Quantifying and Valuing Displaced Power Plant Emissions as a Greenhouse Gas Mitigation Option

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ABSTRACT

This paper reports new results for estimating emission factors for electric generation affected by energy efficiency programs in Wisconsin. This is part of ongoing work that informs the benefit-cost analysis for the overall program portfolio (Focus on Energy programs). We quantify and value displaced power plant emissions associated with the programs' energy impacts. For the first time, we have combined hourly emission factor estimates with load shape data representing the programs' distribution of energy impacts across 8,760 hours. Because emission factors vary by hour, the timing of energy savings is important to the environmental impacts associated with them. Using the EPA's "Acid Rain Hourly Emissions Data," we identify marginal plants and calculate marginal hourly emission rates. These hourly rates are then used to estimate the displaced power plant emissions attributable to the programs. In addition, the Governor's Task Force on Global Warming in Wisconsin has recommended that carbon reductions and other power plant pollutant reduction benefits be valued "at some range of values or actual market rates." Thus, we also discuss proposed values for the portfolio benefit –cost analysis.

Although EE program planners and sponsors universally recognize that greenhouse gas emission benefits need to be included in their benefit-cost ratios, as yet there has not been significant research into how these benefits should be calculated. The important new development presented in this paper is converting the 8,760 program load impacts to a reduction in greenhouse gas emissions by integrating the distributed hourly impacts and generator "use rate" analytics to identifying marginal hourly emission factors. This approach will be useful for implementing policy decisions concerning the goals of energy efficiency programs. For example, trade-offs between carbon mitigation, capacity reductions, and/or energy savings can be assessed more accurately. This will enable policy decision to be more reliably implemented by portfolio managers of energy efficiency programs, with respect to policy objectives regarding optimization of energy savings, demand reductions, or greenhouse gas (GHG) emissions.

Introduction

In accounting the benefits and costs flowing from energy efficiency programs, increasing attention is being paid to the avoidance of pollution emissions from generating plants as electric consumption decreases. With the prospect of a "cap and trade" market for CO_2 emissions a reasonable likelihood, the monetization of pollution may help shift the balance further in favor of program-based energy savings. Critical to this development, however, will be a methodology for assigning credit to programs that is rigorous, defensible, and clear.

For the past several years, as part of our role as evaluators of Wisconsin's Focus on Energy (Focus) programs, we have estimated emission factors (i.e., pounds of pollutant per MWH of avoided generation) to calculate environmental impacts from Focus net energy savings. We produce factor estimates for CO_2, NO_X, SO_X, and HG. Our estimates are based on the Environmental Protection Agency's Office of Air and Radiation "Acid Rain Hourly Emissions Data," which derives from actual stack monitoring. Appropriate allowance prices for displaced emissions are then used for the benefit-cost and economic impact analyses, including a forecast of future prices (2007–2026). The energy savings are substantial: Focus on Energy estimates an annual net electric savings in 2008 of 756 GWh from activities since 2001.

On an ongoing basis, we have sought to improve our estimate of emissions avoided from Focus savings.1 Most recently, we have aligned our approach with the World Resources Institute's "Guidelines for Quantifying GHG Reductions from Grid-Connected Electricity Projects." Chief among the requirements of these guidelines is the identification of plants operating on the margin of system supply as the source of emission reductions. Our approach uses the average duration of operation of each generating unit—we call this the "use rate"—to identify the dispatch order and thus plants operating on the margin. Using EPA's Acid Rain Hourly Emissions dataset, this produces data specific to the geography of the programs, based on emissions at generating plants most likely to be affected by program impacts—i.e. plants at the operating margin--for every hour of the year.

For a benchmark emission rate, the average across all hours of the year is adequate. Applying this value to actual program savings, however, ignores the critical dimension of the timing of savings. It is fundamental that savings are not distributed equally across the year but are timed to the use of energy consuming technologies. This is important because the marginal emission rate also fluctuates significantly--and systematically--over each day and across the year. The movement of these two relationships, emission rate and savings rate, relative to one another creates a complex pattern, which is missed when an average annual emission factor is applied to annual savings. Moreover, specific programs promote different technologies to different types of consumers and therefore save energy at different times of the day. The size and even the direction of error in an estimate of avoided emissions that does not account for the timing of savings can be expected to differ from one program to another. To get the estimate right, therefore, we need to allocate both savings and emissions across all 8,760 hours of the year.

