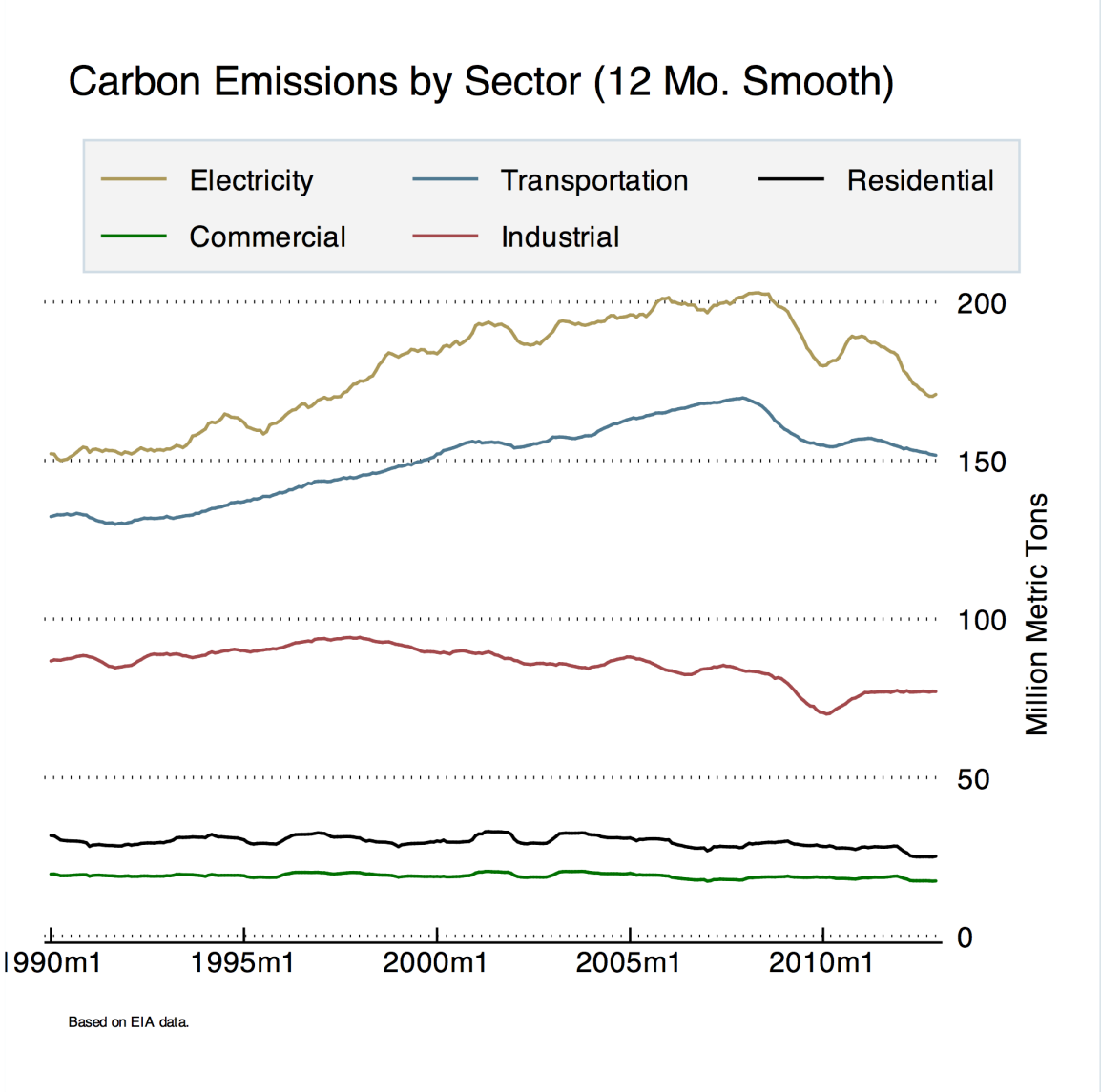

Figure 2: U.S. monthly CO_2 emissions from energy by sector, January 1990 through December 2012 with a 12-month lagging average applied to remove seasonal cycles.

There are five sectors that use energy and emit carbon dioxide. The largest of these by far are electricity generation and transportation. Electricity generation burns coal, oil, and natural gas, while transportation is primarily oil-based. Industrial is the next largest, consisting of on-site fuel consumption of industrial processes (including on-site electricity generation for internal use), while residential and commercial emissions primarily involve natural gas and fuel oil use for space and water heating.

The largest declines have occurred in the electricity sector, followed by the transportation sector and the industrial sector. To analyze what caused these declines, it's helpful to focus on each sector in depth, creating an alternative scenario in which behaviors, technologies, and fuel mixes stayed at 2005 values (either fixed per-capita, fixed percentage, or fixed absolute values depending on the scenario). With this approach, we can examine individual factors in turn to show how much CO_2 reduction is attributable to each.

Electricity Generation

Electricity is the single largest sector contributing to U.S. CO_2 emissions, and also the focus of the largest changes over the past five years. Emissions from electricity include all direct CO_2 emissions from the combustion of coal, oil, and natural gas for electricity generation, but they do not include indirect emissions from methane leakage, powerplant construction, mining, or other factors.

Natural Gas

The rapid increase in domestic natural gas production in the U.S. over the past 5 years has led to a transformation of how electricity is produced. Coal has lost its perch as the undisputed champion of power generation, falling from 50-plus percent of total electricity generation to around 35 percent. Natural gas has grown from only 15 percent of total generation in 2005 to 30 percent in 2012, even reaching the same level as coal for a month, though increasing gas prices in late 2012/early 2013 have led to somewhat increased coal use.

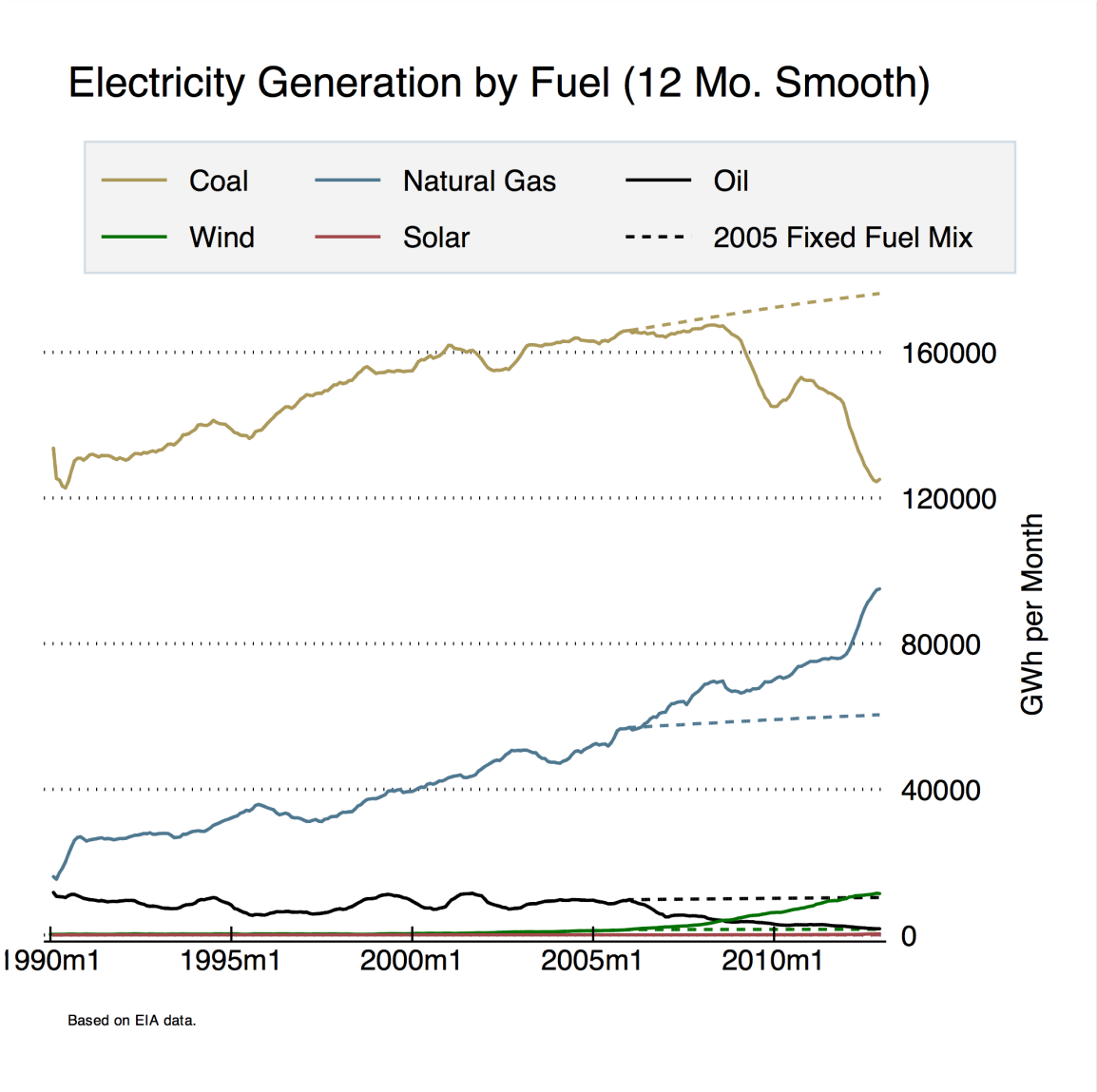

Figure 3: U.S. monthly electricity generation by fuel from January 1990 through December 2012 with a 12-month lagging average applied to remove seasonal cycles. Dashed lines represent fixed grid fuel mix and fixed per-capita electricity consumption at 2005 levels for each fuel.

While natural gas is still a carbon-emitting fossil fuel, it emits far less carbon than coal. Its molecular composition means that for a given unit of heat produced, natural gas results in slightly more than half the carbon emissions as coal. Additionally, heat from natural gas can be converted into electricity with a much higher efficiency (around 60 percent) than coal (between 30 and 40 percent). The combination of these two factors means that a kilowatt hour of electricity from natural gas has only about one-third the direct CO_2 emissions as a kilowatt hour generated from coal. Even accounting for indirect emissions from methane leakage, based on the latest

figures from the EPA,[1] electricity from natural gas still emits only about 40 percent of the carbon dioxide-equivalent emissions of coal.

Assuming that energy consumption per capita and grid fuel mixes remain fixed at 2005 levels (represented by the dashed lines in figure 3, above), we can create an alternative scenario to estimate the reductions from natural gas. We also assume that natural gas has directly offset coal-based generation, as both are effective sources of reliable base-load generation.

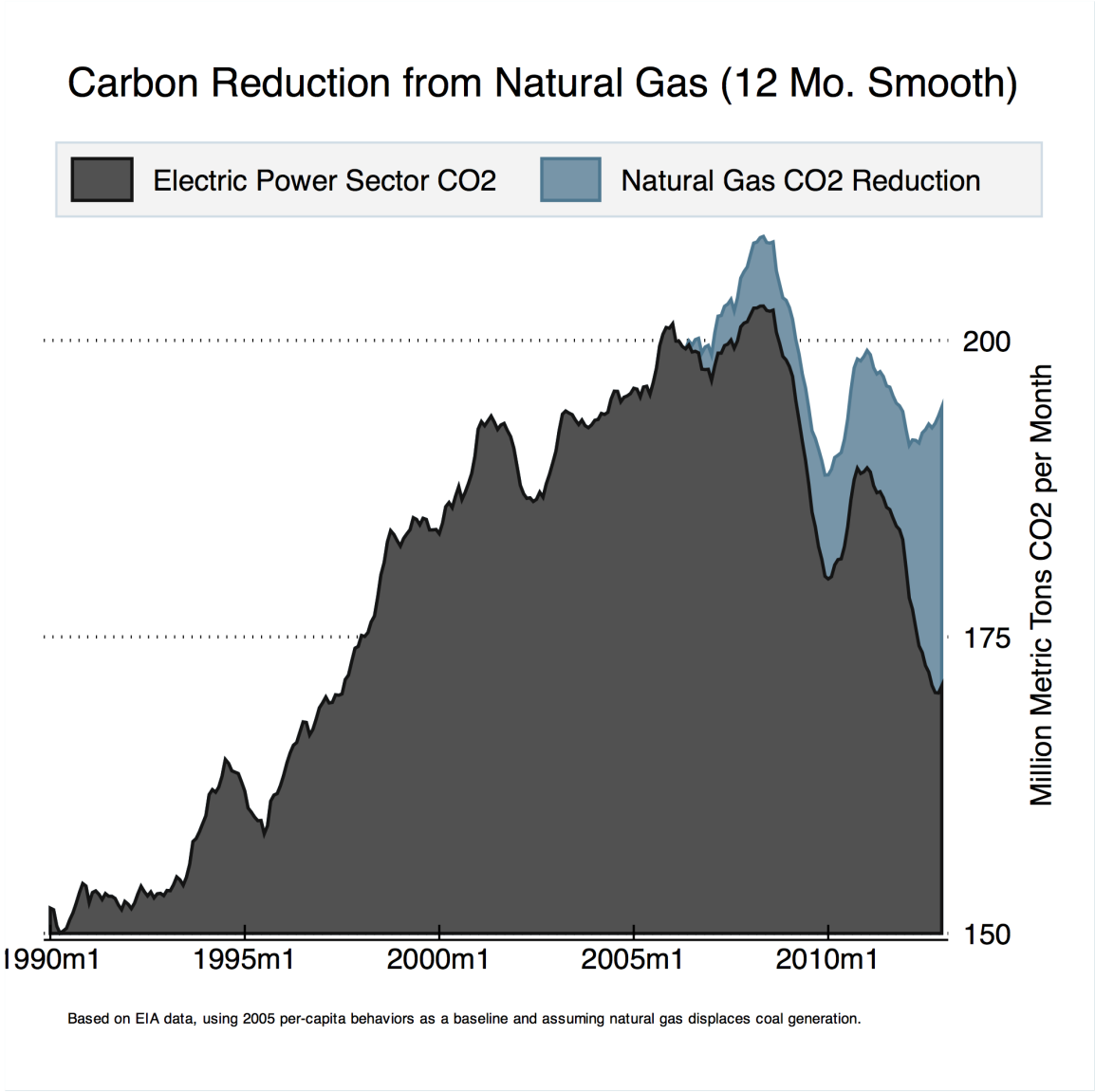

Figure 4: U.S. monthly CO2 emissions from electricity generation, January 1990 through December 2012 with a 12-month lagging average applied to remove seasonal cycles. Estimated CO_2 reductions from substituting coal for natural gas are shown in dark blue. Note that the y-axis begins at 150 MMT.

