Timing of Residential Electric Loads to Reduce Air Emissions from Power Generation

Michelle Rogers, GuoYao Xu, Carol Miller, Shawn McElmurry, Caisheng Wang

Wayne State University

ABSTRACT

Electric generators are often significant contributors of air emissions that cause environmental and human health hazards. Over the course of a day, power utilities must respond to changing demand by dispatching or shedding output from different generators. Each generator is associated with a unique profile of air emissions, based on the type of fuel consumed, installed pollution controls, and the generator's efficiency. Many older plants that are extremely inefficient by modern standards are still in service, and these plants produce far more emissions per kilowatt-hour generated than their modern counterparts. Clearly, the ability to shift electric demand to times when cleaner generation sources are available would result in overall emissions reduction.

Dynamic wholesale pricing in the electric power market, specifically the Locational Marginal Price (LMP), provides a means to estimate the marginal generator fuel type. This knowledge was used to roughly estimate local emission rates in real time. Based on estimated historical emission rates of five different pollutants, best and worst case timing schedules were determined for five household appliances and for the charging of electric vehicle batteries. The amount of reduction possible from worst to best case for appliances was about 70% on average for the five pollutants. For electric vehicle battery charging, the average emissions reduction from worst to best case varied from 10-20%, depending on type of charging available.

A smart phone app called HERO, or Home Emissions Read-Out, has been created to provide consumers with real-time emissions information at their fingertips. HERO serves to educate people and lets them take on a sense of personal responsibility for the emissions that result from their energy use.

OBJECTIVES

1. Estimate marginal emission rates based on LMPs
2. Determine the emissions that can be avoided by changing the timing of electricity.
3. Create a smart phone app that can provide consumers with real-time emission estimates.

BACKGROUND

ISOs, or Independent System Operators, act as a market place for wholesale power trading. ISOs publish LMPs for many node locations across the U.S.

LMPs represent the cost to produce and deliver the next marginal amount of energy at a location. This cost includes the cost of generation, losses, and constraint in the transmission lines. The next incremental increase or decrease in load will cause a change in output from the highest-priced, "marginal" generator.

LMPs are useful as a tool to approximate emissions because they are available at many locations and for many times. Historic LMPs are published for every hour, day-ahead LMPs provide a projection of the future day, and real-time LMPs are published at 5-minute increments.

When transmission lines are constrained, large variation in LMP is observed, and more than one marginal unit may exist at once.

LMP Contour Map-Aug 7, 2012. Midwest ISO. (High constraint observed)

LMP Contour Map August 30, 2012. Midwest ISO. (Largely unconstrained)

LEEM - LMP EMISSIONS ESTIMATION METHOD

When the system load and LMP change, this serves as a signal to the marginal generator to increase or decrease output. For any small change in demand, only the marginal generator's electrical output and resulting emissions are affected.

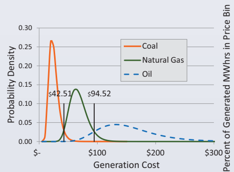
We have developed a model that estimates the marginal fuel type based on LMP. Then, air emissions from that marginal generator are estimated based on regional emission rates.

Outline of LEEM - LMP Emissions Estimation Method

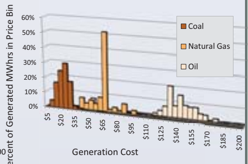
To link LMP to marginal fuel type, the generation cost of various fuel types must be determined. Fuel purchases from many fossil power plants (EIA 923) and plant efficiencies (eGRID) were used to plot probability density functions and histograms of the generation cost.

$$Marginal\ Generation\ Cost = Fuel\ Cost \times Plant\ Heat\ Rate$$

$$\frac{Cost\ (\$)}{MWhr} = \frac{Fuel\ Cost\ (\$)}{Quantity\ consumed} \times \frac{Quantity\ consumed}{MWhr\ output}$$

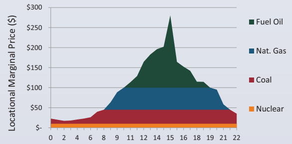


Log-normal distribution curves of fuel prices for generating plants in Midwest ISO, 2009.



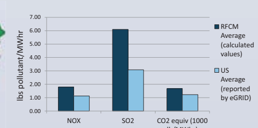
Histogram of fuel prices for generating plants in Midwest ISO, 2009.

Once generation cost ranges are determined for each fuel type, then the marginal fuel type can be estimated based on LMP.



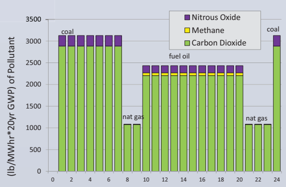
Marginal generator type estimates based on node in River Rouge, MI, July 16, 2008.

Emission rates are then estimated for each fuel type based on data reported for local plants in each eGRID subregion. It is important to use local rather than national averages, because fuel types and plant efficiencies vary greatly from region to region.



Avg. emission rates for subregion RFCM and entire US.

Emissions for every hour are predicted based on the marginal fuel type estimations, and the average emission rate for each fuel type.