Until now, common practice has been to apply a single emission factor to all savings. In this study we bring together both pieces of this dynamic process. Although our emission rate estimates cover four pollutants, to simplify and focus our discussion we report only on CO2 emissions. Additionally, we apply forecast CO2 allowance prices to our analysis, to monetize both the impact of the programs and the differences in estimation approaches.

Methods

We align our emission rate estimation method with the Greenhouse Gas Protocol of the World Resources Institute (WRI). Its "Guidelines for quantifying GHG Reductions from Grid-Connected Electricity Projects" is the most recent and most comprehensive effort to standardize measurements of the type we are undertaking with this research. In part, we derive the following two principles from these guidelines.

- The proper geographical framework is the grid that serves electric customers affected by programs.
- The relevant portion of load is the operating margin, i.e. load that would first be called off line by energy savings.

The Wisconsin Grid. We define the grid serving Wisconsin as coterminous with the two NERC regions that bisect the state: MRO and RFC. Although the RFC covers a smaller territory—primarily the southeastern corner of the state—Wisconsin's energy consumption is roughly equally split. These combined territories stretch from eastern Montana, across the north plains and Midwest to the mid-

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[1] For a discussion of our prior work, see 2008 ACEEE Summer Study paper, "Energy Efficiency, Emission, and Policy-Strengthening the Links."

Atlantic coastal states of New Jersey, Delaware, and Maryland.

Identifying the Operating Margin. The WRI Guidelines are clear that estimating emissions on all generation does not correctly account for the effects of energy efficiency programs. Rather, generation at the operating margin is what counts: this is generation in any hour that is first in line to be removed under reduced demand. To simplify, somewhat, natural gas is

In our current approach we model the dispatch order using data available in the EPA dataset. We calculate for each plant an average amount of time it tends to stay on once it is called on-line. The total number of hours a plant operates per year, divided by the number of on/off cycles, gives this datum. We refer to this as the use-rate of a plant. We note that use-rates tend to fall into distinct patterns, with one group of plants coming on for about 5 hours, another set for about 9 hours, a smaller group coming on for roughly 18 hours, and a large group coming on for hundreds or thousands of hours.

Figure 1 shows a plot of on/off cycles and operating hours for the year 2005. We have used a demarcation for use-rates of 6, 12, 24, and 96 hours to bound five groups of plants. Plants in the less-than-6 hour category are peaking plants. Plants in the more-than-96 hour category are base load plants. In between are plants with intermediate characteristics: the shorter the average use-rate the more sensitive to demand.

