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Quantifying Pollution Impact from New Generation and Demand-Side Management

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SUMMARY

Climate change and greenhouse gas emission have become drivers of new environmental policies for the power systems industry. The United States, amongst many other countries, has a long history of encouraging the addition of non-air-polluting resources such as Demand-Side Management (DSM) programs and non-emitting renewable generation. By virtue of DSM programs, decreased energy use can lead to system energy cost savings and air emissions reductions. Additionally, the use of non-emitting renewable generation – versus air emission heavy fossil fuel units – can provide substantial emission reductions.

However, determining the appropriate level of financial and policy support for these non-air-polluting resources require thorough understanding of their environmental impacts and associated costs and benefits. The ISO New England (ISO-NE) Marginal Emission Analysis (MEA) provides valuable information regarding environmental impacts, including marginal generator air emission rates and relating system operations. The goal of MEA is to quantify various historical generation emissions so that different stakeholders can use this information to address topics of their concern or interest, such as:

- How much emission reduction can be attributed from DSM programs and/or renewable generation programs, like Renewable Energy Certificates (RECs)?
- If a new generator (of any fuel type) is built and goes in-service, does it support the goal of emission reduction?
- Have or will policies demonstrate measureable benefits in emission reductions?

Since 1994, the ISO-NE MEA has informed wide audiences, including policy makers, resource developers, and energy consumers regarding generation air emissions. The MEA calculates marginal emission rates for nitrogen oxides (NO_X), sulfur dioxide (SO_2), and carbon dioxide (CO_2). It performs this calculation by using available energy market data to examine the emissions associated with marginal units. Marginal units represent the resources that respond to changing electric system demand by providing the next increment of energy at the lowest energy price. Marginal units are identified through the energy market's Locational Marginal Price (LMP) process. This process minimizes total energy costs for the entire New England region, while being subject to a set of constraints reflecting the physical limitation of the power system.

Resulting metrics include Marginal Emission Rates (lb/MWh) and identifying the Share of Time Fuel Types are marginal. These are presented over monthly or annual time periods in terms of on-peak, off-peak, or all hours.

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KEYWORDS
NO_X – SO_2 – CO_2 – Emissions – Demand-Side Management– Renewable Energy – Energy Policy – Locational Marginal Price

1. Background

There is a long history of regulatory bodies that examine and quantify the trend of greenhouse gases emitted by electric generators. Some of the first US DSM programs began in the 1970's [1]. The more recent incarnation of this historical trend is in the development of the US EPA Clean Power Plan. States, utilities and generator owners are already taking action to address the risks of climate change. The EPA's proposal seeks to further encourage these efforts of cutting pollution and protecting our health and environment, while maintaining an affordable, reliable energy system [2].

The draft Clean Power Plan was released in June 2014 and is scheduled to be finalized in 2015. The plan establishes state-by-state carbon emissions rate reduction targets. It aims to reduce US electric generation emissions by an estimated 30% below 2005 levels by 2030.

One of the first steps on the road to track compliance with the Clean Power Plan is to quantify the existing air emissions and potential benefits from developing new requirements or reduction programs. For example, consider a new 1 MW solar farm is built. How much emission does it reduce for the state? How does that compare to other new and more efficient fossil fuel generators? How can we determine its potential benefits?

2. ISO New England Marginal Emissions Analysis

The ISO-NE MEA results support the creation of well-informed, thoughtful, and achievable goals. The MEA examines the current New England emission environment and provides a reference of how added resources, whether air-polluting or not, impact the system.

ISO-NE has produced and evolved the Marginal Emissions Analysis (MEA) methodology since 1994. The advancement in information technology over the past decade has resulted in the availability of unit specific energy market data that were technically and economically unattainable in the past. In response, ISO-NE developed the Locational Marginal Unit (LMU) MEA methodology. This method uses available energy market data to examine the emissions associated with marginal units. Marginal units represent the resources that respond to constant changing electric system demand by providing the next increment of energy at the lowest energy price.

Furthermore, marginal units are identified through the energy market's Locational Marginal Price (LMP) process, which minimizes total energy costs for the entire New England region, while being subject to a set of constraints reflecting physical limitation of the power system. The LMP process will identity at least one marginal unit during each five-minute period. The number of marginal units per five-minute period is directly associated with the physical limitations on the power system, such as a transmission constraint. Each binding constraint will add an additional marginal unit. The MEA ultimately identifies the share of time each unit is marginal in each hour, month, and year.

