Wisconsin's Public Benefits Approach to Quantifying Environmental Benefits: Creating Different Emissions Factors for Peak/Off-Peak Energy Savings

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ABSTRACT

This paper will present an extended approach and preliminary results for the quantification of environmental benefits in Wisconsin's Focus on Energy Program. A key objective of the evaluation is to document the environmental benefits associated with avoided electricity generation attributable to energy impacts of the Department of Administration's statewide programs, with specific attention to reductions in air pollutants (NOx and SO2) and emissions of the green house gas CO2.

The emissions model described in this paper was developed as an expansion of a model developed under the pilot Focus on Energy program by staff from Lawrence Berkeley National Laboratory (LBNL). The earlier model used plant-specific data from Energy Information Administration's (EIA's) National Energy Modeling System to calculate emissions rates for each plant. This approach was taken to create a simple, straight-forward model that provides area-wide emissions factors that could be used to calculate emissions savings from energy efficiency programs. The emissions factors created in this model are applied across full-year savings, regardless of seasonal or daily variations in energy savings patterns. Since some kinds of energy efficiency measures and some kinds of programs are more likely to create energy savings in certain times of the year or certain times of day, it seemed a natural extension of this model to examine emissions on a seasonal and peak vs. off-peak basis. This paper describes the extension of the model using hourly emissions and energy data to calculate winter and summer, peak and off-peak emission factors. We present results of the model, application to early evaluation energy savings results, discuss a possible interpretation of the results, and discuss possible enhancements to the model.

Summary

Wisconsin is implementing statewide energy efficiency programs with public benefits funds, replacing programs previously run by investor owned utilities under Public Service Commission regulatory supervision. Called "Focus on Energy" (Focus), the programs are being run through the state Division of Energy in the Department of Administration (DOA) who provide direction and oversight, and are being implemented and evaluated by private firms. The programs must address a variety of legislative goals including energy efficiency, system reliability, environmental protection, and rural economic development. This paper presents an emissions estimation model developed to estimate emissions avoided or saved from the Focus energy efficiency programs.

A key objective of the overall evaluation of Focus is to affirm the environmental benefits associated with the energy impacts of the Focus programs. In the past, these benefits

were projected by DOA using spreadsheet algorithms to convert energy impacts (by fuel type) to reductions in the ground level air pollutants NOx, CO, and SO2. Program energy impacts can also be expected to reduce emissions of CO2, an anthropogenic greenhouse gas, and DOA is further interested in quantifying reductions in mercury, and particulates. In addition, the environmental benefits quantification analysis must be based on defensible energy impacts. Thus, a prerequisite for the environmental analysis is documentation by the evaluation contractor of sound research design, measurement, and analysis at the program-specific level in producing estimates of energy impacts.
This paper describes: (1) an Excel-based approach developed at LBNL for calculating emission factors; and, (2) the extension of this approach to different time periods on a seasonal and daily basis.

The Environmental Benefits Quantification Analysis

This analysis approach is designed to:

- Provide the DOA with a tool that will support estimation of various environmental benefits associated with the energy impacts of the Focus programs.
- Provide the DOA with appropriate emissions factors for NOx, SO2, and CO2 based on plant-specific data for power plants that supply Wisconsin.

Approach

Estimation of the emissions that are avoided by programs that reduce electricity demand through efficiency improvement requires an emissions rate or factor that represents what would have happened if not for the implementation and effects of the programs. Such estimation hinges upon finding the type of power plants whose use would be avoided by the programs, and the emissions avoided by their reduced operation.

The approach described here allows estimation of the power plants that are expected to be the marginal source during a given period. It provides a reasonable estimate of which sources are likely to be curtailed in response to the load reduction from programs (PA Consulting Group, Inc. 2001).[1]

The load of an electricity generation system during a given period can be represented in a diagram that plots system power output as a function of time. In order to clarify the respective roles of different power sources in meeting the load, chronological load data can be converted into a load duration curve. A load duration curve is a reordering of chronological load data into the form of Figure 1, in which the x-axis shows how many hours the load was equal to or greater than the power level shown on the y-axis. For each hour in the period, there is a particular cost-minimizing dispatch of power sources to meet the demand. The basic goal of the method is to approximate this dispatch, by filling in the area underneath the load duration curve. In so doing, one can estimate which sources operate at the margin and for how long (see Figure 2).