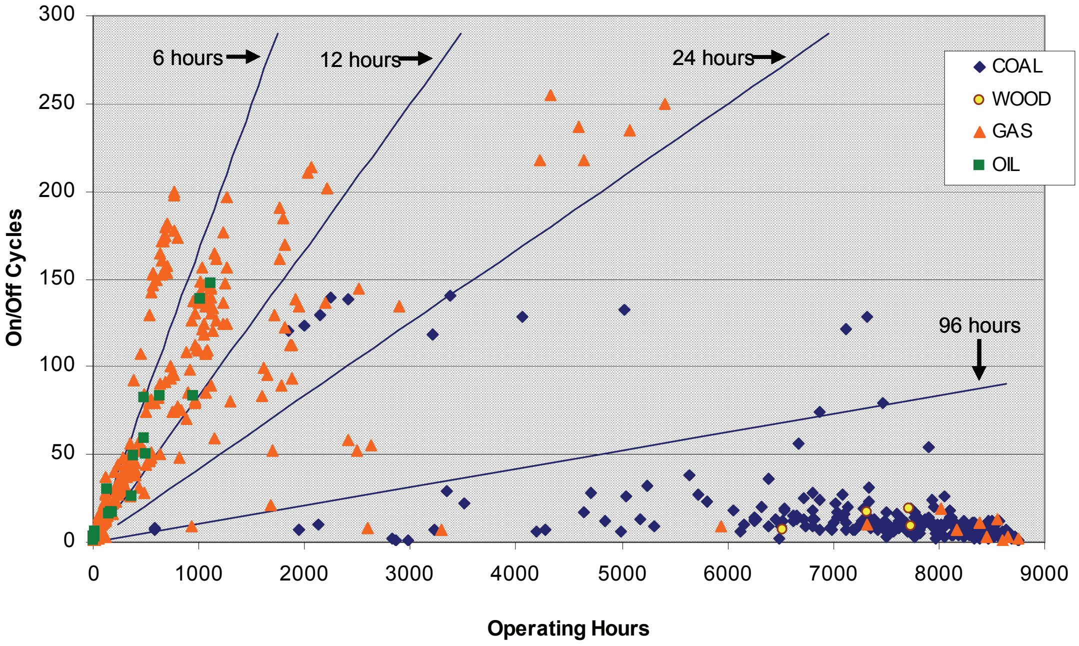

Figure 1. Plant On/Off Cycles and Annual Operating Hours by Fuel Type—2005

Following this logic, we define marginal emissions as those produced by the set of plants in the lowest use-rate group that is operating in each hour. At peak times in the mid-summer, the marginal emission rate is defined by the shortest cycling plants, which tend to remain on about 5 hours once they are called up. In mid-winter in the middle of the night, the marginal emission rate is defined by what are essentially base load plants—because these are the only plants in operation. We eliminate from the estimate plants that are generating less than 1 MW because these typically are shutting down in the hour and are subject to low-load emissions problems. We average emission rates across all marginal plants in each hour, and then average across hours of the year, to get an annual average.

Energy Impacts of Focus on Energy Programs. Near-term program energy impacts are critical to the success of Focus. As a core evaluation responsibility, evaluation activities identify, document, quantify, and monetize these impacts. For all Focus programs that have energy impact objectives (including the Low-income Programs), the evaluation team designs and conducts program-specific data collection and reporting that supports unbiased independent estimations of verified gross and verified net-energy impacts for all programs with: (1) independent verification of the implementation of energy efficiency improvements, and the engineering calculations used to estimate the energy saved, and (2) independent verification of the extent to which energy savings can confidently be attributed to Focus efforts.

These energy impacts are reported in semiannual (technical) reports plus an annual overview. Energy impacts are reported by program area (Business, Residential, and Renewable Energy) and specific program, and by the previous quarter, the contract year-to-date, and cumulative program-to-date. They are also geographically reported by county, utility territory, and Assembly and Senate Districts.

As the Focus programs progress, the evaluation team has also quantified energy savings attributable to the Focus effort that are not directly counted (or tracked) by program administrators. These *nontracked energy savings* consist of a combination of savings that are attributable to the Focus program – particularly market effects of the programs – that should be credited to the program. An important source of nontracked energy savings for Focus is the ENERGY STAR® Labeled Products program compact fluorescent lighting (CFL) initiative in the residential sector.

The Timing of Energy Savings

The timing of Focus energy savings is estimated using load shapes from a variety of sources. Recently, Wisconsin Energy Conservation Corporation (WECC), the Focus residential program administrator, has developed load shapes for their program benefit / cost analysis. WECC has produced load shapes for different types of building activities. We have applied load shapes for residential consumption in homes with gas heat, and commercial load shapes for small consumers. In addition, we have load shapes for specific end-uses, including:

commercial lighting
commercial HVAC
commercial hot water
commercial refrigeration
commercial motors
residential lighting
residential HVAC
residential hot water
residential appliances

These are not from WECC, but originate from a variety of sources.[2] We convert average hourly consumption to a percent of total annual consumption in each hour of the year. We multiply the annual savings for each end-use by the percent of end-use consumption in each hour of the year. An assumption is made that energy savings are a constant proportion of consumption. This assumption could be relaxed by applying savings load shapes rather than consumption load shapes. These were not available to us when we conducted this analysis.

Estimating Carbon Prices

A range of policy and market variables will determine the future cost of carbon in a carbon constrained world. Uncertainties around those variables make it impossible to predict carbon prices with real certainty, and the impact of such variables will differ across short-, mid-, and long-term time horizons. The

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[2] Cahill, James M, Keith Ritland and Wendy Lin-Kelly, Bonneville Power Administration. "Description of Electric Energy Use in Single-Family Residences in the Pacific Northwest: 1986-1992. End-Use Load and Consumer Assessment Program (ELCAP)." Portland, OR. December 1992.

availability of "low-hanging fruit," for example, is particularly important to near-term carbon price analysis, while macroeconomic assumptions, and assumptions about technology innovation and deployment, are key to longer-term projections of carbon market prices. Carbon costs should not be thought of exclusively in the context of emissions trading systems, although such systems are the easiest way to generate a carbon price signal.

Any effort to anticipate GHG markets and prices must also recognize that carbon is a "policy commodity," and carbon markets are fundamentally different than other commodity markets. The magnitude of carbon prices will likely be determined by the policy decisions that establish the demand for emissions reductions, and by the policy decisions that define and constrain the supply of qualifying emissions reductions. This kind of policy derived market, where both sides of the market dynamic are subject to near- mid- and long-term policy uncertainty, differentiates carbon market forecasting from most other commodities, and can make forecasts quite volatile.