Marginal units consist of different fuel and technology types, each with specific unit emission rates. Since marginal units can include non-air-polluting units (e.g. wind, solar, hydro, nuclear), a question is raised of the appropriateness to include them in determining the emission benefits from new resource or DSM programs. Including these non-emitting units would lower the marginal emission rate, in comparison to when non-air-polluting units are excluded. Whether the non-emitting units should be excluded from the group of marginal units is a decision that should consider the number and frequency that non-emitting units are marginal, how the results are used, etc. It may even be appropriate to include some non-emitting units while excluding some others. For example, a group of non-emitting units are marginal for just a determined period, due to special transmission maintenance, should be excluded. For illustration purposes, this paper only presents the methodology and associated results of including all LMUs.

When the marginal units are paired up with its individual monthly, on-peak or off-peak emission rates, the results are summarized to form various system emission metrics, such as the NO_X marginal emission rate during ozone season on-peak hours. The results also include the Share of Time Fuel Type is Marginal. Further studying the results can bring observations and estimates on the impact of different programs, such as additional renewable energy and DSM resources. Comparing different time periods can show the impact of implemented programs, such as DSM and renewable energy incentives.

ISO-NE conducts this calculation process annually and publishes the results in the ISO-NE Electric Generator Air Emissions Report. All electric generators dispatched by ISO New England are included. Emissions from "behind the meter" generators or those generators supplying energy to New England but are not located within the ISO-NE balancing authority area are not included.

This ISO-NE MEA methodology is used by New England Air Regulators and new generator developers, such as wind turbines and plug-in-vehicles, to examine and justify the benefits of different additions to the power system [3] [4] [5]. The methodology has also been recommended to be carried out in other parts of the US by Northeast States for Coordinated Air Use Management (NESCAUM).

3. Methodology

MEA is based on the Locational Marginal Units (LMUs) identified through the Locational Marginal Price (LMP) process, which minimizes total energy costs for the entire New England region, subject to a set of constraints reflecting physical limitation of the power system.

The unit-specific NO_x, SO_2 and CO_2 emission rates were based primarily on the U.S. EPA Clean Air Markets Division (CAMD) database and the actual megawatt-hours (MWh) of generation from ISO-NE.

It is also important to distinguish on-peak and off-peak hours, as industrial and commercial users may only provide load response during a traditional weekday. On-peak hours are defined as Monday through Friday from 8 AM to 10 PM; while off-peak hour is its complement. The MEA also distinguishes ozone and non-ozone season; ozone season runs from May 1 to September 30.

3.1 Step-by-Step Analysis

Step 1. Five Minute Periods

The LMP process reflects economic dispatch of the system, which occurs every five minutes. In these five minute periods, there may be physical limitations on the power system, such as a transmission constraint. For each binding constraint, there will be an additional marginal unit. This results in *n + 1 locational marginal unit* (LMUs) for every *n* binding constraints, in each five minute period. Table I shows an example of LMUs identified for one hour.

Five Minute Period	Locational Marginal Units (LMUs)
1/1/2010 12:00	Generator A, Generator B, Generator C
1/1/2010 12:05	Generator A
1/1/2010 12:10	Generator A
1/1/2010 12:15	Generator A
1/1/2010 12:20	Generator A
1/1/2010 12:25	Generator A
1/1/2010 12:30	Generator A
1/1/2010 12:35	Generator A
1/1/2010 12:40	Generator A
1/1/2010 12:45	Generator A
1/1/2010 12:50	Generator A, Generator B
1/1/2010 12:55	Generator A

Table I –Locational Marginal Units Identified in One Hour (Example)

Step 2. One Hour Periods

The percentage of time each generator is marginal in that hour is then calculated by

$$f(k) = \frac{\sum_{t=1}^{N} \frac{count(k)}{\sum_{i=1}^{units} count(i)}}{N} \quad (1)$$

For each hour, f(k) denotes the percentage of time k (the LMU) is marginal within the hour. N is the number of five minute periods in the hour. Applying Equation (1) to Table I's example will lead to Table II's results.

Generator	Percent Marginal
A	90.28%
B	6.94%
C	2.78%

Table II – Percent of One Hour Locational Marginal Units are Marginal (Example)

Step 3. On- and Off-Peak Hours

For each generator, the percentages calculated in each hour by Equation (1) are summed, and then organized by on- or off-peak hours and month. The distinction can be useful to quantify generators or DSM programs that are targeted for time period during the day, such as on-peak (high electric demand) hours.