[1] EPA U.S. GHG Inventory, 2013, available: http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2013-Chapter-3-Energy.pdf

Wind

While not quite growing at quite the same speed as natural gas, wind generation has also expanded rapidly over the past five years, increasing from less than 1 percent of total U.S. generation in 2007 to 4 percent in 2012. Unlike natural gas, wind generation is effectively carbon free.

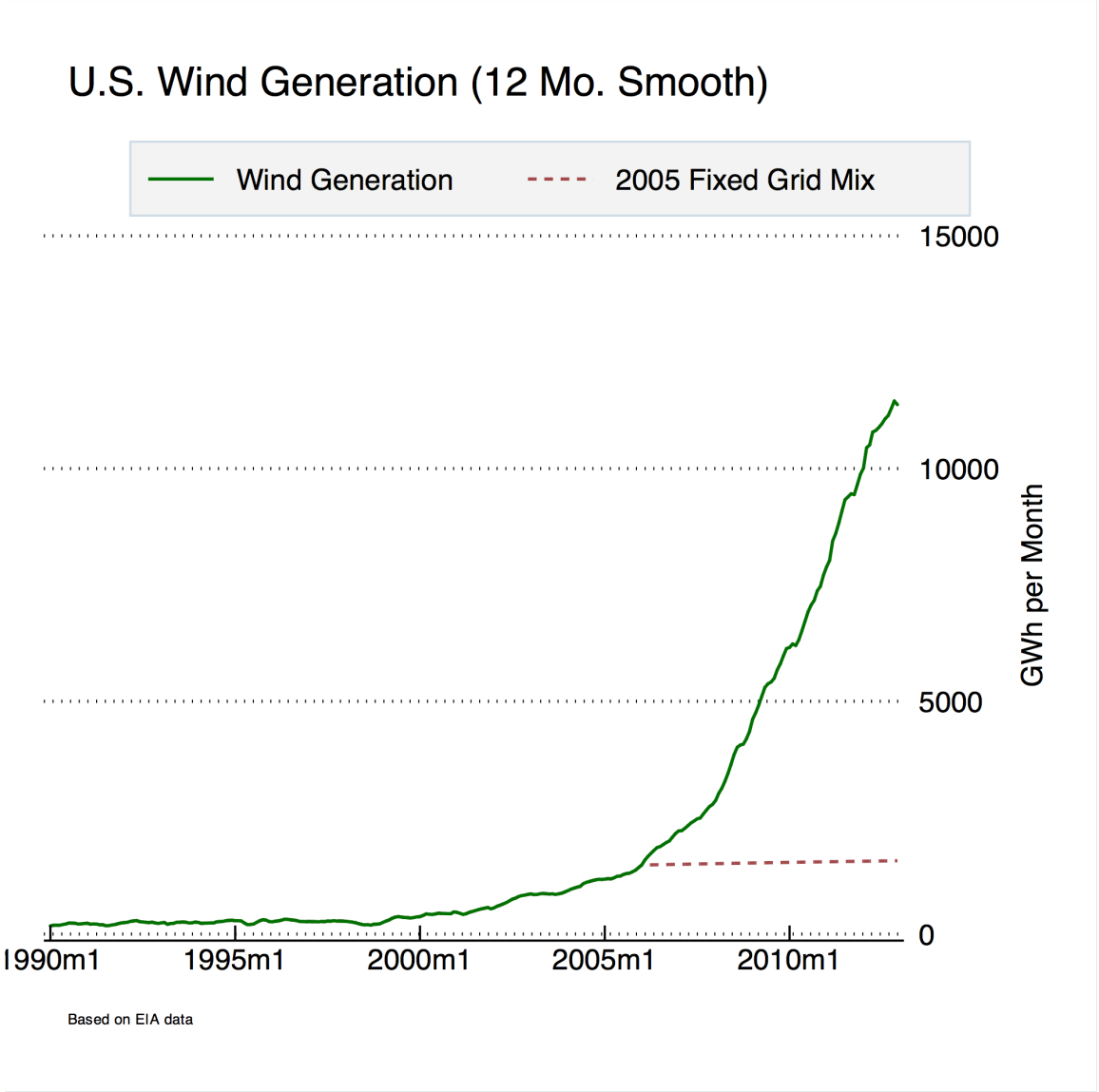

Figure 5: U.S. monthly wind electricity generation from January 1990 through December 2012 with a 12-month lagging average applied to remove seasonal cycles. Dashed red line represents a scenario where the wind grid generation percent is fixed at 2005 levels.

Wind generation is intermittent and generally cannot be used to directly displace coal base-load generation. Instead, wind often displaces more dispatchable generation sources like natural gas and oil. We assume here that increases in wind generation result in carbon reductions that reflect the average 2005 grid mix (which was a bit over 50 percent coal). By comparing a scenario in which wind power

remained at its 2005 percent of generation with what has actually occurred, we can estimate the carbon reductions attributable to the expansion of wind power.

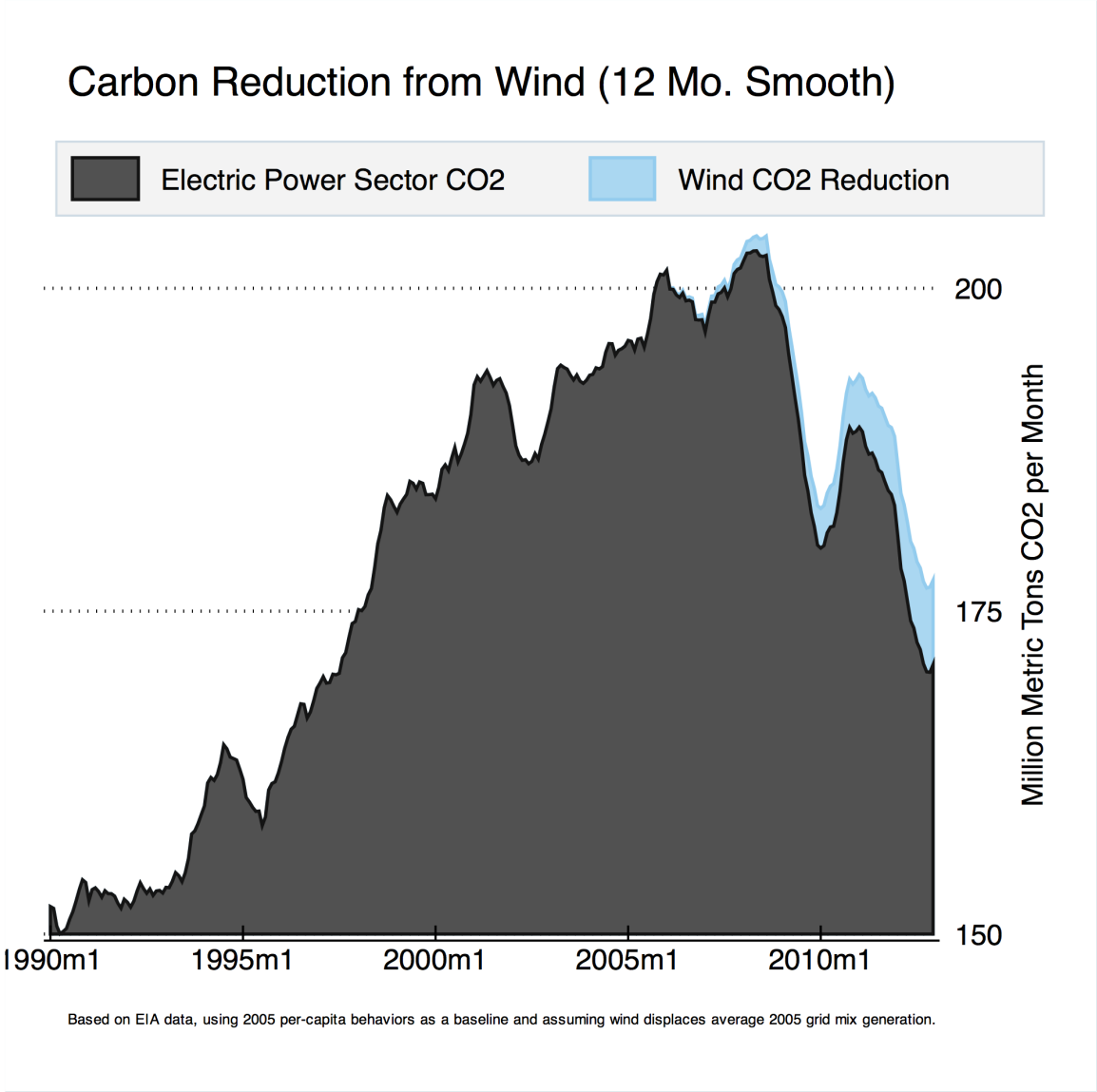

Figure 6: U.S. monthly CO_2 emissions from electricity generation, January 1990 through December 2012 with a 12-month lagging average applied to remove seasonal cycles. Estimated CO_2 reductions from expanded wind generation are shown in light blue.

Electricity Use

In addition to changing how we produce electricity, Americans are also using less electricity per person. Despite the growing U.S. population, electricity consumption has remained relatively flat over the past five years. Figure 7, below, shows actual U.S. electricity consumption compared to a scenario in which 2005 per-capita usage had remained constant.

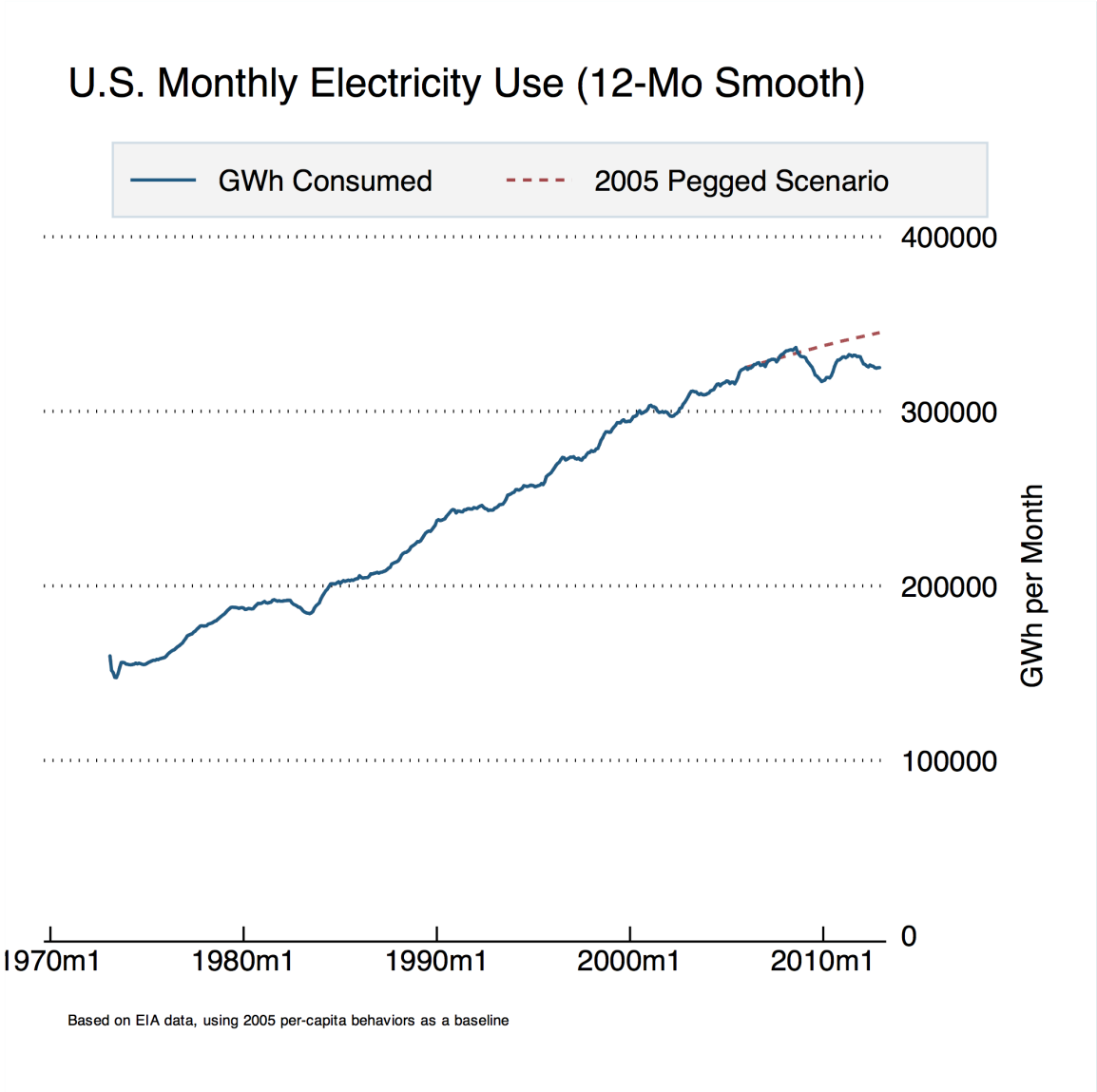

Figure 7: U.S. monthly electricity consumption from January 1973 through December 2012 with a 12-month lagging average applied to remove seasonal cycles. An alternate scenario is shown where per-capita consumption is pegged to 2005 values.

