Estimating the Air Emissions of Fossil Fuel-Fired Stationary Engine Electric Generators under Two Megawatts in New York City, Westchester County, and New York State

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March 2019

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Acknowledgements

The Project Team, comprising of Pace Energy and Climate Center, Power Systems Research Inc., Dr. Sreekanth Venkataraman, Dr. Praveen Amar, and Daniel Leonhardt, would like to express our appreciation and thanks to the numerous individuals and organizations who assisted us in the development and execution of this report. We are particularly grateful to Environmental Defense Fund (EDF) for furnishing the financial resources that made this report and tool possible. Their efforts went well beyond a monetary contribution. Rory Christian, Marc Rauch, Elizabeth Stein, Beia Spiller and others at EDF expended a great deal of time and effort providing comments, questions, guidance and perspective that made for a much better final result.

The Project Team would like to express our gratitude to Natural Resources Defense Council's (NRDC) Jackson Morris and Miles Farmer for their provision of supplemental financial resources that allowed us to add additional emissions factors that weren't part of the original study design. At a time when the project team was being advised of the usefulness of extending the emissions matrix design to cover additional emissions factors, NRDC generously offered to provide supplemental funding that made those additions possible.

Several outside experts provided us important information and data that was essential to the design of the tool and the construction of the report. The New York City Department of Environmental Protection (DEP) was extremely generous with their time and assistance in providing information from their databases for our review and comparison. Geraldine Kelpin, Kit Liang, Krish Radhakrishnan answered numerous emails and phone calls. They performed several analyses comparing the engine generators on file in their database, vis-à-vis the PSR estimated inventory. NYC DEP configured their records into power size classes that were congruent with those provided by PSR.

William Slade and Kai Wu at Con Edison reviewed draft versions of our database, compared results to their internal records where some overlap might exist and provided us some very helpful insights. John Barnes, P.E. Chief, Stationary Source Planning Section, Division of Air Resources and Michael Sheehan Director, Bureau of Air Quality Planning at New York State Department of Environmental Conservation (NYSDEC) provided our Project Team with information over the course of several phone conferences and email exchanges.

Other individuals that provided us time, information, advice, and references included Vijay Ganugula at the New York Independent System Operator (NYISO), Michael Worden at New York Department of Public Service, and Iyad Kheirbek formerly at the New York City Department of Health. We are grateful to university experts, past and present, at University of California Riverside who patiently dealt with our questions pertaining to research that they had conducted over the years on emissons of certain types of stationary engine power generators. The development of our emissions matrix benefitted from technical specification sheets, prior research datasets, published reports, and informed observations that were provided to us by several individuals including Patrick Barrett and Scott Yappen at Caterpillar, Dr. Sandip Shah, Ani Natekar, and David Chou at the California Air Resources Board. We apologize for those individuals who we have forgotten to acknowledge here, who generously gave of their time, advice, comments and references in our preparation of the Excel Tool and associated report.

Any errors that occur anywhere in the report, or in the underlying databases that are the foundations for the Excel Tool and the scenarios that were analyzed are exclusively the responsibility of the Project Team and not of the many individuals who counseled and advised us in preparation of this work.

Executive Summary

This analysis provides several important insights and re-confirms certain prior research conducted by the Northeast States for Coordinated Air Use Management (NESCAUM) on a similar topic, more than a dozen years ago. One critically important conclusion is the strong evidence of a significant data gap when comparing information available regarding the stock of smaller-sized stationary engine generators in the electronic records of the State as contrasted with this report's estimated inventory of stationary generators based on several decades of engine sales information.

The estimated stock of operating engine generators, in the 1kW to 2,000kW power size class, is quite significant, totaling nearly 750,000 units. A very sizable share of that total are engines less than 25kW.

Power Range	Diesel	NatGas	Gasoline
<25 kW	553	51,028	633,845
25-150 kW	13,388	16,006	2,503
150-300 kW	10,521	1,074	120
300-450 kW	5,734	122	-
450–560 kW	893	190	-
560–1,000 kW	3,607	273	-
1,000–2,000 kW	3,133	274	-
Total by Fuel type	37,829	68,967	636,468
Grand Total			743,264

Table 1, Estimated Generator Installations by Size Class and Fuel Type.