Step 4. On- and Off-Peak Emission Rates

Once each units has its percentage marginal in on- and off-peak hours in all months, a monthly marginal emission rate can be found by

$$Monthly\ Marginal\ Emission\ Rate =$$

$$\sum_{k=1}^{marginal\ units} \sum_{h=1}^{on/off-peak\ hours\ in\ month} \left(\%\ of\ Unit\ Marginal_{k,h} \times Unit\ Emission\ Rate_{k,m,o}\right) \quad (2)$$

The monthly percent of time each generator is marginal is calculated and linked to the generator's month-specific on- and off-peak unit emissions rate. Generator *k* is identified to be marginal during hour *h*, and has a specific monthly on- or off-peak *o* emissions rate during month *m*.

Step 5. Annual Marginal Emission Rate

The All Hours LMU Marginal Emission Rate is calculated by combining the on- and off-peak in a weighted calculation of the amount of hours each month has in the year. This calculation can be done with respect to only on- or off-peak hours to create an annual on- or off-peak Marginal Emission Rate.

4. Results

Many useful metrics can be created through the MEA methodology and some examples are presented here. Please see the 2013 ISO-NE Electric Generator Emission Report for extensive results. [6]

Table III tabulates the 2013 NO_x, SO_2 and CO_2 marginal emission rates. It shows that on average, the New England system marginal resource that responds to system needs has a 0.34 lb/MWh NO_x emission rate, 0.55 lb/MWh SO_2 emission rate, and 930 lb/MWh CO_2 emission rate.

Ozone / Non-Ozone Season Emissions (NOx)					
Air Emission	Ozone Season		Non-Ozone Season		Annual Average (All Hours)
	On-Peak	Off-Peak	On-Peak	Off-Peak	
NO_X	0.32	0.21	0.35	0.43	0.34
Annual Emissions (SO_2 and CO_2)					
Air Emission		Annual			Annual Average (All Hours)
		On-Peak	Off-Peak		
SO_2		0.51	0.59		0.55
CO_2		921	937		930

Table III – 2013 Marginal Emission Rates (lb/MWh)

Figure 1 graphs the last five years of marginal emission rates to show the system trend. The SO_2 decrease is largely attributed to the decrease of coal- and oil-fired generation and increase of natural gas generation.

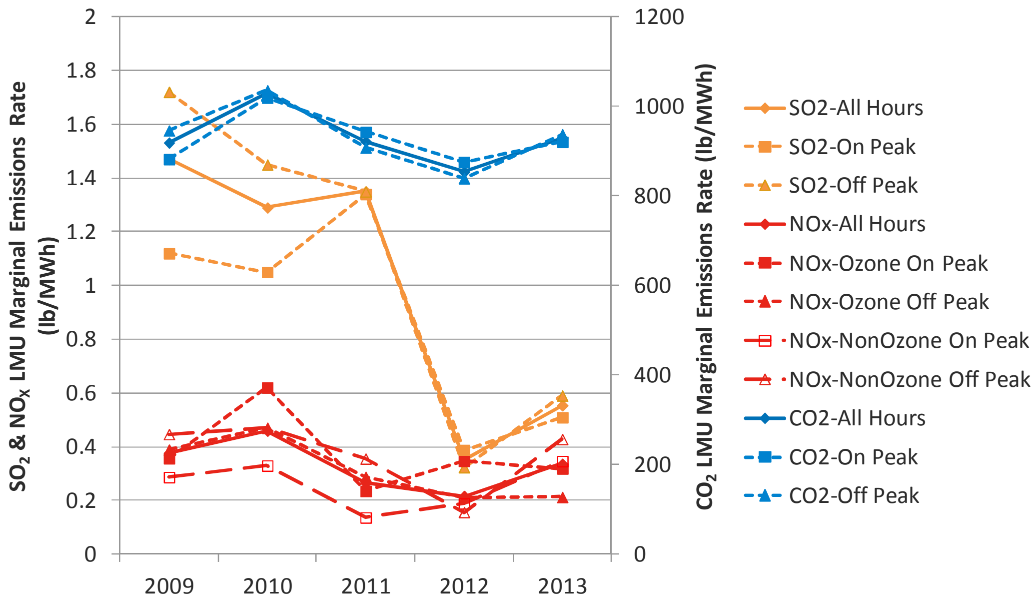

Figure 1 – 2009 – 2013 NO_X, SO_2, and CO_2 Marginal Emission Rates (lb/MWh)

To further explore the fuel makeup of these marginal emission rates, Figure 2 shows the historical percentages that each fuel type is marginal within a calendar year. It can be observed that natural gas has been the primary fuel type marginal in the last five years. But from 2012 to 2013, natural gas decreased, while coal and other renewables increased[1].