Although there is no such thing as a "correct" forecast of future carbon market prices, the forecasting process can contribute to better decision-making today. The notion of a "one size fits all" forecast is particularly inappropriate for carbon. A useful forecast for a given entity will reflect its future view of key policy and market variables, the materiality of carbon prices to the entity's operations, and how sensitive the entity is to acting on the basis of a price forecast that ends up being materially too high or too low. The greater the risk associated with choosing the wrong forecast, the more entities should consider using a forecast that hedges that risk.

The results section of this paper includes a table that provides carbon price forecasts for two policy and market scenarios, not attached to a specific existing market, and not reflecting specific legislative proposals. The two forecasts can be respectively characterized as 1) politically pragmatic, and 2) stabilization-driven. The first, while assuming a serious political commitment to climate change policy, also reflects the political realities associated with policy development around a topic as complicated and long-term as climate change (which will tend to make it difficult to generate and maintain higher carbon prices). The second reflects an implemented commitment to stabilizing concentrations of CO2 in the atmosphere (which will likely require expectations of significantly higher carbon prices both to incentivize emission reductions, and to catalyze new low-emission technologies). These are only two of many scenarios that could appropriately reflect the views and risk perceptions of individual corporate or policy entities wanting to utilize such forecasting to improve their decision making, and the two price forecasts provided are not the lowest or the highest forecasts that could reasonably be used.

Results

Using the methodology discussed above we show, first, the relative movement of CO_2 emission rates and consumption. This indicates at what time of day avoided emissions are greatest and could inform policy about targeting programs to garner emission savings. Second, we show avoided emissions by hour, based on current program offerings. Third, we show annual avoided emissions by end and compare that value with other approaches to estimating avoided emissions. This reveals that avoided emissions are higher using the hourly estimates than using annual average emissions rates and total savings. Finally, we estimate a monetary value for avoided $C0_2$ emissions using projected carbon market prices.

CO_2 Emission Rates for the Wisconsin Electricity Grid

Figure 2 shows hourly CO_2 emission rates--plotted against the right axis--for two weeks in 2006, January 7 to 13 and July 15 to 21. (In each case this is Saturday to Friday.) We have selected one mid-season heating and one mid-season cooling week, neither of which has a holiday. Against the left axis of the figure we have plotted total load shapes for residential and commercial sectors as a percent of annual consumption in each hour.

Although the emission rate changes in a complex way, the pattern is counter-cyclical with load. This is more evident in the summer period than in winter; but even in winter there are consistent emission rate peaks in the load trough between 11 PM and 5 AM, and another smaller peak in the mid-day residential load trough. The reason for this counter-cyclical relationship is that the rate of CO_2 emission is tied to the type of fuel on the margin. When demand is relatively high, expensive-to-run, gas-fired peaking plants are on the margin. These have relatively low emissions compared to relatively cheap-to-run, coal-fired base-load. When demand is low, however, base load is on the margin so emission rates are relatively high. The highest emission rates occur when a set of semi-retired, coal-fired plants with older, dirtier technology are on the margin. These have longer cycling periods than gas-fired plants so are on the margin during off-peak times when expected demand for the day is high, i.e. during the summer season.

For Wisconsin, and other regions where the predominant base-load fuel is coal, the implication is that programs designed to avoid emissions should target their efforts at technologies or sectors that operate off-peak