However, even if one were to ignore the smallest power size class, 1kW to 25kW, there are estimated to be nearly 60,000 stationary engine generators in New York State between 25KW and 2,000kW.

Power Range	Diesel	NatGas	Gasoline
25-150 kW	13,388	16,006	2,503
150-300 kW	10,521	1,074	120
300-450 kW	5,734	122	-
450–560 kW	893	190	-
560–1,000 kW	3,607	273	-
1,000–2,000 kW	3,133	274	-
Total by Fuel type	37,276	17,939	2,623
Grand Total			57,838

Table 2, Estimated Generator Installations between 25kW and 2,000kW.

The information that is currently available in electronic State records represents a very small percentage of this estimated stock. The confidence level bounding the estimates based on the national sales totals from Power Systems Research (PSR) were not developed in this analysis. However, we can say with certainty that, for a variety of reasons, the information in the electronic records of the State will fall markedly short of the actual stock of stationary engine generators.[1]

The PSR estimated generator inventory sheds light on the stock of engines, their size, their vintage (age of installation) and their rough geographical location across New York State. This analysis has made that information significantly more valuable for policy analysis by conjoining the data with a matrix of emissions factors. The emissions factors are appropriate to models in years 1981-1990 (as one aggregate) and for each of the individual years 1991– 2016). The project team has included emissions rates for CO_2, NO_X, $PM_{2.5}$, PM_{10}, VOCs, and CO.

So, for example, a "cell", or an "observation" in the generator database is the estimated number of 1995, diesel engines, in power size class 150kW – 300kW. That cell can now be multiplied by a "vector" of emissions rates (CO_2, NO_X, $PM_{2.5}$, PM_{10}, VOCs, and CO) that are applicable and appropriate to the 1995 diesel engines in the 150kW to 300kW power size class.

All of this has been incorporated in an Excel Tool that allows users to perform a scenario analysis (i.e., change the number of run-hours of the DG or change the distribution of vintage – like "early retirement" of pre 1996 diesel engines, built before EPA's Tier 1, Tier 2, Tier 3 and Tier 4 rules).

By estimating the current and potential future emissions of small fossil-fired generators in New York State, we now have a benchmark for the quantity of the current emissions from these generators, and the potential impact on emissions from changes in the operation of these generators. This tool provides the gross emissions from the estimated installed generator inventory under various operating conditions. It does not include net impacts on other sources of emissions, such as offset grid emissions from fossil-fuel fired central station generation.

This tool provides the ability to examine numerous scenarios of generator use, regulation, or retirement across six criteria pollutants. In one scenario, we modeled the potential emissions changes resulting from a climate event. Our analysis found that a climate event would result in an annual increase in generator emissions of up to 128,772 metric tons of CO, 4,904 tons of NOx, 357 metric tons of PM, 15,556 metric tons of VOCs, and 865,524 metric tons of CO_2. This is the equivalent of the annual CO_2 emissions from 185,337 cars.

In a second scenario, we modeled the potential change in emissions resulting from two economic incentives for the operation of fossil-fired DG. One was an expanded demand-response program, and the other a critical peak pricing program. Our analysis found that an expanded demand-response program could increase fossil-fired DG emissions by up to 209 tons of CO, 423 tons of NOx, 38 tons of PM, 82 tons of VOCs, and 84,247 metric tons of CO_2. This is the equivalent annual CO_2 emissions of 18,040 passenger cars.

[1] See Section II.1.b, External Corroboration of the Estimated Generator Inventory

A critical peak pricing program could increase fossil-fired DG emissions by an extra 17,183 tons of CO, 164 tons of NOx, 34 tons of PM, 2067 tons of VOCs, and 59,799 tons of CO_2, or the annual CO_2 emissions of 12,805 cars.