This decline is not primarily the result of people switching off light bulbs. Rather, the observed declining per-capita electricity use almost solely concentrated in the industrial sector. As the U.S. economy increasingly moves away from heavy manufacturing, electricity use per person in that sector is falling quickly. The industrial sector also had larger declines as a result of the recent recession than other sectors, though energy use has not recovered to anywhere close to pre-recession levels.

Commercial and Residential sector electricity use per capita has been flat since 2005, in contrast to a gradual increase in per-capita usage prior to 2005. Some of this decline in the residential sector may be attributable to a switch away from

electricity and toward natural gas for space heating and water heating given the increasing price of electricity and declining price of gas since 2005.

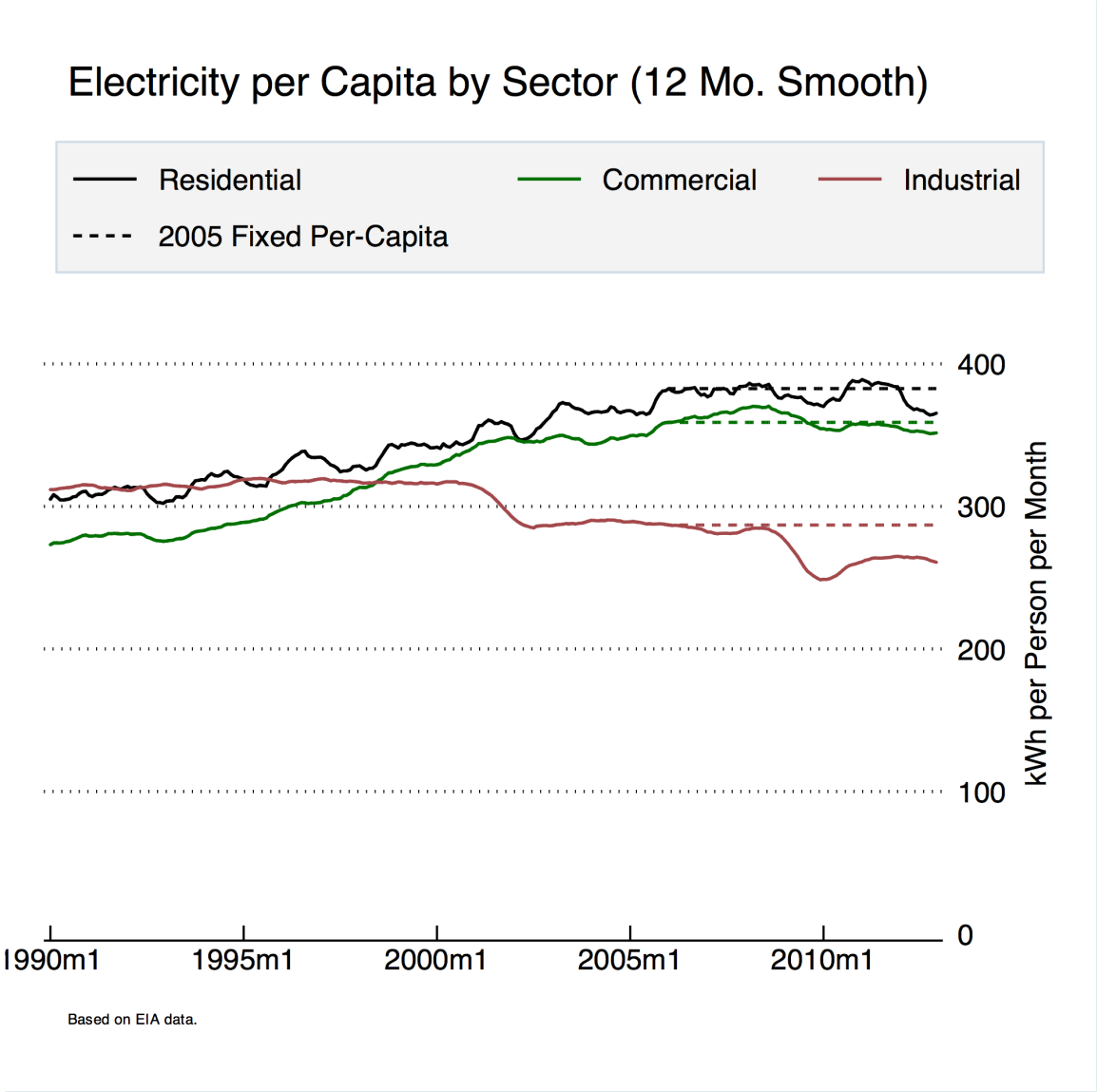

Figure 8: U.S. monthly per-capita electricity consumption by sector from January 1990 through December 2012 with a 12-month lagging average applied to remove seasonal cycles. Dashed lines represent 2005 fixed per-capita electricity consumption for each sector.

To estimate CO_2 reductions attributable to decreased energy consumption we create a scenario in which grid fuel mixes had remained fixed at 2005 values, changing only energy use per-capita. As per-capita emissions were either roughly constant or increasing prior to 2005, this provides a reasonably conservative counterfactual scenario. The results are shown in Figure 9, below, with the brown band representing estimated reductions resulting from lower per-capita electricity use.

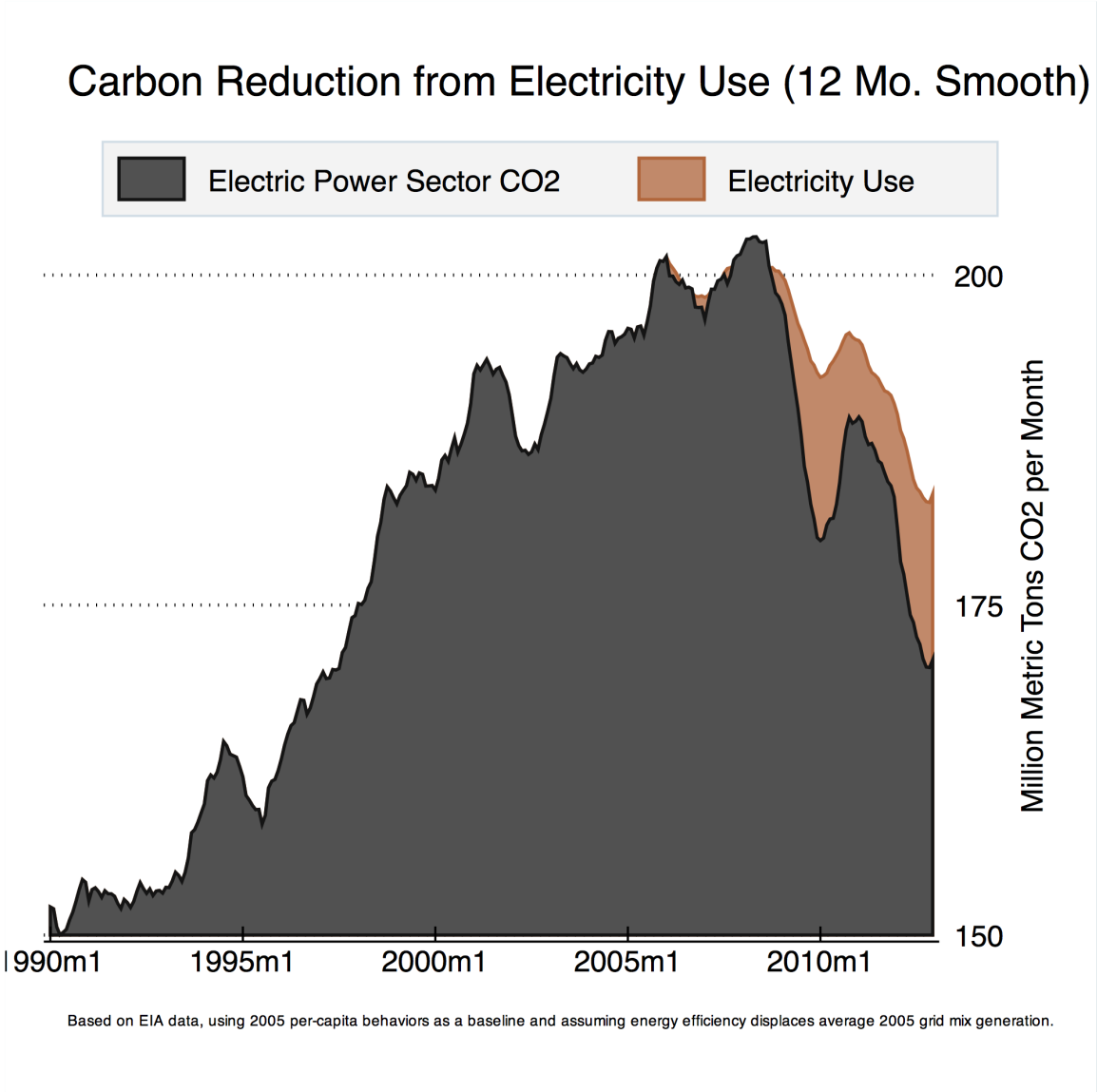

Figure 9: U.S. monthly CO_2 emissions from electricity generation, January 1990 through December 2012 with a 12-month lagging average applied to remove seasonal cycles. Estimated CO_2 reductions from reduced electricity use per-capita are shown in light brown.

It is important to note that some of the emission reductions attributable to declining industrial energy use might not represent actual emission reductions from the perspective of a global carbon budget. As industrial production moves from the United States to countries like China, the energy and emission intensity may actually increase. However, as this analysis focuses solely on U.S. emissions, we do not attempt to account for these shifts in emission location.

Overall Electricity CO_2 Reductions

Combining all three sources of estimated CO_2 reduction in the electricity sector into a single plot helps analysts compare their relative magnitudes and get a sense of what the world might have looked like in the absence of these factors.

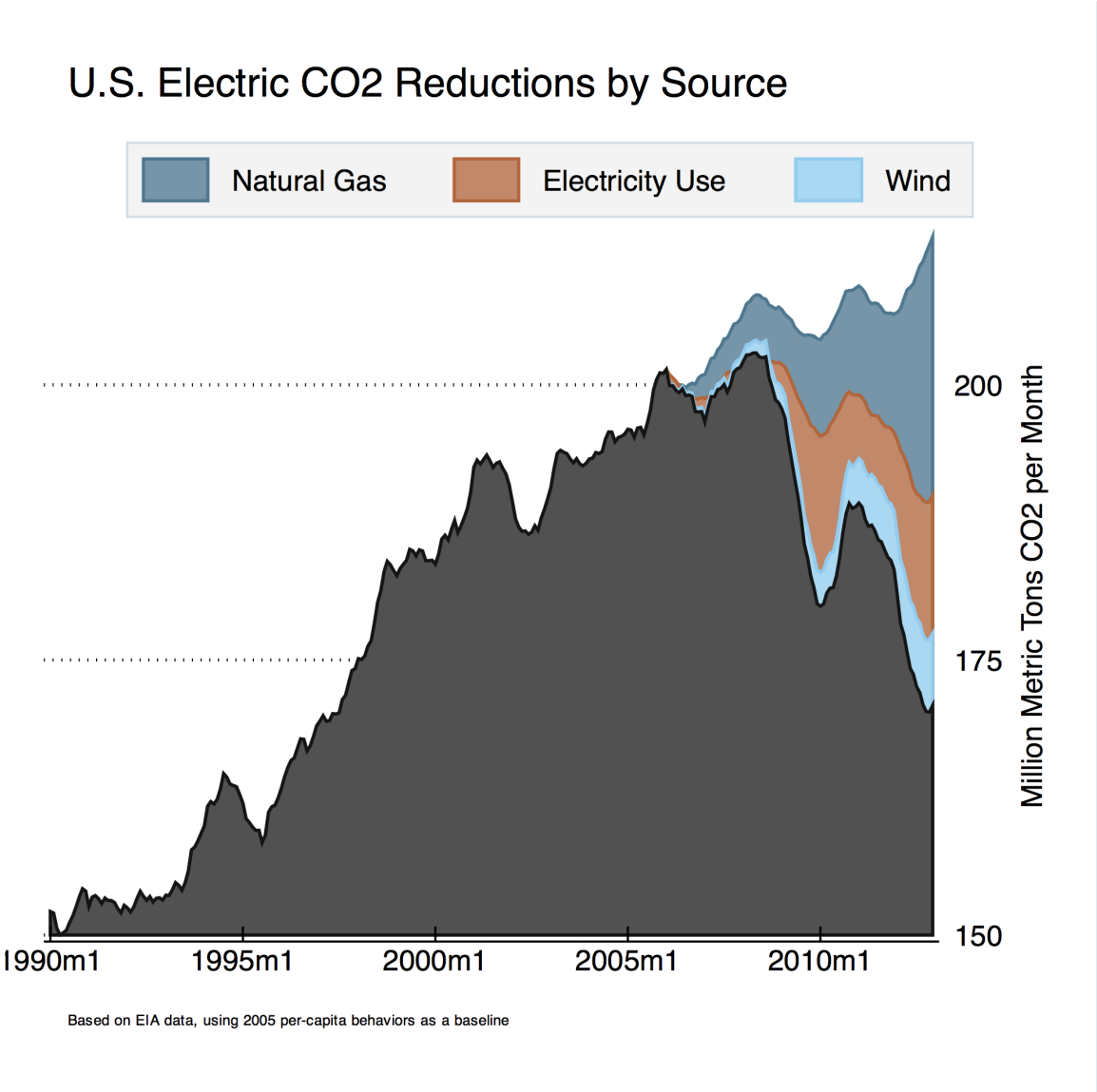

Figure 10: U.S. monthly CO_2 emissions from electricity generation, January 1990 through December 2012 with a 12-month lagging average applied to remove seasonal cycles. Estimated CO_2 reductions from three identified factors are shown.