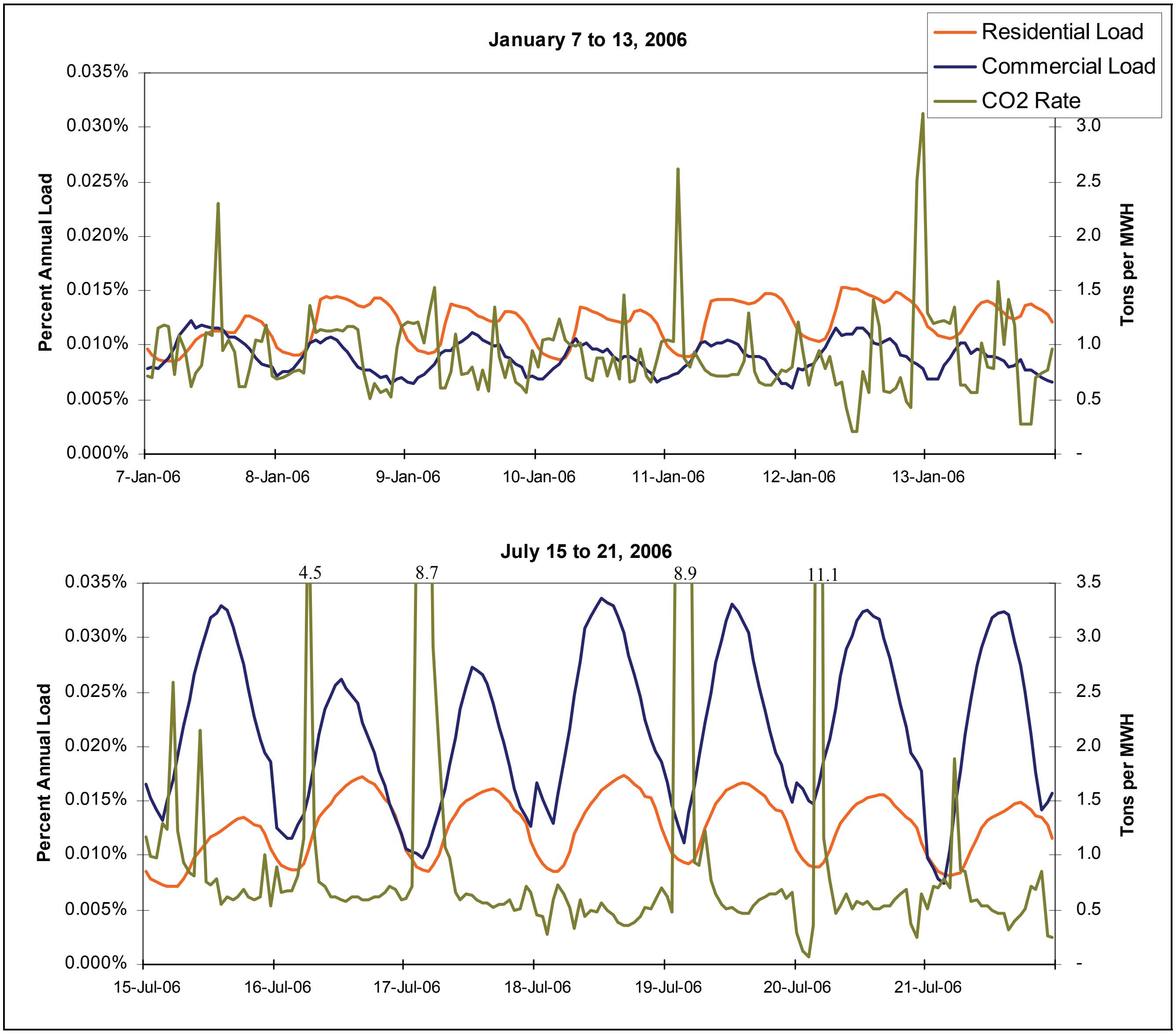

Figure 2. CO2 Emission Rate and Load Shapes for Two Time Periods

Applying Emission Rates to Focus on Energy Savings

Figure 3 shows hourly avoided emissions resulting from commercial and residential Focus program savings from January 7 to January 13, 2006 and July 15 to July 21 2006. The lines represent the interplay of load shape and emission rate. Note that savings are substantial during peak periods—especially for commercial programs--even though marginal emission rates are lower at these times. The amount of energy saved more than compensates for the lower emission rates.