The scenario analyses within this paper demonstrate just a few of the ways in which the tool can be used. There are many opportunities for future work with this tool, both in environmental policy applications as well as improvement to and enhancements of the tool itself, for example, attaching the tool to existing air quality models and sharpening its accuracy at sub-national areas.

I. Overview

I.1 Purpose of study

The provision of electric power to homes, businesses and industry via distributed generation (“DG”)[2] technologies has increased at a rapid pace over the last 10 to 15 years. New York has made the development of a distributed energy future a centerpiece of the Governor’s path breaking “Reforming the Energy Vision” initiative. Widespread deployment of DG holds the promise of delivering significant environmental and economic benefits as well as facilitating the development of a more efficient, reliable and resilient electricity system.

The environmental consequences of dramatic increases in distributed generation, however, have not been empirically examined. Because certain forms of DG have previously only run to a very limited extent, their emissions were not regulated closely. However, evolving markets and new rate structures could create incentives that encourage an increase in the operating hours of fossil-fired DG. Because the lax regulation relied on low run hours to control emissions, increased run hours could have a dramatic impact on their total emissions. Older vintage DG running on diesel fuel are likely to emit criteria pollutants[3] and greenhouse gases at rates per kilowatt hour generated that are far in excess of those of even coal fired plants.

Growing public concerns for reliability and resiliency are an additional factor spurring demand for the acquisition of smaller-sized stationary power generators. The proliferation of residential and small commercial generators, purchased after the several storms (Hurricane Irene, 2011 Halloween nor'easter, Hurricane Sandy) that hit the Northeast in 2011 and 2012, may also precipitate non-trivial environmental and public health damages when operated during outages of extended duration, particularly if the outages occur during high heat days.

New policy interventions may be required to mitigate the impact of smaller DG units, particularly if the use of such units is encouraged by new rate structures and market opportunities. Current federal, state and local regulations were targeted to a regime dominated by large central station generating units and as a consequence are not designed to comprehensively address concerns regarding the environmental impacts of increased usage of “dirtier” forms of DG. There are several plausible scenarios that could arise and may warrant regulatory intervention. One such plausible case is a larger number of high emissions DG units operating for significantly more hours per year. The collective impact, particularly in densely populated areas could trigger significant increases in local air pollutant emissions. Regulatory intervention might also be warranted if increased hours of operation of small diesel and gas powered generators make New York’s ambitious greenhouse gas goals more challenging to meet.

The opportunity for efficacious intervention is limited by a lack of good information about the stock, the vintage, the location and the emissions profiles of existing DG in New York City and State. The existing records on smaller-scale engine generators maintained at New York State Department of Environmental Conservation (NYSDEC) are quite limited. This data gap can impede our understanding of the potential

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[2] See Appendix 3, List of Defined Terms
[3] See Appendix 3, List of Defined Terms

local or regional impacts of current or increased operation of smaller-scale engine generators, and limits our ability to fashion optimally designed policies and operational guidelines for these generators.

In this study we have created an estimated inventory of fossil-fired distributed generators in New York State, the five counties of New York City, and Westchester County. While this is an “estimated” rather than an actual inventory, it provides a much more comprehensive source of data than is available in the State and local environmental information systems on the number and age distribution of engine generators, by power size classifications and fuel types. In the second stage of the project we have developed a detailed matrix of estimated emissions factors that correspond to each record in the estimated generator inventory. In the third stage, we have built an Excel modeling tool that matches each entry in the estimated generator inventory to a corresponding list of 7 emissions factors, and provides several features permitting the user to alter the underlying assumptions. This tool provides the gross emissions from the estimated installed generator inventory under various operating conditions. It does not include net impacts on other sources of emissions, such as offset grid emissions from fossil-fuel fired central station generation. In stage four, we have conducted a few proof of concept tests on the Excel Tool. We use the model to estimate the annual gross pollution contributions of this estimated inventory of distributed generators in these geographies, under baseline conditions and under two possible future scenarios.