Without the effects of natural gas, wind, and reduced electricity use, CO_2 emissions from the electricity sector would likely have continued to increase in line with past trends. In 2012, we would have had electricity sector CO_2 emissions almost 20 percent higher than today's emissions.

Transportation

Transportation is the second largest source of U.S. carbon emissions after electricity generation. It is comprised of personal vehicles, corporate fleets, freight trucks, airlines, private jets, trains, subways, busses, ships, and any other mobile emission source.

Reductions in transportation sector emissions have primarily come from three sources: people are driving less, the vehicle fleet is becoming more energy-efficient, and air travel traffic has declined while the aircraft themselves have become more fuel-efficient.

Driving Less

U.S. vehicle miles travelled per person increased dramatically over the past 40 years, from around 500 miles per month in 1973 to nearly 850 miles per month in 2007. After 2007, however, both miles driven per-person and total miles traveled began to decline. As of 2013, people are traveling about 7 percent fewer miles than they did five years ago. This is particularly noteworthy, as miles driven per capita have increased fairly monotonically since the 1980s, and the decline in miles driven per capita has persisted with no real recovery after the end of the recent economic recession.

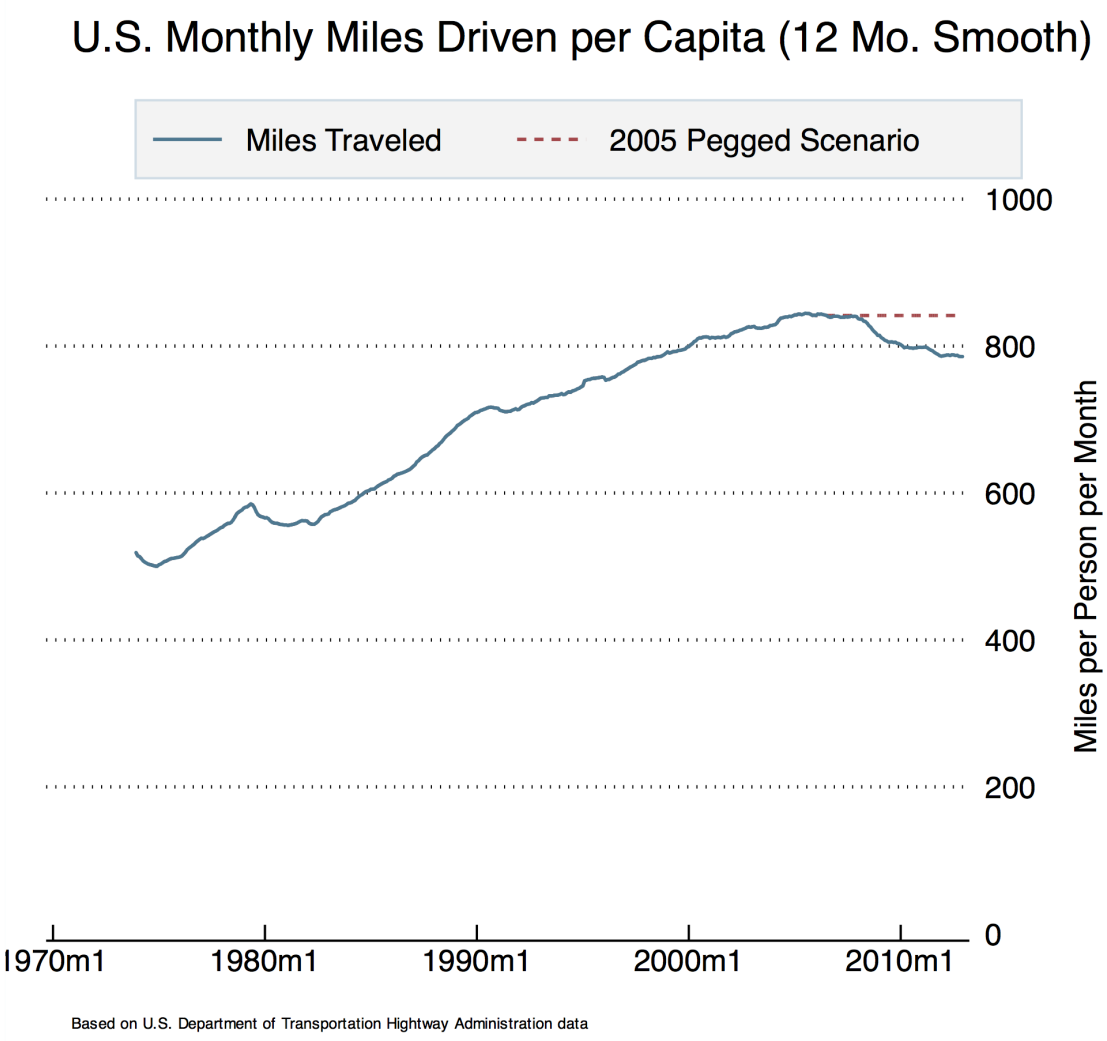

Figure 11: U.S. monthly miles driven per capita, January 1973 through December 2012 with a 12-month lagging average applied to remove seasonal cycles. Dashed line represents an alternative constant 2005 per-capita scenario.

Comparing this observed behavior to a counterfactual world in which miles driven per-capita had remained at 2005 values and vehicle fuel-economy had remained constant, we can estimate the effect reduced miles driven alone would have had, as shown in Figure 12 below. That graphic displays actual transportation sector CO_2 emissions in black and the additional CO_2 emissions that would have occurred if miles driven had not changed in teal.

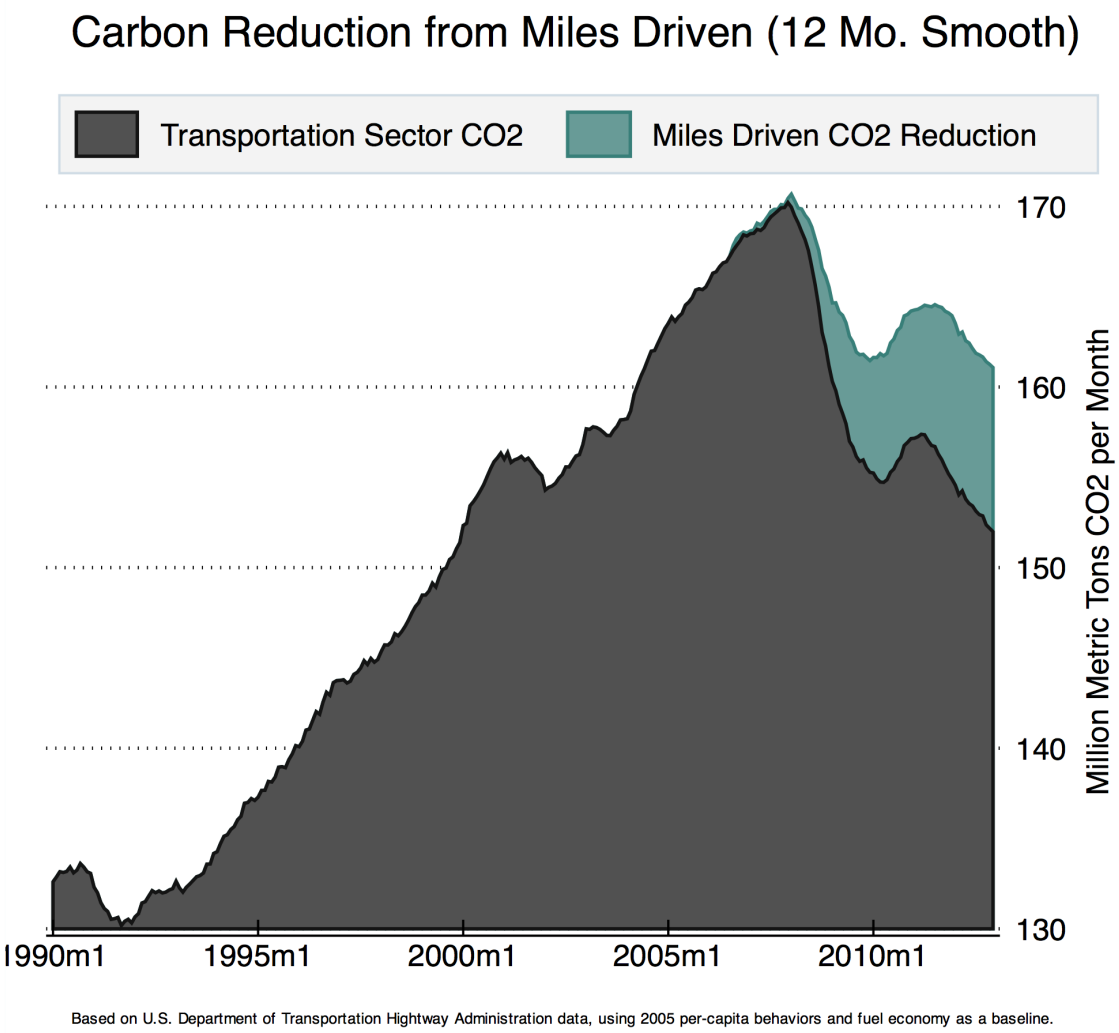

Figure 12: U.S. monthly CO_2 emissions from transportation, January 1990 through December 2012 with a 12-month lagging average applied to remove seasonal cycles. Estimated reductions due to reduced miles driven are shown in teal. Note that the y-axis begins at 130 MMT.

Fuel Efficiency

Along with reduced vehicle miles travelled, the cars and trucks also have become more efficient. Contrary to some claims, however, the increases in fuel economy in recent years across the entire U.S. vehicle fleet actually have been relatively modest. Fuel economy in this case is calculated by dividing the total monthly vehicle fuel consumption (both gasoline and diesel) by the total miles driven by all vehicles.

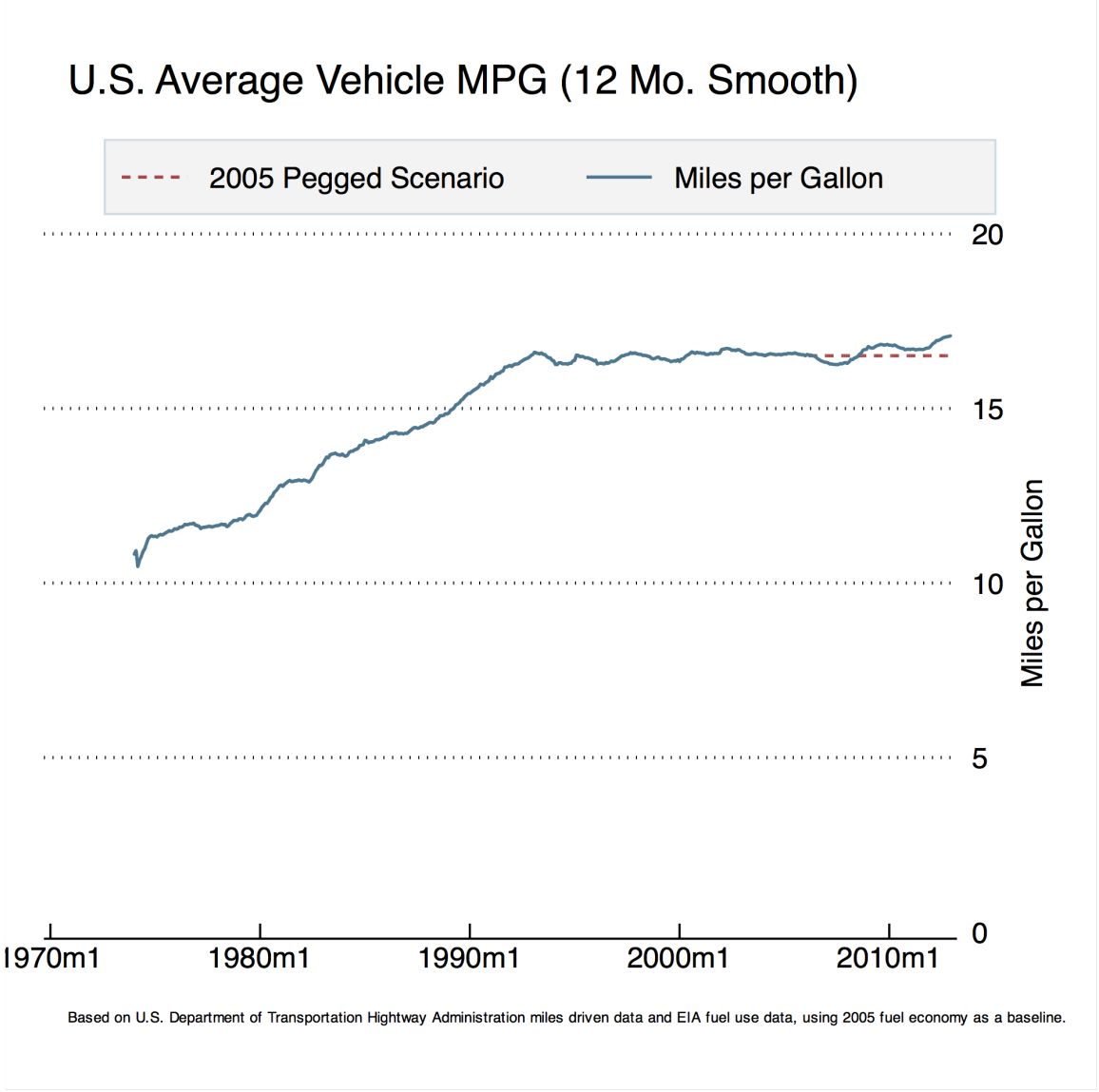

Figure 13: U.S. average vehicle fuel economy by month from January 1973 through December 2012. Based on transportation sector gasoline and diesel fuel consumption data from the EIA and miles traveled data from the U.S. Department of Transportation.