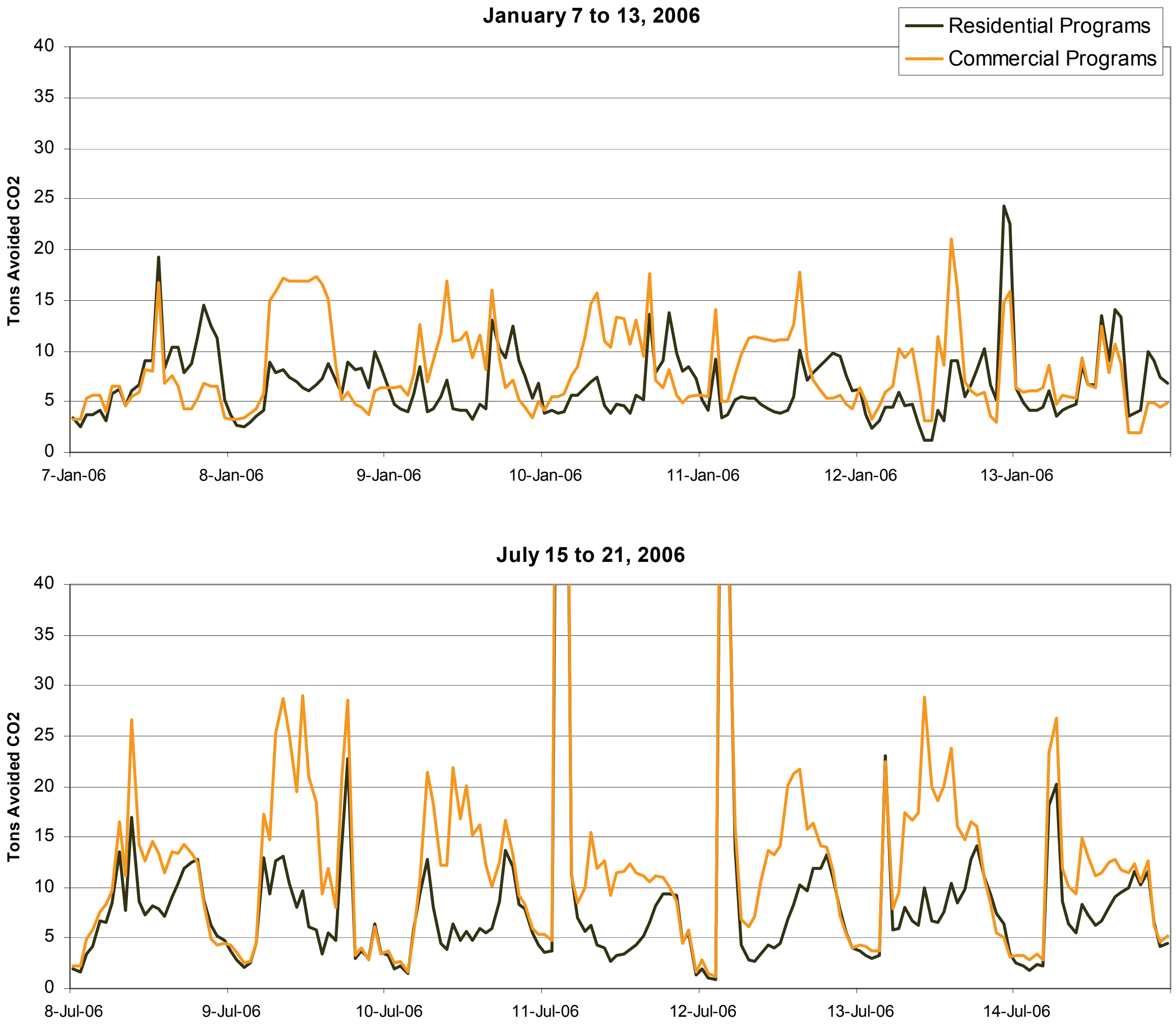

Figure 3. Hourly Avoided CO2 Emissions from Focus on Energy Programs for Two Time Periods

Table 1 sums avoided emissions and energy savings across the two study weeks, for residential and commercial programs. It also shows the emission factor for each period and sector. In January, residential and commercial programs have similar effects, though the timing of avoided emissions is such that commercial programs have a higher emission factor. In summer, Commercial programs have substantially higher energy savings and avoided emissions, but the timing is such that the emission factor is much lower.

Table 1. Hourly Avoided CO_2 Emissions from Focus on Energy Programs for Two Time Periods

	Residential Programs		Commercial Programs	
	January	July	January	July
CO_2 Savings (tons)	1,123	1,452	1,357	2,172
Energy Savings (MWH)	1,488	1,372	1,347	3,369
Emission Factor (tons / MWH)	0.75	1.06	1.01	0.64

Figure 4 shows different avoided CO_2 emissions for eleven different end-uses that result from three different way of estimating the emission factor. These are annual total avoided emission values. If the average of all annual generation is used, without attempting to identify generation on the margin (i.e. "Annual All Load"), the estimate is exaggerated for all end-uses by 35% to 70% compared to a factor based either on an annual average of marginal load ("Annual Marginal Average") or an hourly marginal rate applied to hourly savings ("Hourly Marginal").