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[1] The method used in this work was extended from a model originally developed by staff at LBNL. The authors would like to thank in particular Stephen Meyers, Chris Marnay, and Diane Fisher for that effort.

Geographic Area Selected

The State of Wisconsin is primarily supplied by power plants in the Mid-America Interpol Network (MAIN) region, though parts of the state are supplied by plants in the Mid-Continent Area Power Pool (MAPP) region. In the near future, these two regions will be combined into one. Thus, for this project we considered all plants in both of these regions. The approach could also be used if one elects to choose a subset of power plants.

Figure 1. Load Duration Curve

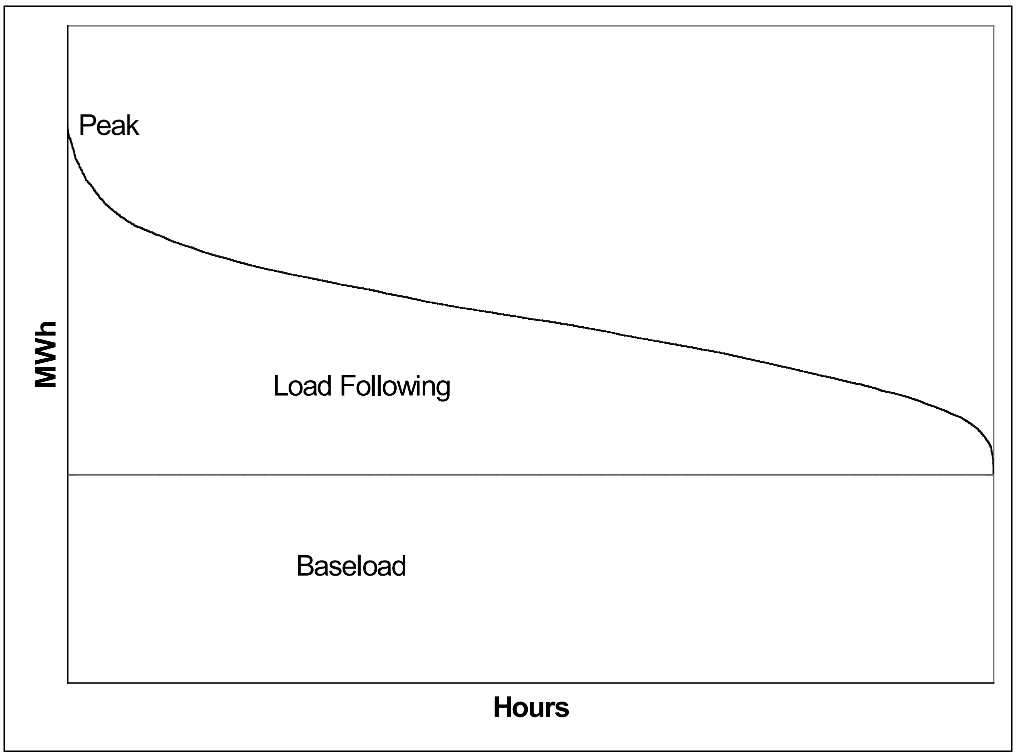
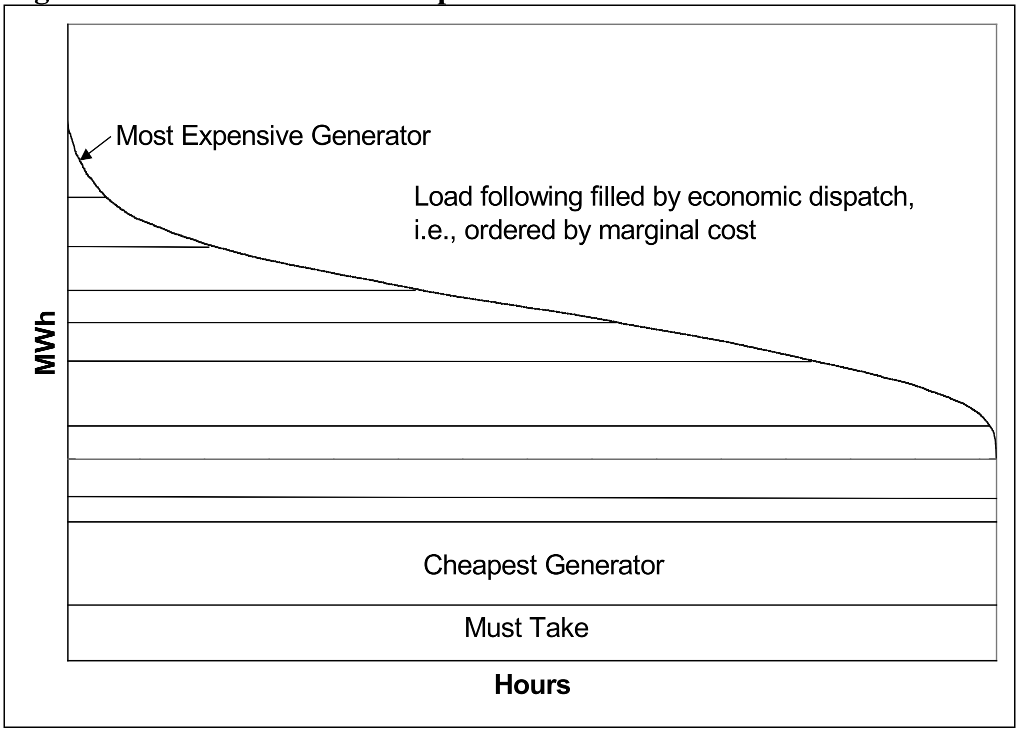