To estimate effects of fuel economy changes, consider a counterfactual scenario in which miles driven and fuel economy both remain fixed at 2005 levels. This approach leads to the results shown in Figure 14 below.

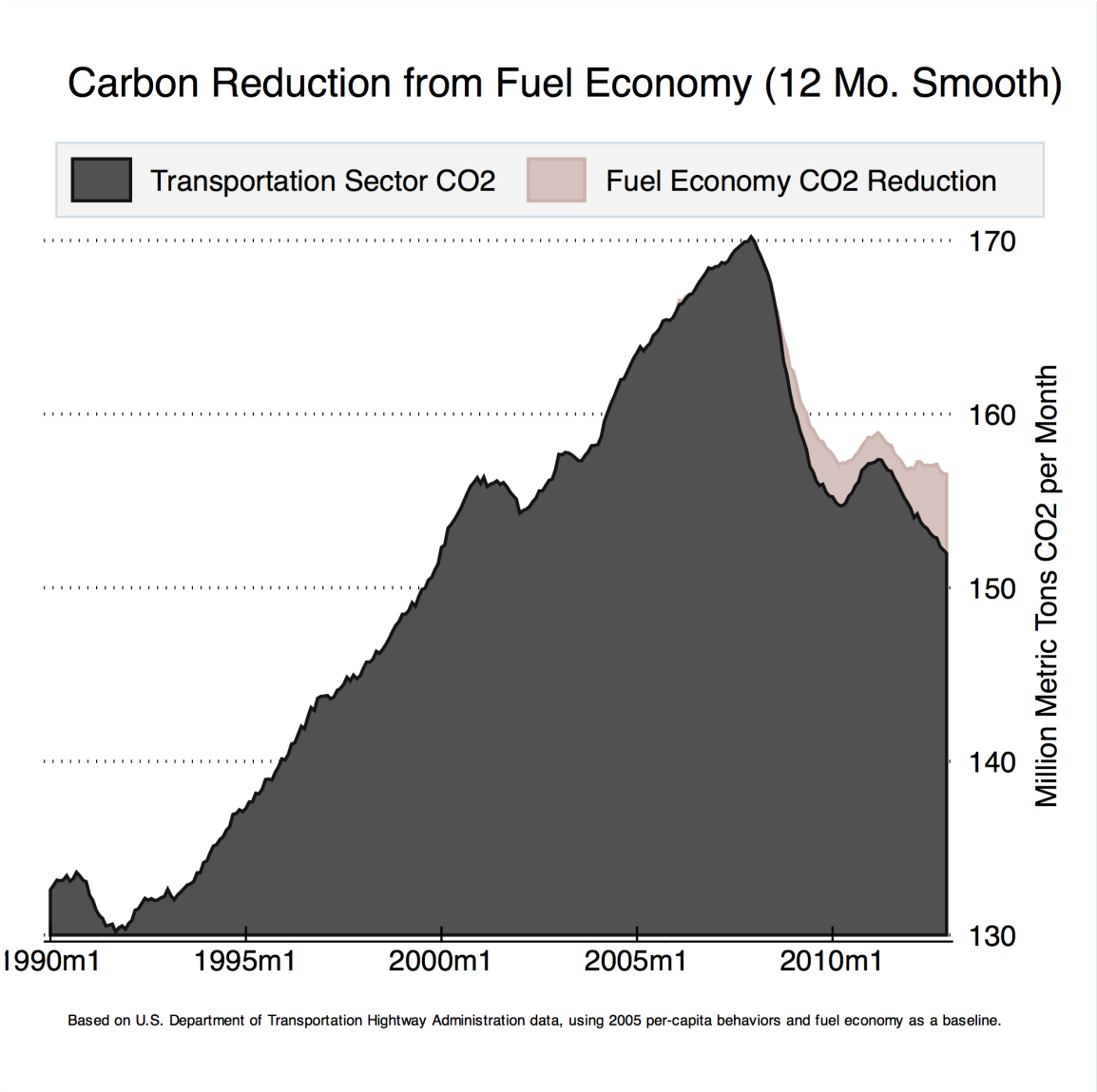

Figure 14: U.S. monthly CO_2 emissions from transportation, January 1990 through December 2012 with a 12-month lagging average applied to remove seasonal cycles. Estimated reductions due to increased fuel economy are shown in pale red.

While significant, transportation sector CO_2 reductions from increased vehicle fuel efficiency are fairly small compared to reductions resulting from people driving Recently strengthened fuel economy standards, as they are phased in over coming years, unquestionably will have a larger effect on the vehicle market.

Flying Less (and More Efficiently)

In addition to driving fewer miles per-person, Americans have been flying less over the past decade, and high fuel prices have led airlines to focus more on fuel efficiency. Consider combining both factors into a simple measure of airline fuel use per person per month. Significant declines are evident both after the September 11th terrorist attacks and after the 2008/2009 recession. Interestingly, fuel use per person never recovered from these drops, and has fallen even faster in recent years.

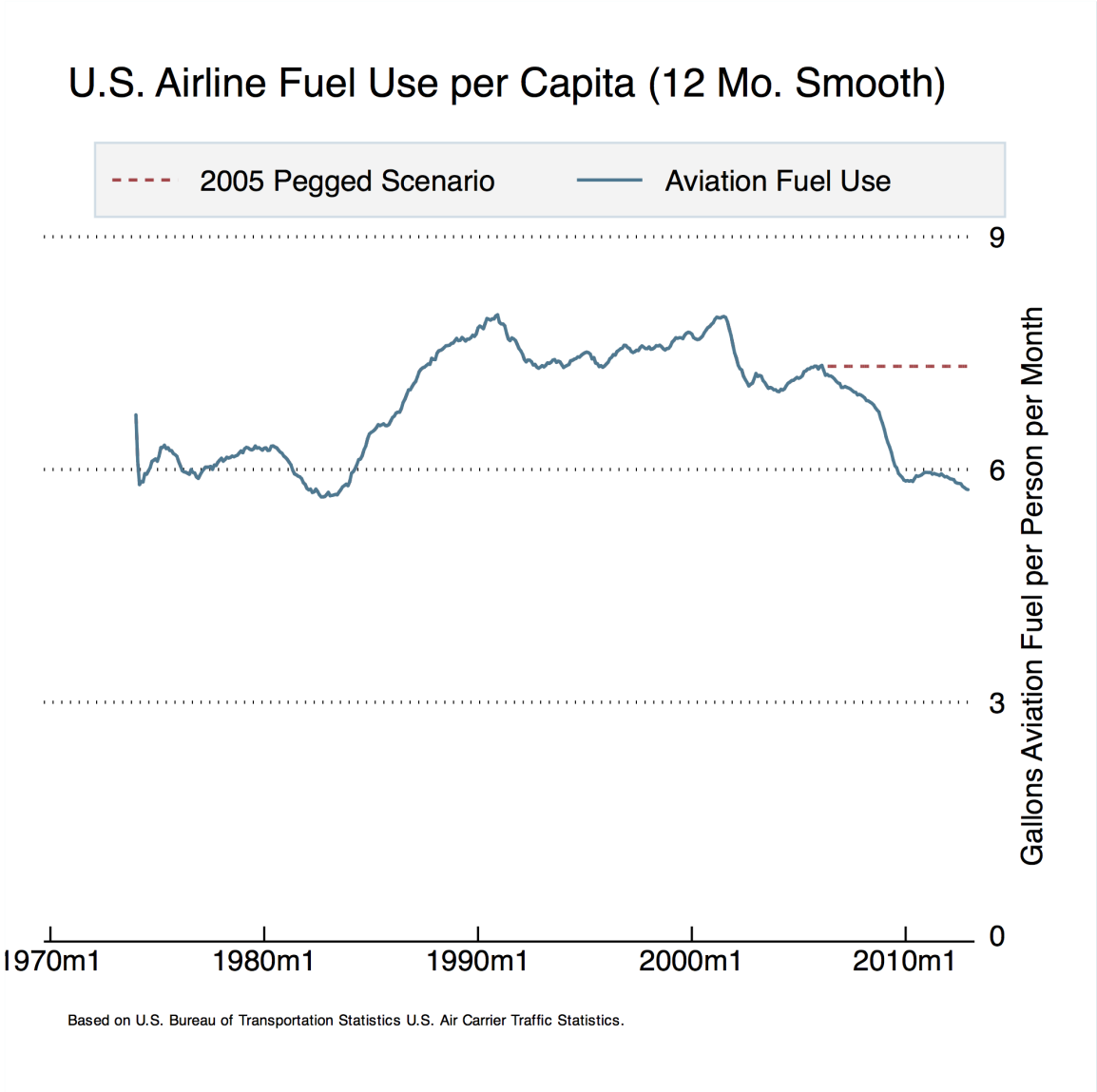

Figure 15: U.S. per-capita aviation fuel consumption, December 1973 through December 2012. Based on jet fuel and aviation gasoline consumption data from the EIA and miles traveled data from the U.S. Bureau of Transportation Statistics.

To tease out the combined effects of people flying less and airlines increasing fuel efficiency, it's useful to consider an alternative scenario where aviation fuel use per person remains pegged at 2005 levels. By comparing this approach to actual fuel use, we can estimate the transportation sector carbon emission reductions, as shown Figure 16 below.

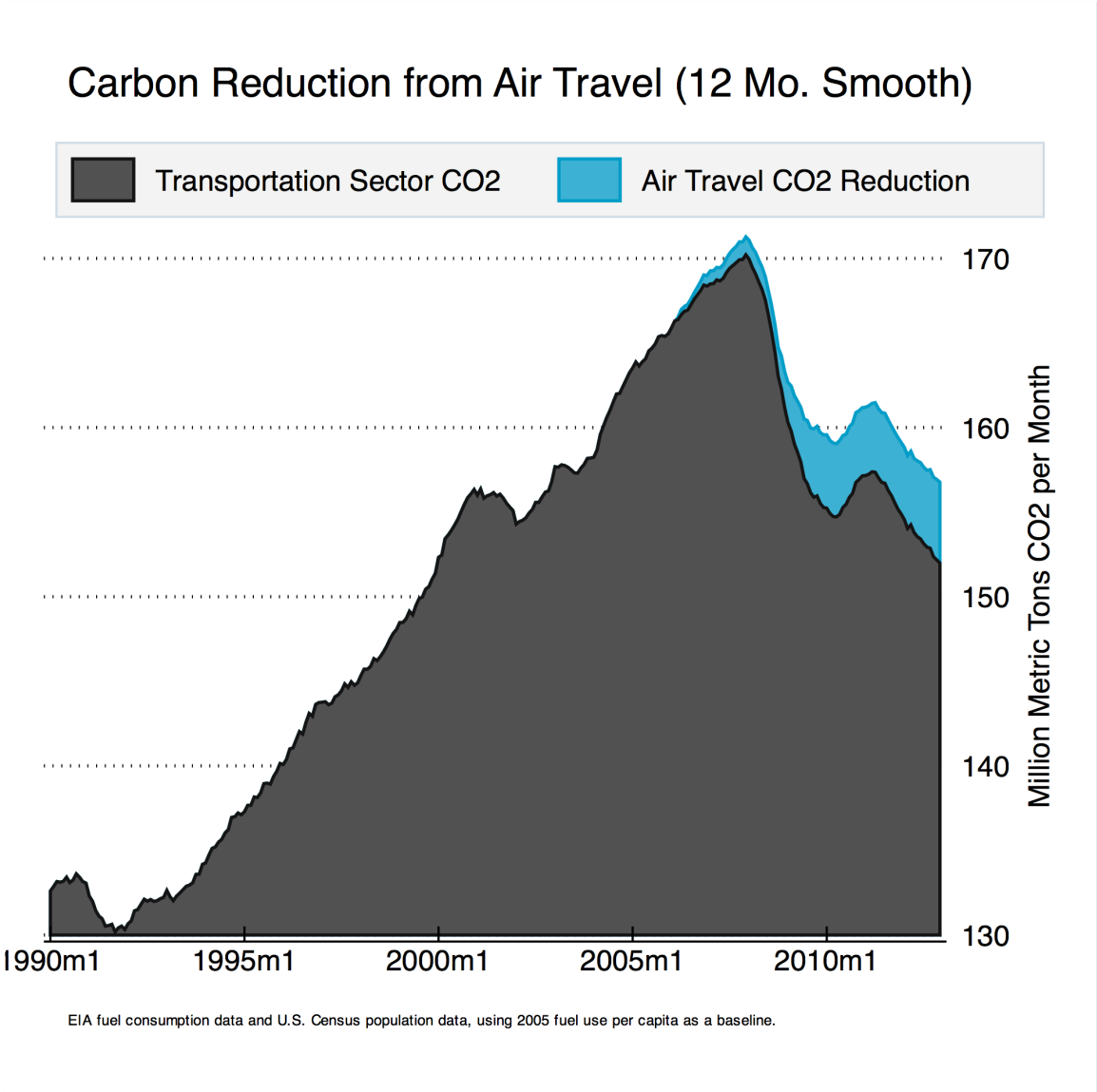

Figure 16: U.S. monthly CO_2 emissions from transportation, January 1990 through December 2012 with a 12-month lagging average applied to remove seasonal cycles. Estimated reductions due to reduced miles flown and increased airplane fuel efficiency are shown in sky blue.