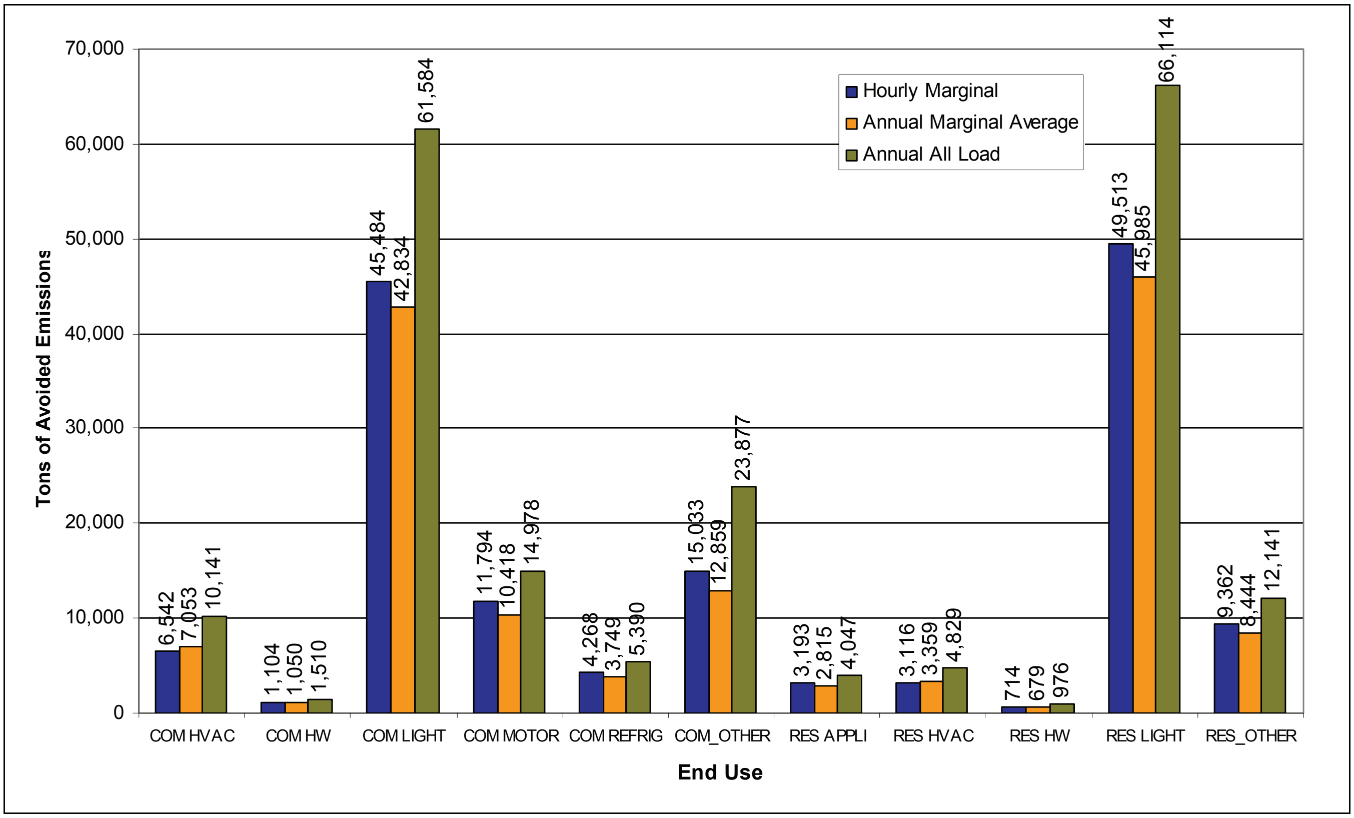

Figure 4. 2006 Avoided CO_2 Emissions from Energy Efficiency Programs, By End-Use, Under Three Approaches to Identifying the Emission Rate

More interestingly—because it is increasingly accepted that an all-load emission factor is inappropriate--calculating avoided emissions using an hourly marginal rate against hourly savings *increases* the value of the emission factor for most end-uses relative to a rate calculated as an annual marginal average against a total savings value. The difference is as much as 14% for the residual "other" category; and it is 12% for commercial refrigeration, motors, and residential appliances. The differences are similar for commercial (7.4%) and residential (7.0%) sectors.

The implication of this finding is that the timing of energy program savings works to the benefit of avoided emissions. This is true even though, as we saw above, the timing is not optimal in this regard, i.e. greater avoided emissions could be obtained if savings could be shifted further off peak. To underscore the point: *Accounting for the timing of energy savings and avoided emissions increases the estimate of avoided emissions*.