Figure 2. Assume Economic Dispatch



Discussion of Data

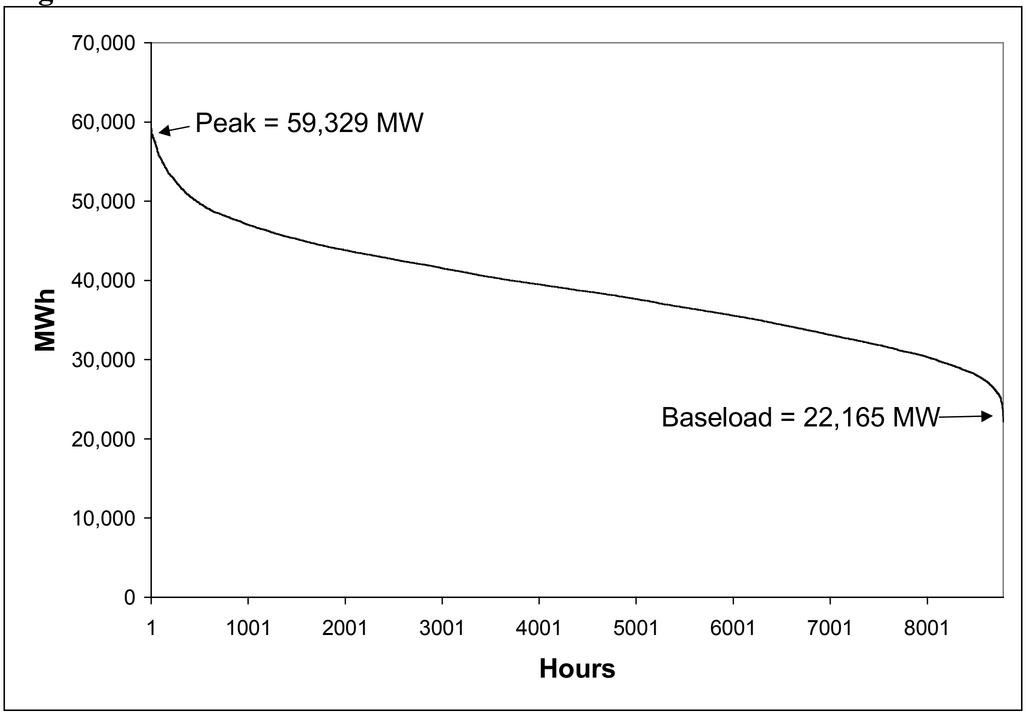
The data used for this model come from the Clean Air Markets Division of the U.S. Environmental Protection Agency (EPA). Under the Electronic Data Reporting system EPA collects hourly emissions and energy use data from generators throughout the country. EPA collects a large range of emissions-related data. We analyzed a full year of data for 2000, the latest full calendar year available. For the purposes of this analysis, we made use of the following data:

- Unit Name
- Calendar Date
- Hour
- Unit Operating Time
- Gross Unit Load During Unit Operation (MWe)
- Hourly Heat Input Rate During Unit Operation (mmBtu/hr)
- Total Heat Input for the Hour (mmBtu)
- SO2 Mass Emission Rate (lb/hr)
- SO2 Mass Emission Rate (Adjusted) (lb/hr)
- Total SO2 Mass Emissions (lb)
- NOx Emission Rate (lb/mmBtu).
- NOx Emission Rate (Adjusted) (lb/mmBtu)
- NOx Mass Emission Rate (lb/hr)
- Total NOx Mass Emissions (lb)

- CO2 Mass Emission Rate (ton/hr)
- Total CO2 Mass Emissions (ton).

The gross unit load was used to calculate the load duration curve shown in Figure 3.[2]

Figure 3. MAIN and MAPP Load Duration Curve 2000

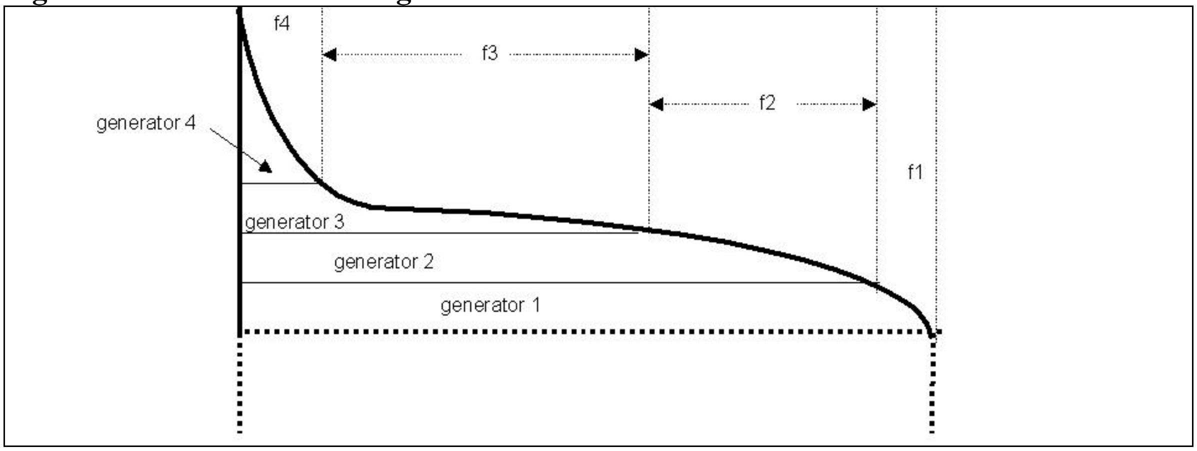


Calculation of Marginal Emissions Rates

The marginal emissions rate for a given pollutant is calculated as the average of the respective emission factors for each source, weighted by the percentage of hours in the period for which each source is marginal (see Figure 4).

[2] Since this was based on emissions data, it does not include non-emitting generators such as hydro, solar, and wind.

Figure 4. Calculation of Marginal Emissions



1. Marginal emissions rate = (f1*e1) + (f2*e2) + (f3*e3) + (f4*e4)
2. Fi = time fraction generator i is marginal, and ei = emission rate of generator i

Overview of the Model

The model as defined so far is critically dependent on two pieces of data: the area-wide load duration curve and the plant-specific emissions factors for NOx, SOx, and CO2. The initial model, developed under the pilot Focus program by staff from LBNL, used plant-specific data from EIA's National Energy Modeling System to calculate emissions rates for each plant. This approach was taken to create a simple, straight-forward model that provides area-wide emissions factors that could be used to calculate emissions savings from energy efficiency programs. The emissions factors created in this model are applied across full-year savings, regardless of seasonal or daily variations in energy savings patterns. Since some kinds of energy efficiency measures and some kinds of programs are more likely to create energy savings in certain times of the year or certain times of day, it seemed a natural extension of this model to examine emissions on a seasonal and/or peak/off-peak basis.