Overall Transportation CO_2 Reductions

Combining estimated reductions from reduced miles drive, increased vehicle fuel economy, and air travel-based reductions offers a good picture of their relative importance and what the transportation sector might have looked like in the absence of these factors.

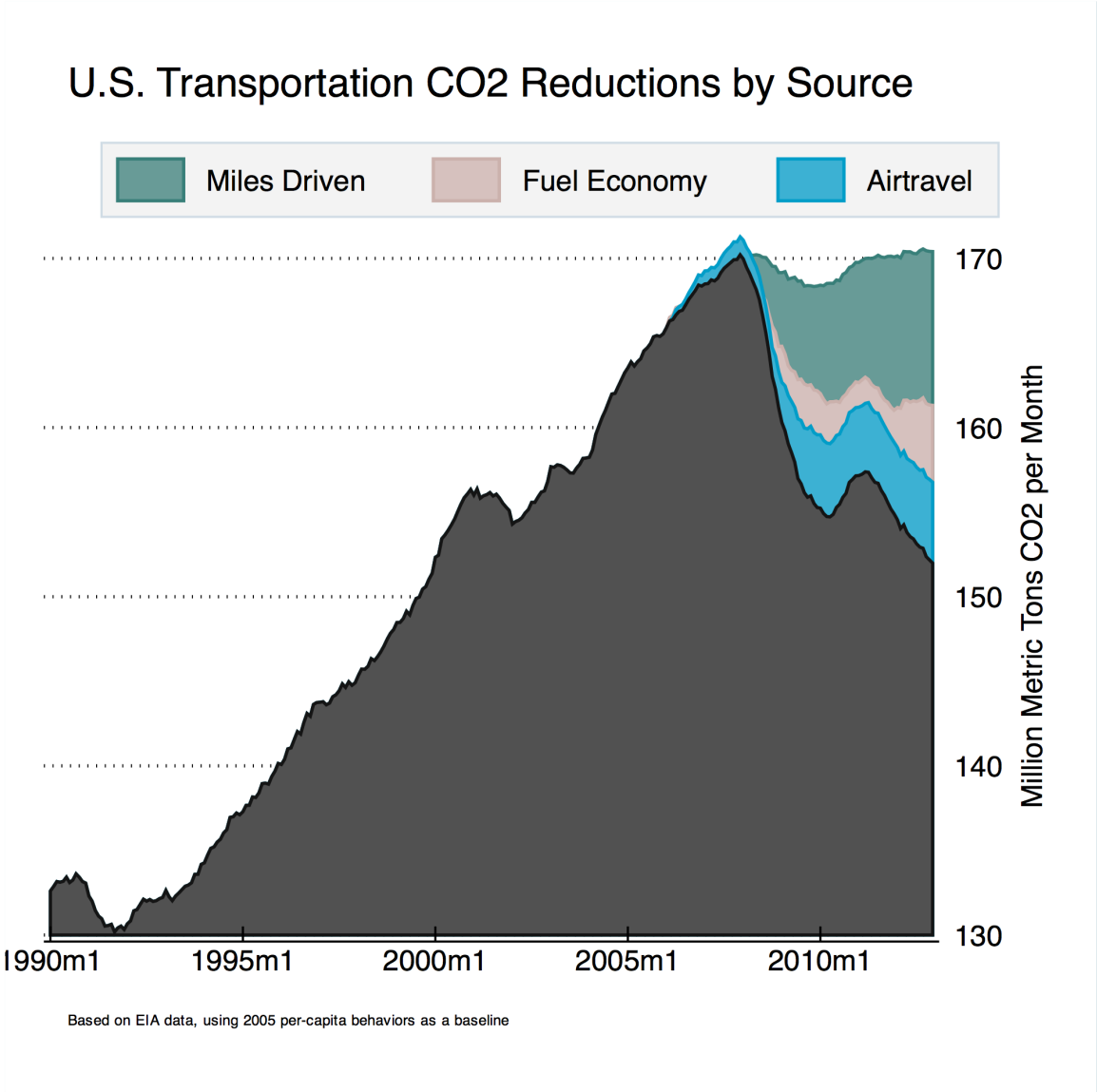

Figure 17: U.S. monthly CO2 emissions from transportation, January 1990 through December 2012 with a 12-month lagging average applied to remove seasonal cycles. Estimated CO2 reductions from three identified factors are shown.

These three factors have been responsible for a decline in transportation CO_2 emissions of around 10 percent relative to a scenario in which none of the three had occurred. Miles driven was responsible for the bulk of reductions, followed by changes in air travel. In recent years, however, the effects of fuel economy have increased to rival those of air travel, and will likely eclipse them in the next few years.

This is not a complete analysis of the entire transportation sector, however as it does not cover sources including public transportation and shipping. Future work could add in estimates of changes in emissions from these sources and disentangle

the effects of airline miles traveled and fuel efficiency so each factor can be quantified separately.

Industrial, Commercial, and Residential Non-Electric Emissions

In addition to electricity and transportation-related emissions, industrial, commercial, and residential sectors also contribute significantly to total U.S. energy-related CO2 emissions. Residential and commercial sector non-electricity emissions are largely driven by the combustion of natural gas, fuel oil, and propane for space and water heating. Industrial emissions include these, as well as electricity generated on-site (which is not considered part of the electricity emissions examined previously) and combustion of fossil fuels for other industrial purposes.

Industrial

Industrial CO2 emissions are by far the largest of the three sectors, amounting to between 70 and 95 million metric tons CO2 per month. They have been gradually decreasing since a peak in the late 1990s, likely due to a combination of the offshoring of energy-intensive industrial processes and a general move away from manufacturing goods in the U.S. It is important to note that while this trend has decreased direct U.S. emissions, it has likely not resulting in a decline in overall carbon emissions, as many countries with rapidly expanding industrial manufacturing have both a relatively carbon-intensive grid mix and lower standards for energy efficient processes.

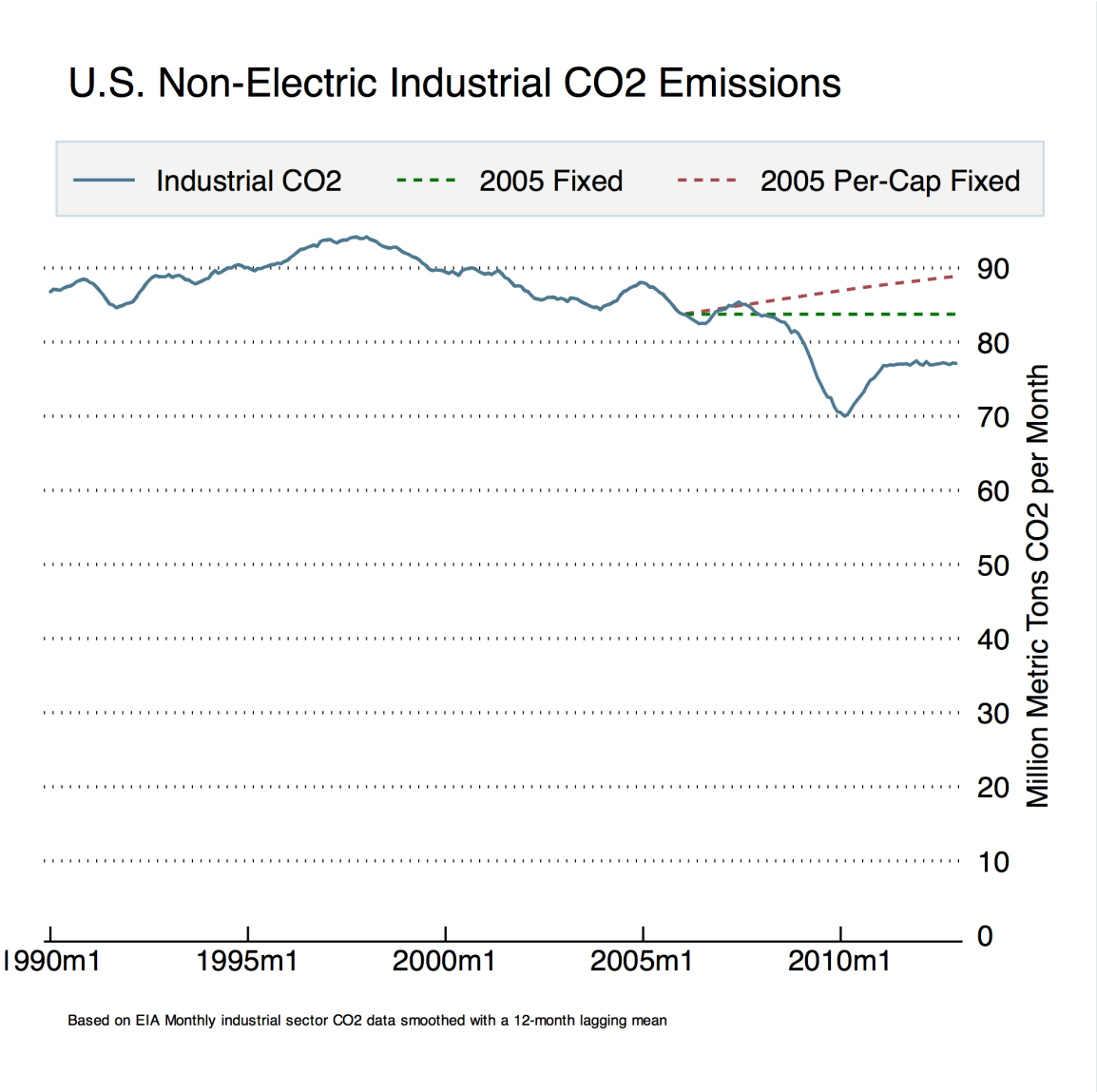

Figure 18: U.S. monthly industrial CO2 emissions with a 12-month lagging average applied, excluding emissions from purchased electricity generated off-site. Dashed lines represent 2005-fixed and 2005-fixed per-capita counterfactual scenarios.

There are two relatively straightforward ways to create a counterfactual scenario to try and detect the effect of recent declines in activity on carbon emissions. The first is to hold per-capita emissions constant at 2005 levels, as we have done previously for industrial sector electricity use. However, unlike industrial electricity use, industrial non-electric energy use has not remained relatively constant on a per capita basis over the past 15 years. Rather, they have been decreasing rather quickly, and an approach that holds per-capita emissions constant leads to a rather improbable increase in industrial activity in recent years.

The second approach is to hold total industrial non-electric emissions fixed at 2005 levels. This scenario maintains declining per-capita emissions, though the rate of the

decline is slightly slower than in prior years. This approach more effectively captures the rapid drop in emissions after 2005 without exaggerating them.

Overall industrial non-electric emissions dipped significantly during the post-2007 economic recession. While they have recovered slightly from their recession lows, they remain significantly below 2005 levels.

Commercial

Commercial sector non-electric emissions have remained relatively constant over the past two decades, with only slight declines post-2005. As commercial per-capita emissions were already declining prior to 2005, a counterfactual scenario where 2005 emissions are fixed provides a more realistic alternative to a per-capita energy use baseline.