Example of marginal emission estimates: Global Warming Potential (CO_2 equivalents) based on node near River Rouge, MI, July 16, 2008.

EMISSIONS FROM RESIDENTIAL ENERGY USE

Purpose of study: to determine whether timing of residential energy use can produce significant reductions in air emissions.

Base case: First five "typical" household appliances were defined.

Typical Household Appliances

Appliance	Frequency (d^{-1})	Cycle Length (hrs)	Power (kW)	Energy/cycle (kWh)	Intermittent (Y/N)	Preferred Time[a] Hr (1 - 24)
Water Heater	1.00	3.00	1.29	3.87	YES	4
Defrost Cycle	2.00	0.33	0.70	0.23	NO	1
Dishwasher	0.50	2.0	0.98	1.97	NO	22
Clothes Washer	1.00	0.5	0.61	0.31	NO	20
Clothes Dryer	0.86	0.75	4.59	3.44	NO	19

Then, best and worst case operating schedules for an entire year were determined based on the emissions estimates provided through historical LMPs. Based on the power draw of the appliance, and the emission rate during each hour that the appliance is on, resulting emissions for the entire year are tallied for the best case, and for the worst case.

$$Emissions\ (lbs) = Wattage(kW) \times Emission\ Rate(lbs/kwhr) \times Cycle\ Time(hrs)$$

Then, the percent change from the worst case to the best case is calculated for each pollutant.

$$Percent\ change = \frac{(Best\ Case\ ER - Worst\ Case\ ER)}{Worst\ Case\ ER}$$

where 'ER' is Emission Rate of a specific pollutant.

Then, the percent change from the worst case to the best case is calculated for each pollutant.

Change in emissions from worst case to best case, for entire household, node in Monroe, MI, 2009

Target Pollutant	SO2	NOX	CO2 Eq	Hg	Pb
Sulfur Dioxide (SO2)	-31%	-14%	-23%	-30%	-31%
Nitrous Oxides (NOX)	-25%	-56%	-22%	-23%	-26%
Carbon Dioxide Equivalents	-31%	-14%	-23%	-30%	-31%
Mercury (Hg)	-31%	-14%	-23%	-30%	-31%
Lead (Pb)	-31%	-14%	-23%	-30%	-31%

The timing of the charging of electric vehicle (EV) batteries was also studied. Four different charging options for an electric vehicle similar to the Chevy Volt were compared:

Electric Car Variables

Variable	Options
I. Charging level	a. The EV is charged with a US standard 120 VAC, 15 amp-max outlet. (Level 1)
	b. The EV is charged with an upgraded 240 VAC, 30 amp-max outlet. (Level 2)
II. Charging location/time	a. The EV is only charged at home, during the night.
	b. EV charging in the day at work or elsewhere (i.e., shopping mall) is also available.

Summary of EV charging scenarios. Change in emissions (reductions in green, increases in red) from worst to best case. Node in Monroe, MI, 2009

Charging Scenario	Average Reduction of Target Pollutant	Greatest reduction achieved by any pollutant	Least reduction achieved by any pollutant
Charging Level 1, Home Only	-10%	-16%	-2%
Charging Level 1, Anywhere	-12%	-18%	-1%
Charging Level 2, Home Only	-19%	-28%	+1%
Charging Level 2, Anywhere	-23%	-31%	-1%

RECOMMENDATIONS FOR FUTURE WORK

Emissions of five pollutants can be affected by the timing of electric demand for household appliances and EV battery charging. Selective timing reduced emissions of the target pollutant by about 60-70% if RT LMPs were used to create the schedule.

The amount of reduction of each pollutant depended greatly on which pollutant was chosen as the target pollutant.

To show what the impact would be if every household used selective timing, the results for 5 appliances were extrapolated and applied to the entire RFCM region. Using RT LMPs to schedule the appliances would result in 14% reduction on average for the target pollutant over the entire region.

Emission rates from charging of EVs depended on the type of charging available and whether charging could take place outside of the home. When more flexible charging options are available, greater impact on emissions can be realized by timing.

"HERO" – HOME EMISSIONS READ-OUT

HERO, or Home Emissions Read-Out, is a smart phone Android application that was created to provide simple "high" or "low" real-time emission information to consumers so that they can selectively time their electric demands to reduce emissions. The purpose is to bring greater awareness about emissions from electric power generation, and to affect change. HERO shows consumers that they have some control over the environmental impacts of their energy use.

Status: HERO is still being developed before being released to a wide audience. Capabilities are currently being added, such as showing two locations at once, and providing recommendations about emissions saved by shifting the timing of certain appliances.

HERO provides a preview of what may someday become the norm: smart meters, appliances, and home energy controls that work as a system to optimize emissions automatically and provide feedback that can be accessed anywhere via mobile device.

RECOMMENDATIONS FOR FUTURE WORK

Currently, our team is studying power system simulations to validate the LMP-to-marginal fuel type estimation.

To better compare various pollutants, it would be useful to monetize the environmental and societal/health effects, then emissions could be compared on a common (dollar) impact scale.

ACKNOWLEDGMENTS

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