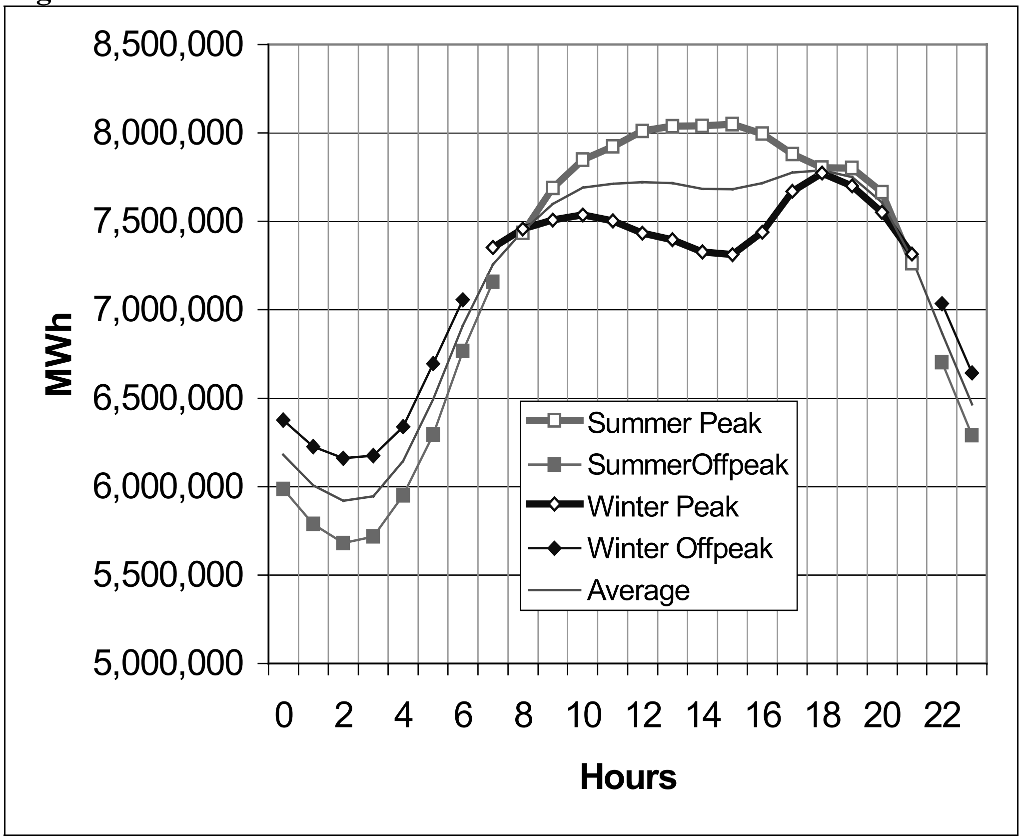
To meet this need we used hourly energy and emissions data from each plant in the MAIN and MAPP regions to calculate plant-specific emissions factors for peak and off-peak hours in the summer and winter. We outline the process below.

Estimate Peak Hours

By aggregating the hourly load data and collapsing on winter (October-March) and summer (April-September) months we created the load curves shown in Figure 5. Wisconsin utilities face a fairly protracted peak in both summer and winter. The summer peak builds through the day to a maximum in the early afternoon. The winter curve shows a small peak around 10:00 in the morning then a small dip before reaching a higher peak around 6:00 in the evening. We examined the peak curves and visually estimated the peak hours as from 7:00 am to 9:00 pm (21:00) in the winter and 8:00 am to 9:00 pm in the summer.

In fine-tuning this model, in the future we will examine the effect of choosing different peak periods.

Figure 5. Peak Hours



Calculate Peak-Season Plant-specific Emission Rates

The model is designed to calculate emissions on the margin based on plant-specific emission factors denominated in pounds/MWh. The EPA data has plant-specific emissions rates and energy use values. To calculate a peak-season-specific emission rate we summed the emissions and energy use across the peak-season and then divided the two.