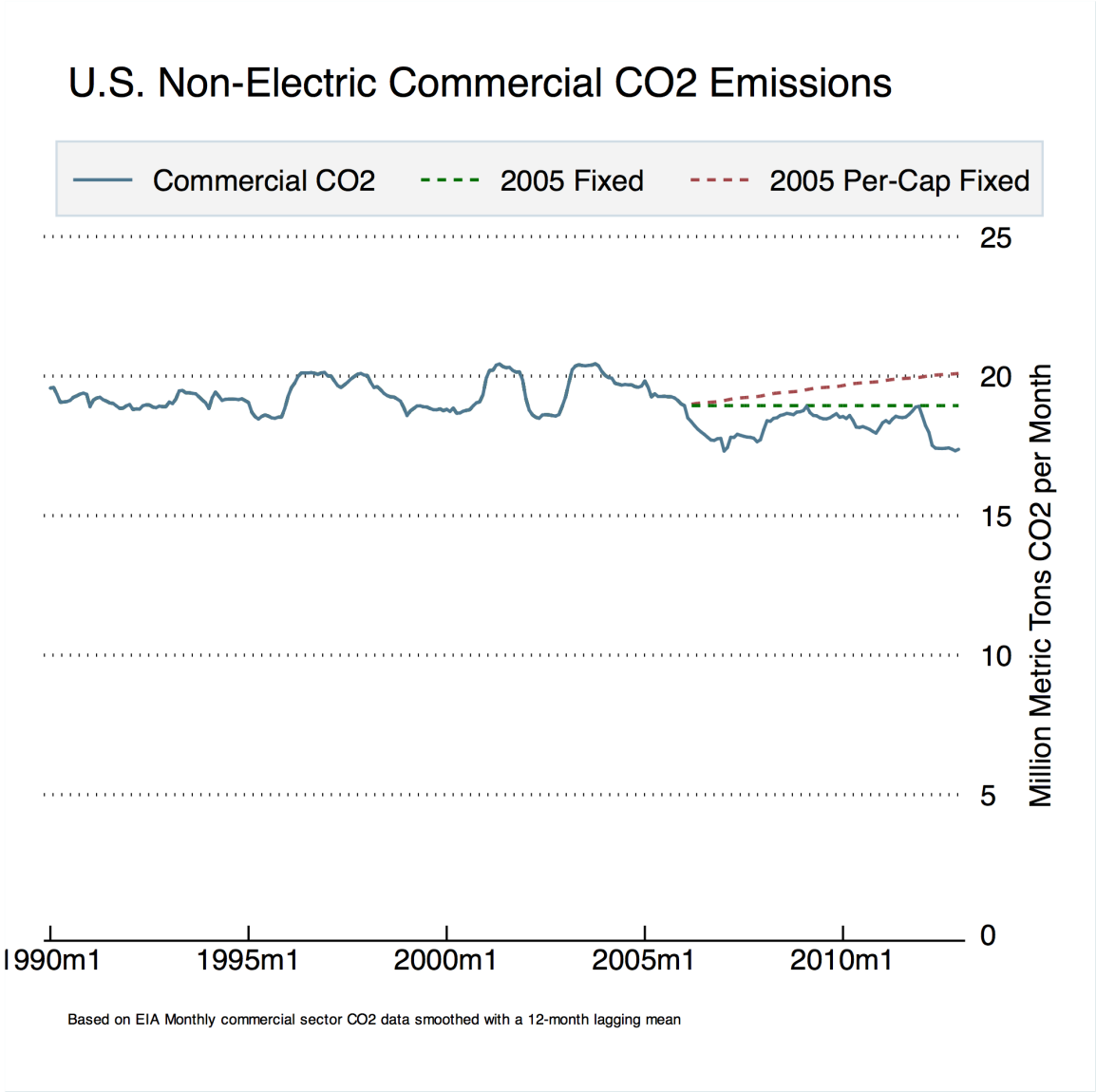

Figure 19: U.S. monthly commercial CO2 emissions with a 12-month lagging average applied, excluding emissions from purchased electricity generated off-site. Dashed lines represent 2005-fixed and 2005-fixed per-capita counterfactual scenarios.

Residential

While smaller in magnitude than industrial sector reductions, residential non-electric emissions have fallen in recent years. This is largely due to a shift away from the use of fuel oil as a space heating and water heating fuel in the Northeast United States, as shown in Figure 20 below. Over the last decade natural gas use has held relatively steady, while fuel oil use has fallen by about 40 percent.

It is likely that a some increase in energy efficiency helped prevent natural gas emissions from rising to accompany fuel oil's decline, though natural gas is also substantially less carbon-intensive than fuel oil when used as a space heating and water heating fuel due both to its molecular composition and higher thermal conversion efficiency.

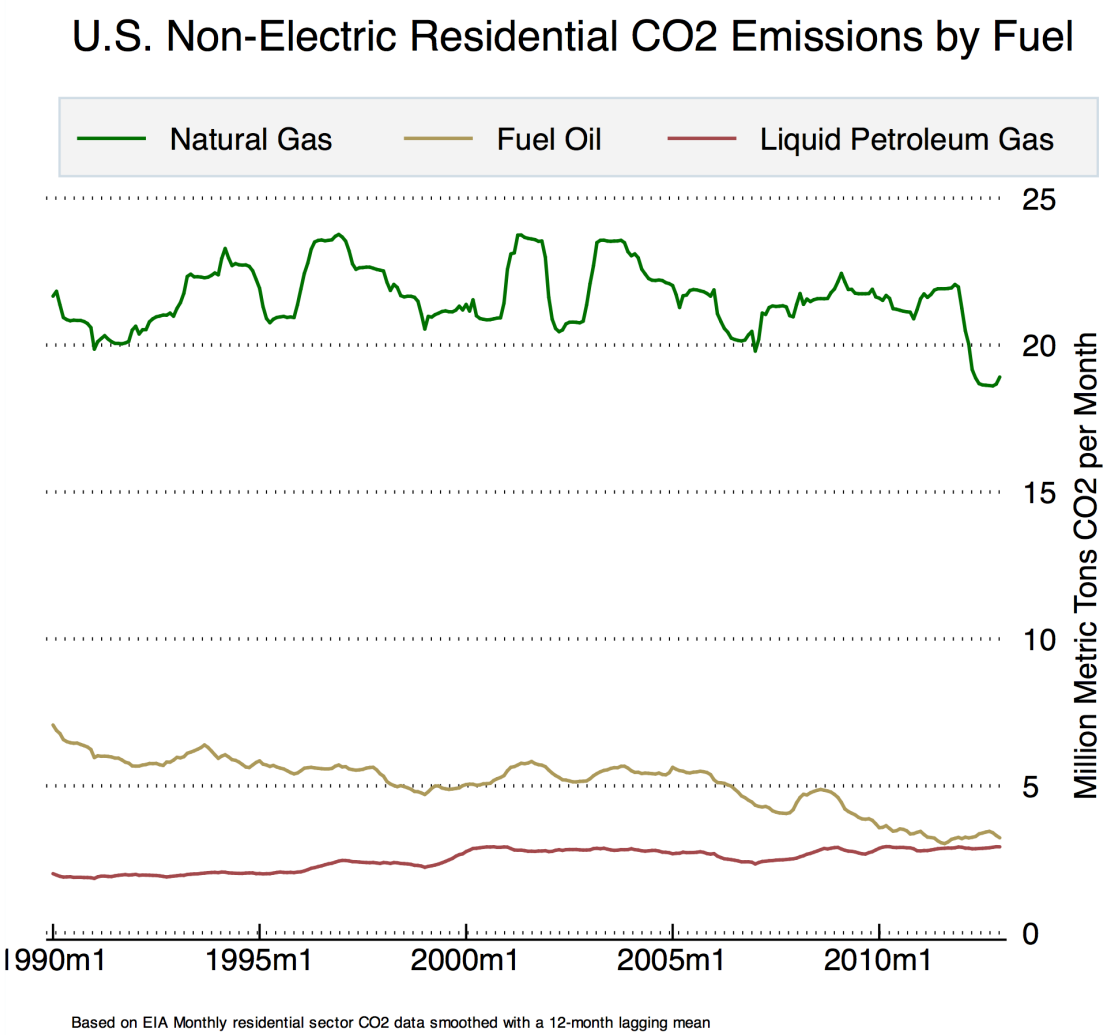

Figure 20: U.S. residential monthly CO2 emissions by fuel with a 12-month lagging average applied.

We can examine two different counterfactual scenarios for residential non-electric CO2 emissions: one where emissions remained constant at 2005 levels, and one where emissions remained constant at 2005 per-capita levels. Similar to commercial and industrial non-electric emissions, we find that per-capita emissions were decreasing prior to the post-2005 period, and that using fixed 2005 emissions produces a more realistic scenario in-line with existing trends.

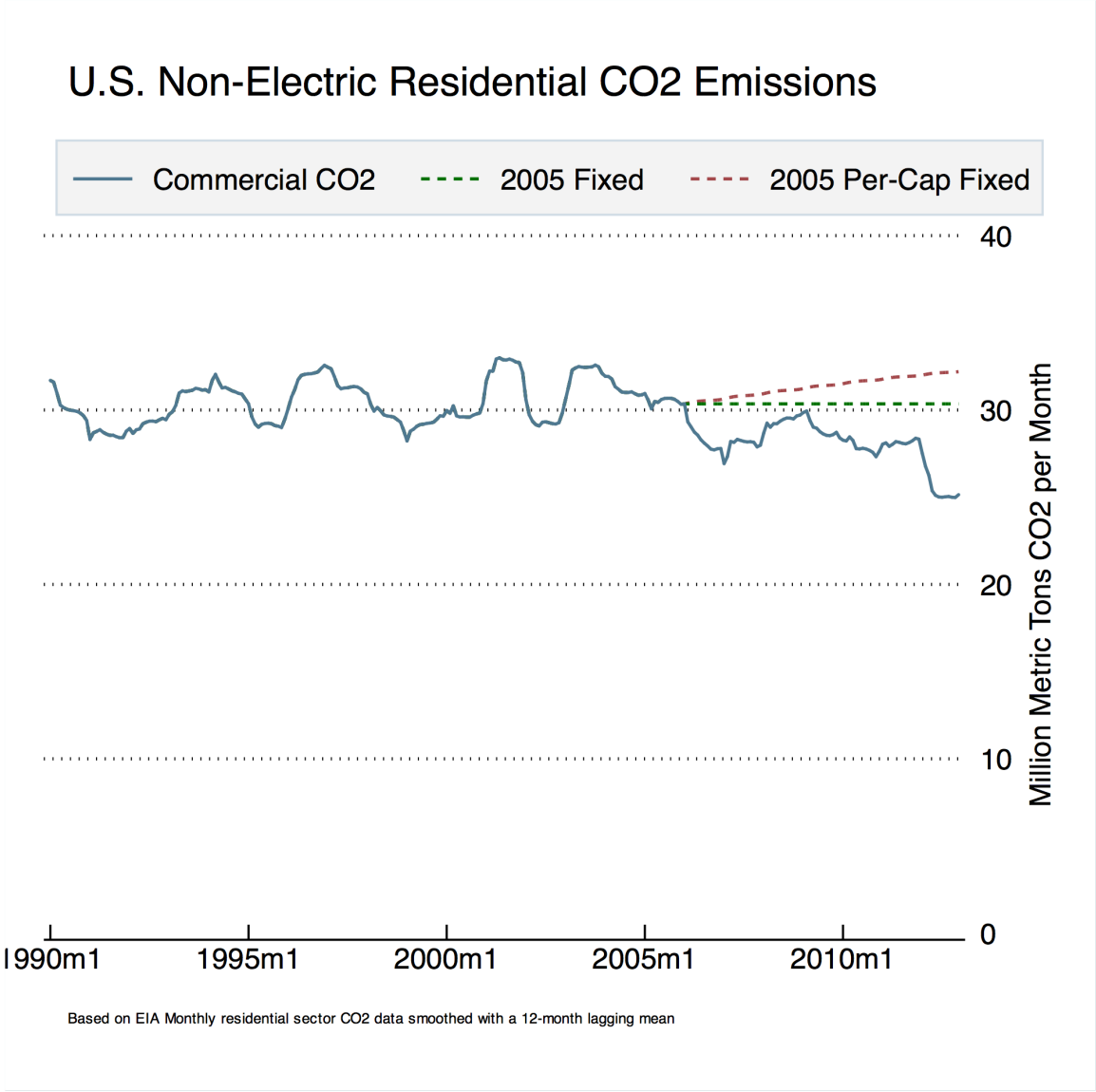

Figure 21: U.S. residential monthly CO2 emissions with a 12-month lagging average applied, excluding emissions from purchased electricity generated off-site. Dashed lines represent 2005-fixed and 2005-fixed per-capita counterfactual scenarios.

The dip in residential non-electric CO2 emissions over past last year, while noteworthy, may be largely due to the unusually warm 2011/2012 winter season and the associated reduction in residential space heating energy use. It should not

be interpreted as a lasting reduction until more data is available to determine if reductions persist.

Overall Industrial, Commercial, and Residential Non-Electric CO_2 Reductions

Declines in industrial non-electric energy use are by far the largest contributor to overall non-electric non-transport CO2 reductions. Residential reductions are also significant, while commercial reductions are somewhat negligible.