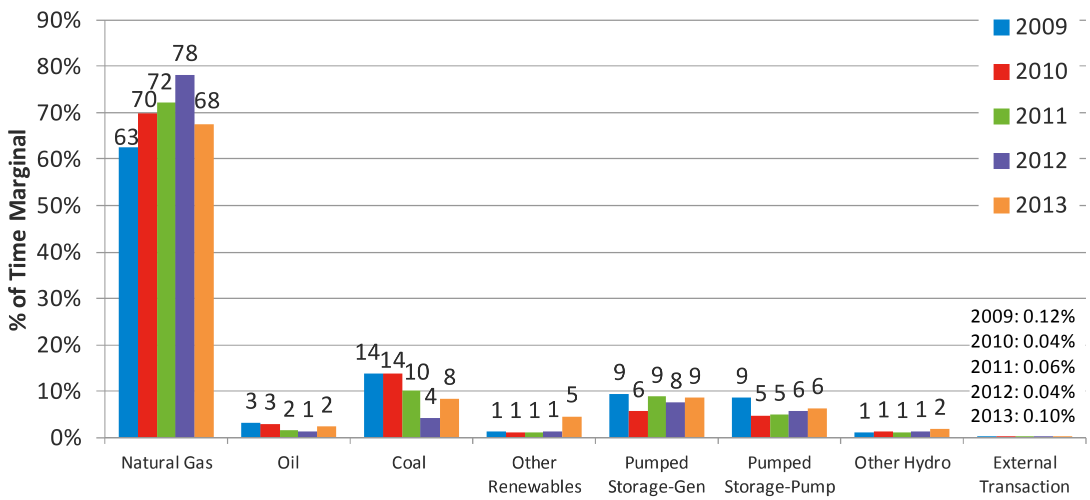

Figure 2 – 2009 – 2013 Share of Time Marginal by Fuel Type

In addition to annual results and observations, many factors within a year impact the marginal unit, e.g. the marginal emission rates. Figure 3 displays the monthly marginal emission rates and demonstrates how marginal emission rates can vary throughout the year. In New England, the winter and summer months are observed to have higher marginal emission rates. As a summer demand peaking region, New England relies on fast ramping units, such as gas and jet turbines to respond to

[1]The Other Renewables category includes landfill gas, biomass gases, wind, solar, refuse (municipal solid waste, wood and wood-waste solids, tire-derived fuels), and fuel cell. In 2009 – 2013, only wood/wood-waste solids unit(s) were identified to be marginal.

the high energy need. In the winter, lack of natural gas fuel supply (usually lower emissions) drives the system's need of reliable fuel and energy supply to coal and oil (usually higher emissions).

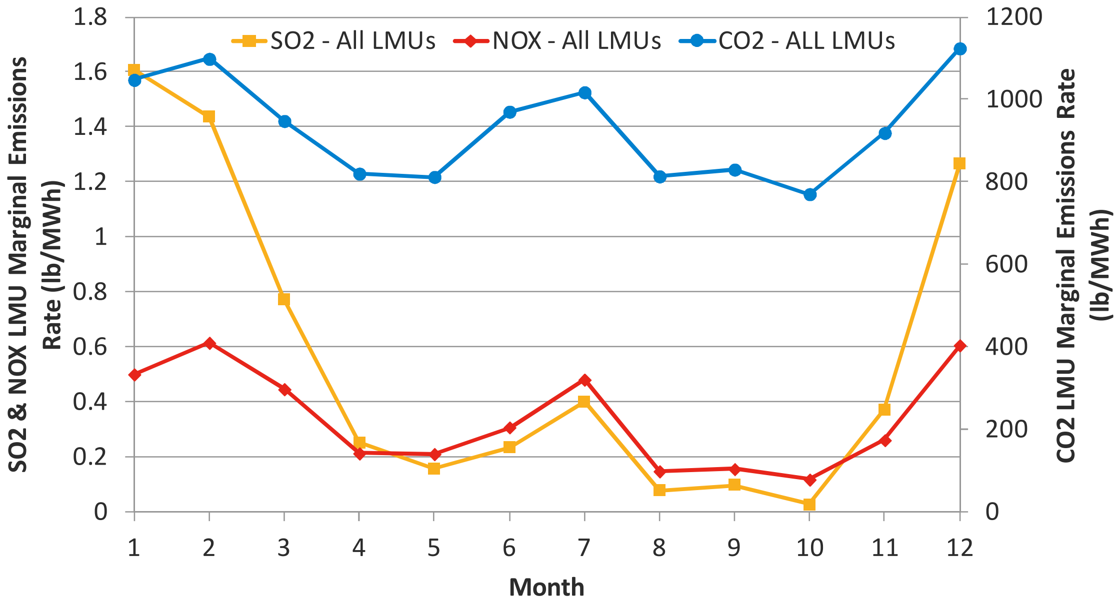

Figure 3 – 2013 Monthly Marginal Emission Rates (lb/MWh)

Figure 4 shows each fuel type's share of being marginal and month-to-month variations. It is useful to compare with Figure 3 to find the impact of different fuel types on the margin. For example, when natural gas generators are on the margin more (August, September, October), there are lower marginal emission rates. The inverse relationship can be seen in January, February, and December.