Figure 6. Model

$$\text{Pounds of Emissions/MWh} = \frac{\text{Sum of Emissions (Pounds)}}{\text{Sum of Energy Use (MWh)}}$$

Capacity Factor

The emissions model dispatches plants to fill up the marginal area of the load duration curve. The user sorts the plants to their liking before starting the model's dispatch macro. Typically, we sort plants to include must-run plants first, and then sort the remainder by either capacity factor or marginal cost. The original model included historic capacity factors and we calculated marginal cost based on fuel data. Our revised version of the model sorts plants by capacity factor alone. (We will examine the effect of sorting by marginal cost in future refinements.) The EPA data did not include a capacity factor for each plant so we calculated it as follows.

Figure 7. Capacity Factor Calculation

$$\text{Capacity Factor} = \frac{\text{Sum of Energy Use (MWh)}}{\text{(Maximum MW for the year) * (Hours in the year)}}$$

The hours in the year factor varies by season and peak period. This calculation assumes that each plant achieves its maximum capacity at some point in the year (keeping in mind that no plant will operate for 8,760 hours per year). If this assumption turns out to be in error, then we must hope that the errors are consistent across plants so no bias is created. We will attempt to link the EPA data with other plant-specific data to verify this assumption.

Incorporate Plant-Specific Emission Rates in the Model

Following calculations of emission rates and capacity factors, we incorporated the plant-specific values in the emissions model, sorted the plants by capacity factor, and ran the dispatch macro. We present the results in the following section.

Results

The emissions factors show a significant variation across seasons and between peak and off-peak hours (see Table 1). Without exception, peak emission rates are **lower** than off-peak rates and winter rates are higher than summer rates.

Table 1. Emission Factors for Seasonal-hourly Model and 2000 Data

	Pounds/MWh			Percent of annual value		
	NOx	**SOx**	**CO2**	**NOx**	**SOx**	**CO2**
Winter Peak	5.7	13.6	1,953	110%	108%	93%
Winter Off-peak	6.6	17.4	2,288	127%	138%	109%
Summer Peak	3.8	8.6	1,907	73%	68%	91%
Summer Off-peak	5.2	13.2	2,215	100%	105%	105%
Annual	5.2	12.6	2,104			

The emission rates calculated using the 2000 emissions hourly data are somewhat lower than the 1999 emissions data calculated with plant-level (not hourly) data for NOx and somewhat higher for SOx (see Table 2). The 2000 CO2 value fell in between the two values calculated with the 1999 data.

Table 2. Emission Factors for Plant-level Model and 1999 Data (Pounds/MWh)

	NOx	**SOx**	**CO2**
Plants Sorted By Marginal Cost	6.4	10.8	2,400
Plants Sorted By Capacity Factor	5.9	10.0	2,035

Interpretation of Results

The generation mix in Wisconsin includes coal plants, nuclear, hydro, natural gas-fired generators, and small amounts of wind and generation from renewables. The bulk of the generation is from coal plants (62% of the total) and nuclear generation (30%) provides base load. At times of high demand, utilities fire up natural gas systems, which generally have lower emission rates than coal plants. Coal plants are probably used more often in shoulder periods because they are readily available since the utilities must keep the boilers fired at temperature so that thermal stress due to contraction does not occur. Thus, it may be that the times of highest emission are the shoulder hours when marginal coal plants are being ramped-up but before natural gas systems have been called into play. Also, it is likely that coal plants are relied upon in Wisconsin to provide reserve capacity and therefore will be kept "spinning."

We can test this theory by adjusting the definition of the peak hours to include or exclude more shoulder hours and examining the resulting affects on the emission rates. We will examine the data in more detail to characterize the types of plants that are dispatched by the model and also interview experts in the area to learn how well the model matches reality.

Application of Results

As early impact analyses are conducted as part of the Focus evaluation, we have estimated preliminary percentages of measure- and technology-specific gross energy savings allocated to the four time periods (New Jersey Clean Energy Collaborative 2001).[3] Table 3 provides the estimated energy savings across Focus residential and major markets (non-residential) programs through March 2002.