The exception to the relationship just described is HVAC; and this is not difficult to explain. HVAC savings are more likely to be coincidental with peak consumption periods, when marginal emissions are relatively low. Hence, accounting for the timing of savings reduces the savings estimate.

Valuing Avoided Emissions

The following table provides carbon price forecasts for two policy and market scenarios, not attached to a specific existing market, and not reflecting specific legislative proposals. The two forecasts can be respectively characterized as *politically pragmatic*, and *stabilization-driven*. It is most likely that the Focus on Energy Benefit-Cost analysis will use the politically pragmatic forecasts. Table 2 shows forecast carbon prices for the years 2008 to 2020.

Table 2. Carbon Price Forecasts 2008-2020

	CO_2 Scenario 1 Politically Pragmatic	**CO_2 Scenario 2 Stabilization Driven**
Year	**$/US Ton, Real**	**$/ US Ton, Real**
2008	$ 4.54	$ 4.54
2009	$ 5.44	$ 5.44
2010	$ 13.61	$ 13.61
2011	$ 15.42	$ 18.14
2012	$ 15.42	$ 18.14
2013	$ 15.42	$ 20.87
2014	$ 15.42	$ 23.59
2015	$ 18.14	$ 25.40
2016	$ 18.14	$ 27.22
2017	$ 18.14	$ 29.03
2018	$ 18.14	$ 30.84
2019	$ 20.87	$ 32.66
2020	$ 20.87	$ 40.82

At the 2010 pragmatic market price for carbon, $13.61, the value of avoided CO_2 emissions (150,124 tons) from Focus on Energy programs for 2006 would have been $2,042,850. We note that estimating avoided emissions using an annual average emission factor would arrive at the value $1,894,811, which is $148,040 less than arrived at through the other, more time-sensitive method.

Conclusions

We have shown it is feasible to improve the estimate of avoided emissions by factoring in the timing of savings. We estimated an hourly emission factor using EPA Acid Rain data, and estimated an hourly allocation of savings using load shapes. Multiplying hourly energy savings by hourly emission factors provides an 8760 view of program effects. We have also shown that estimating avoided emissions in this way alters the total annual savings estimate: in our example, by more than 7% over an approach that applies an annual energy savings value to an annual average emission factor.

We see several implications for program designers from our research, with particular application to the objectives documented by the Governor's Task Force on Global Warming in Wisconsin, and the state's agenda for its Quadrennial Planning process. The Final Report to the Governor from the Task Force included a recommendation for an "Enhanced Conservation and Energy Efficiency Program" (ECEE) that is to have GHG reduction impacts estimated at 14 million metric tons by 2020. The primary policy proposal is to expand significantly the Focus on Energy program, and the Task Force emphasizes that this GHG reduction goal will assume some ability to achieve returns to scale with efficiency spending (based on past Focus impacts and estimated emission reductions). Also, the objective of this ECEE recommendation is to maximize overall aggregate net benefits at the lowest cost. Thus, the ability to understand with some precision how the impacts from different end-use sources of energy savings significantly affect the quantities of associated avoided emissions will be critical to future planning of this Enhanced Conservation and Energy Efficiency Program.[3]

In addition, the state of Wisconsin is about to conduct its Quadrennial Planning Process. This process follows from the recently released "Strategic Energy Assessment – Energy 2014" which also highlighted the state's primary emphasis on energy efficiency and conservation to reach GHG targets that are seen as soon to be mandatory. One of the highest priority agenda items for the Quadrennial Planning Process is to determine the relative mix of priorities in energy efficiency and conservation between GHG reductions, electric demand reductions, and electric energy savings. Again, the analytic ability to understand with some precision how the impacts from different end-use sources of energy savings significantly affect the quantities of associated avoided emissions will be essential to policy makers and program planners for the state's energy efficiency and conservation programs.

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[3] As our paper argues, the precision issue can be quite important. We note that the *Model Energy Efficiency Program Impact Evaluation Guide* (National Action Plan for Energy Efficiency, November 2007) describes two methods for calculating avoided emission factors (page 6-4). The first, termed a simple "system average," is assessed as "generally produces less precise estimates." The second method, termed a "medium effort" calculation approach (and corresponding to the method explicated in this paper), would use "emission rates for marginal generators" and/or load curves and "generally results in moderately precise avoided emission estimates." Our position is that for the purposes sought by, in this case, the state of Wisconsin, the value attributed to quantifying and monetizing displaced emissions justifies the "medium effort" calculation method.