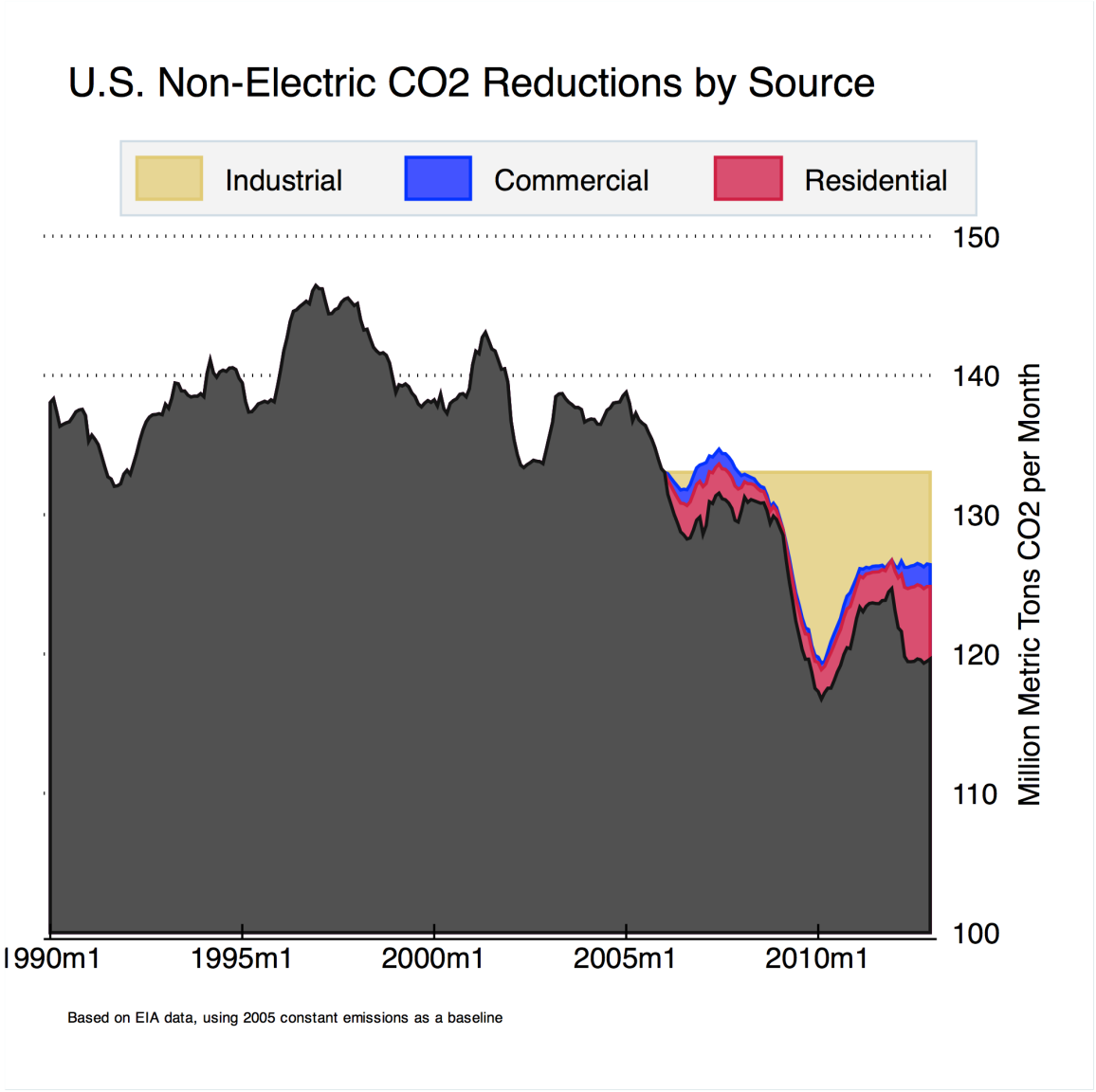

Figure 22: U.S. monthly non-electric CO2 emissions from industrial, commercial, and residential sectors, January 1990 through December 2012 with a 12-month lagging average applied to remove seasonal cycles. Estimated CO2 reductions from three identified factors are shown.

Overall CO_2 Reductions

Examining total U.S. CO_2 emissions from energy, we see that the factors identified (miles traveled, fuel economy, air travel, natural gas, wind, reduced electricity use,

and reduced energy use from industry, commercial, and residential sectors) are responsible for the bulk of the reduction in CO_2 emissions relative to an alternate scenario where 2005-era behaviors persisted. Without their combined effect, emissions would be about 15 percent higher than what was actually observed.

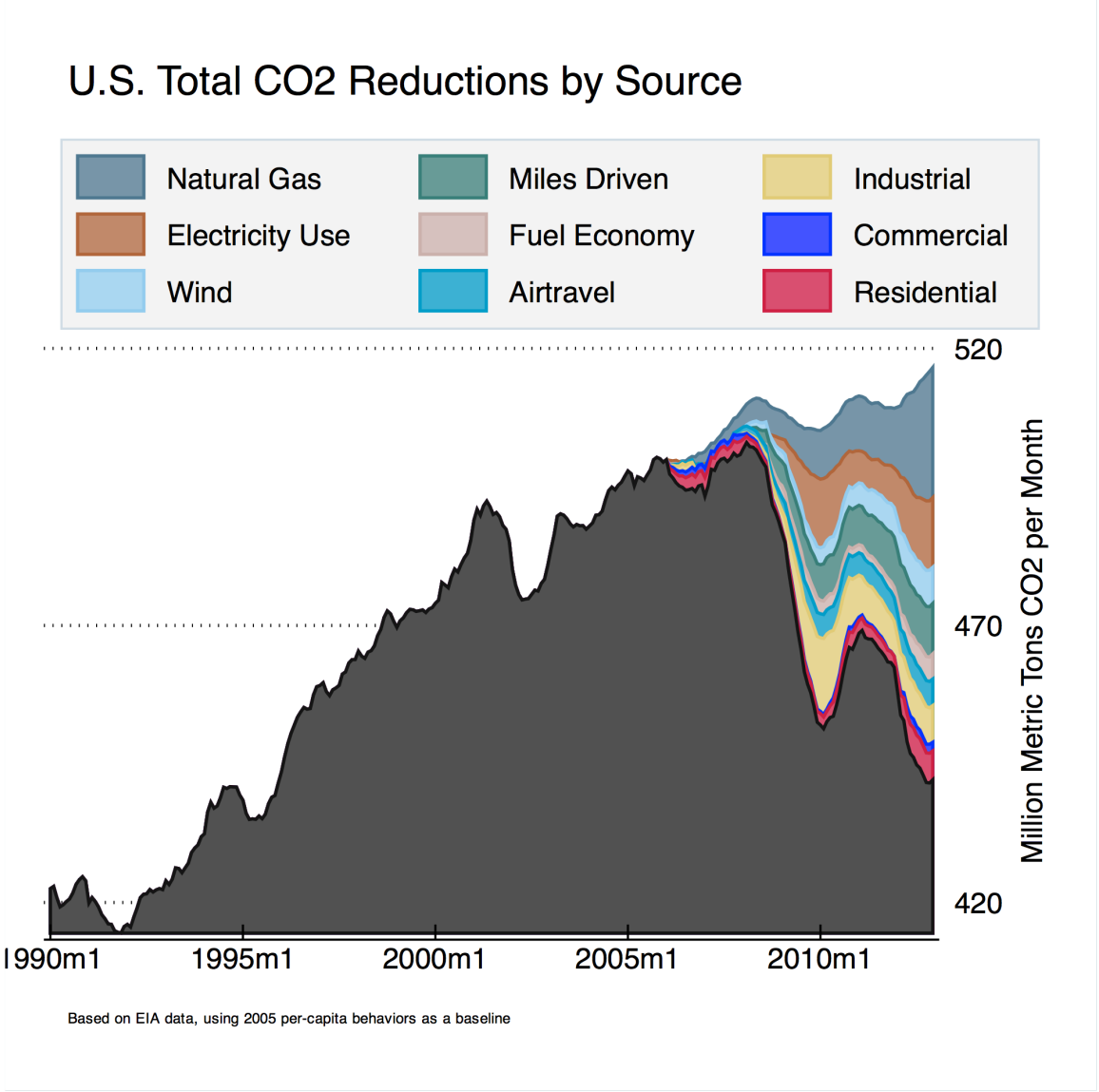

Figure 23: U.S. monthly CO_2 emissions from all energy sources, January 1990 through December 2012 with a 12-month lagging average applied to remove seasonal cycles. Estimated CO_2 reductions from six identified factors are shown.

These factors, while some of the largest, are not the only things influencing U.S. CO_2 emissions. They exclude land-use changes, non-CO2 greenhouse gases, and some smaller sources of energy-related CO2 emissions including public transportation (busses, trains) and shipping. It is also important to put these declines in perspective compared to total U.S. CO2 emissions, as shown in the figure below.

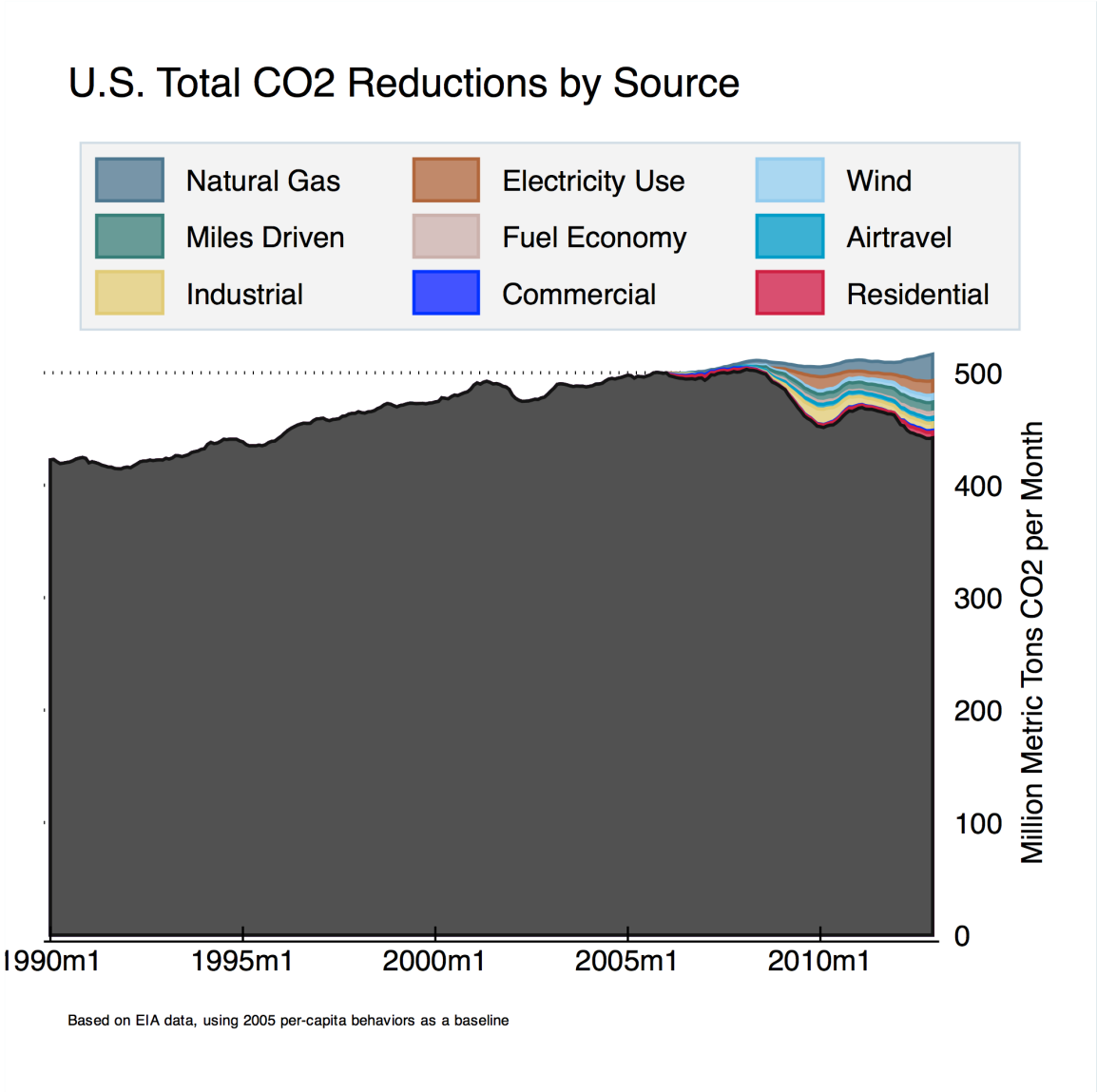

Figure 24: U.S. monthly CO_2 emissions from all energy sources, January 1990 through December 2012 with a 12-month lagging average applied to remove seasonal cycles. Estimated CO_2 reductions from six identified factors are shown. Note that the y-axis begins at 0.

Understanding the drivers of the recent surprising and welcome decreases in U.S. CO_2 emissions is critical to experts' and policy makers' understanding of what the future may hold. While the U.S. economy has been recovering from the recent recession, CO_2 emissions have continued to decline. Factors like natural gas, wind, and vehicle fuel economy will likely continue to play a large role in driving future reductions. And even factors like reduced electricity use per-capita and travel patterns show no signs of returning to 2005 levels. It is too early to tell for certain, but perhaps a case can now be made that U.S. CO_2 emissions may have peaked.

The U.S.'s CO2 trajectory of course falls into the "good news" category for a climate issue for which good news has come all too infrequently. But given that U.S.

emissions, while clearly significant, constitute only about 16 percent of global emissions, there remains the subject of other major emitting countries' own performance in recent years. China, in particular, has had such a dramatic rise in emissions that it has more than offset U.S. declines. In addition, there remain substantial unknowns about just how the hoped-for dividends from a presumed continuing economic recovery, both nationally and globally, will be manifested in terms of CO2 emissions.

Data Sources

Energy use and carbon emission data used in this article is available from the Energy Information Agency (EIA) Energy Monthly Review.[2] Ground transportation data is taken from the Federal Highway Administration's Traffic Volume Trends.[3] Population data is taken from the U.S. Census.[4]

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[2] U.S. DOE EIA Monthly Energy Review, 2013, available: http://www.eia.gov/totalenergy/data/monthly/

[3] U.S. DOT FHA Traffic Volume Trends, 2013, available: http://www.fhwa.dot.gov/policyinformation/travel_monitoring/tvt.cfm

[4] U.S. Census Total Population: All Ages including Armed Forces Overseas, 2013, available: http://research.stlouisfed.org/fred2/data/POP.txt