Table 3. Energy and Emissions Savings

	Emission Savings (Pounds)			Energy Savings
	NOx	SOx	CO2	MWh
Major Markets				
Winter Peak	4,867	11,612	1,667,484	854
Winter Off-peak	3,289	8,671	1,140,198	498
Summer Peak	2,608	5,902	1,308,676	686
Summer Off-peak	2,114	5,366	900,436	407
Total	12,877	31,551	5,016,794	2,445
Residential				
Winter Peak	12,597	30,055	4,315,984	2,210
Winter Off-peak	14,845	39,136	5,146,125	2,249
Summer Peak	7,502	16,978	3,764,672	1,974
Summer Off-peak	9,540	24,216	4,063,575	1,835
Total	44,483	110,385	17,290,356	8,268
Totals				
Winter Peak	17,463	41,667	5,983,467	3,064
Winter Off-peak	18,134	47,807	6,286,323	2,748
Summer Peak	10,109	22,879	5,073,348	2,660
Summer Off-peak	11,654	29,582	4,964,011	2,241
Total	57,360	141,935	22,307,150	10,713

The Major Markets energy savings in this table were taken from the program tracking database on May 10, 2002. They account for 58% of the total program savings claimed in the

[3] The Focus evaluation team is working with the program implementers and DOA staff to calculate energy (and demand) savings by season (summer and winter) and time of day (peak vs. off-peak). The preliminary percentage allocations used in this paper were guided in part by the *New Jersey Clean Energy Collaborative Protocols to Measure Resource Savings*.

Major Markets March 2002 monthly report. It covers measures for which we could make reasonable estimates of program savings.

The Residential energy savings in this table are from the Energy Star Products and Apartment/Condo projects only and represent 64% of the total program savings claimed in the Residential March 2002 monthly report across all residential programs. The data for creating the estimates were derived from the monthly report and program documents of per-unit savings estimates.

Planned Enhancements

As we have discussed above, we will examine several possibilities for improving the model as the Focus evaluation continues. We will examine the impact of changes to peak hours and the definition of winter vs. summer on emission rates. We will calculate cost of generation and use the model to dispatch plants based on marginal cost rather than capacity factor. We will attempt to link capacity factor data to the emissions data to use it rather than the calculated capacity factor for dispatching plants.

The model to date has included all plants in both the MAIN and MAPP regions, which extend considerably beyond Wisconsin's borders. Defining a subset of generators that are more likely to service Wisconsin could improve the model. We will interview utility dispatch experts to see if it is possible to identify generators serving Wisconsin. We could take a purely geographic approach and limit generators in the model to those that are physically close to Wisconsin. (The EPA data includes the latitude and longitude of all generators so we could map them and hand-pick within a certain range of the border.)

Conclusions

We believe that the primary value of this model for calculating winter and summer, peak and off-peak emission factors is twofold. First, the approach provides a tool to assist in planning Focus programs, and in fact complete portfolios of programs (e.g., residential and major markets). A more realistic understanding of how these environmental benefits "map" onto program measures/technologies and markets will assist the State in optimizing the distribution of energy efficiency public benefits. For example, programs delivering commercial HVAC projects would likely realize greater environmental benefits because they tend to operate during the shoulder hours when most emissions occur.

A second application of separate emissions factors for seasonal and peak/off-peak energy savings is in the cost-benefit analysis. As the avoided emissions from electricity generation are monetized for this analysis, we expect that a more accurate valuation of these environmental benefits will be produced.

References

Meyers, Stephen, and Jeff Erickson, Diane Fisher, Chris Marnay, and David Sumi. June 25, 2001. *Wisconsin's Focus on Energy Program—Pilot Study: Development of Emissions Factors for Quantification of Environmental Benefits (Final Report)*. Middleton, Wis.: PA Consulting Group, Inc.

New Jersey Clean Energy Collaborative, New Jersey Utilities, and the Natural Resources Defense Council. July 9, 2001. "New Jersey Clean Energy Collaborative Protocols to Measure Resource Savings." In *Program Compliance Filing–Supplement 1*. Board of Public Utilities.