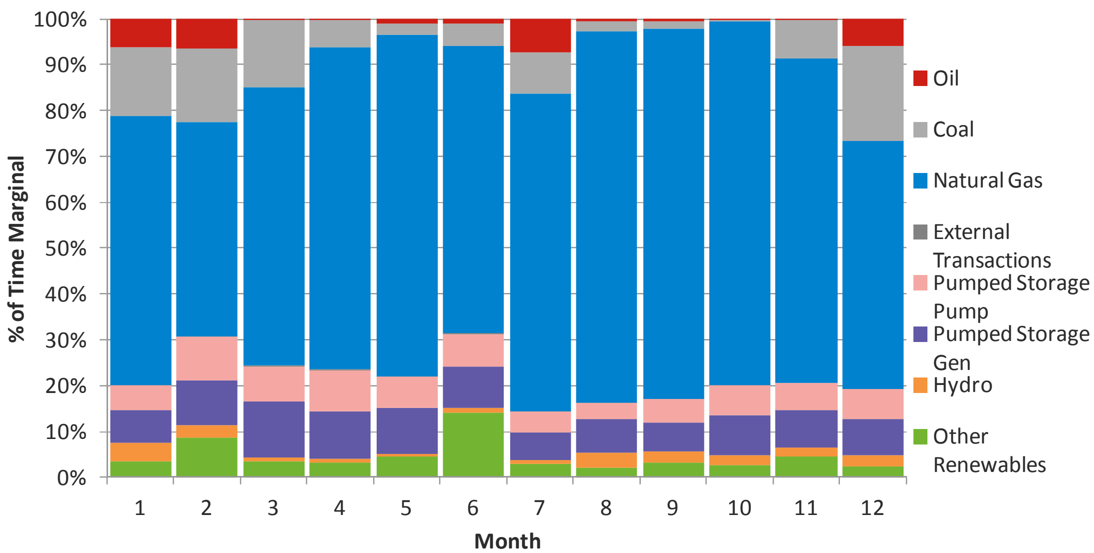

Figure 4 – 2013 Share of Time Marginal by Fuel Type

5. Application

Avoided air emissions can subsequently be calculated using the different marginal emission rates.

$$Avoided\ Emission\ (lb) = (Marginal\ Emission\ Rate - Resource\ Emission\ Rate)(lb/MWh) \times Generation(MWh) \quad (3)$$

Provided is an example of calculating avoided emissions for a 1 MW non-emitting renewable resource with estimated annual 3,500 MWh of generation.

	NO_X	SO_2	CO_2
System Marginal Emission Rate (lb/MWh)	0.34	0.55	930
New Resource Emission Rate (lb/MWh)	0	0	0
Avoided Emission Rate (lb/MWh)	0.34	0.55	930
Annual Avoided Emission (lb)	1,190	1,925	3,255k

Table IV – Calculated Avoided Emissions for 1 MW Non-Emitting Resource (Example)

The same calculation of avoided emissions can be conducted for an emitting resource. Table V demonstrates the process for a 200 MW fossil fuel (assumed natural gas turbine) generator with estimated annual 85,000 MWh of generation. This unit is expected to operate during on-peak (peaking) hours; therefore the On-Peak Marginal Emission Rates are used.

	NO_X	SO_2	CO_2
System Marginal Emission Rate (lb/MWh)	0.32	0.51	921
New Resource Emission Rate (lb/MWh)	0.20	0.01	1200
Avoided Emission Rate (lb/MWh)	0.12	0.50	(279)
Annual Avoided Emission (lb)	10,200	42,500	(23,715k)

Table V – Calculated Avoided Emissions for 200 MW Fossil Fuel Resource (Example)

The avoided emissions from one resource can be compared to the total system emissions (lb) to understand its impact. The system emissions are also presented in the ISO-NE Electric Generator Air Emissions Report. From Table IV, the calculated avoided CO_2 emission is 3,255k lb. That is 0.004% of the 2013 New England total system emissions. A program to encourage 500 MW of these non-emitting resources could aggregate the avoided CO_2 emission to 2% of the total New England system.

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