I.2 Power System Research’s (PSR) Estimated Engine Generator Inventory

A key feature of this study is a new estimated inventory of DG units in service in New York State and select sub regions. The estimated inventory is derived from a unique database on North American engine sales. That information is provided by project team member Power Systems Research (PSR), an organization with extensive background and experience in conducting market research analysis of power system equipment. PSR originally began conducting research on estimated generator inventories to provide engine manufacturers with market studies and accurate statistics of engine sales. This led to the development of the first estimated database of North American engine sales.

Since 1980, PSR has conducted targeted surveys, developed industry relationships, and accumulated market knowledge. They have continuously used these studies to refine their methodology for estimating the inventory of engines for states, regions and sub-state areas. This estimated generator inventory (hereafter “estimated inventory”) fills significant information gaps that exist in state air permitting records, allowing a more robust assessment of the air emissions of fossil-fired DG. It is especially insightful in providing information on the rising adoption of unpermitted residential home generators through their quarterly surveys. PSR’s engine generator estimated inventory serves as the basis for the plausible use scenarios conducted by the other principal investigators on the team.

This is not the first time that the PSR PartsLink™ database has been used to develop state and regional estimates of the installed base of smaller-scale engine generators. PSR has prepared sub-national estimated databases for private sector and public sector entities over the years. In so doing, they have evolved and refined a set of methods and procedures for utilizing industry, economic and sectoral data to allocate the national database to sub-national areas. For a detailed discussion of the methodology used for creating New York State and sub-state estimates from the PSR PartsLink™ database please refer to Section II.1.a of this report.

I.3 This Project's Relationship to the 2003 NESCAUM Study

The last broad-based estimated engine inventory of DG in the Northeast was published in a study conducted by NESCAUM in 2003. [4] NESCAUM inventoried the number of diesel-fired DG units in the Northeastern States. There has been no similar inventory undertaken in the intervening period of more than a dozen years. The 2003 NESCAUM project team included Power Systems Research (PSR), who served as subject matter consultants and provided an estimated inventory of diesel generators by state.

In many ways, the focus of and the motivation for the current study are very similar to the 2003 NESCAUM study. The 2003 NESCAUM study, however, had a much larger geographic extent, in that it covered eight Northeastern states. The NESCAUM study focused only on the inventory of commercial and industrial diesel engines, whereas this report includes gasoline and natural gas-fired engines, and includes residential engines. Both studies provide data useful for ascertaining the environmental/air pollution impacts from utilizing smaller-scale electric generators to meet the needs of customers and the electric grid during emergencies and peak load situations.

Similar to the current study, the 2003 NESCAUM report used the PSR approach as the foundation for estimating a diesel engine inventory. The 2003 report compared the resulting PSR engine inventory to information in the member states' stationary source permits files. The current study also looks at PSR inventory data and compares the PSR estimates to information that is recorded in the electronic records of New York State as well as New York City stationary source permits data, to the extent that common and overlapping information in comparable size classes is available.

There were no overlapping records available at NYC DEP for engines under 40kW. There is overlapping but not complete information in the 25kW to 50kW PSR size class, because DEP data covers only that portion in the 40kW to 50KW size class.

The project team shared the estimated engine generator inventory with experts at several external organizations, including the New York State Department of Environmental Conservation (NYSDEC) and the New York City Department of Environmental Protection (NYC DEP), as described in detail in Section II.1.b.

Over the intervening period of 15 years that separates the 2003 NESCAUM study from this project, PSR's national estimated inventory database has grown much more robust, with greater granularity across size class and fuel types. PSR has developed a far more sophisticated understanding of market structure and dynamics, acquired from quarterly surveys and other market research data. This accumulated body of knowledge and experience results in the construction of a superior set of estimates compared to those produced in 2003. Adding PSR's improved database to the additional scope of generator sizes and the more specific geography provides the foundation for a much more detailed analysis than the 2003 NESCAUM study.

In another critically important area, this study is more detailed and comprehensive than the 2003 NESCAUM report. The current study has developed a more thorough and all-inclusive emission factors matrix. The 2003 report used a set of highly averaged emission factors. This study incorporates and applies emission factors based on EPA and state regulations as they have evolved over the years. Where

[4] Stationary Diesel Engines in the Northeast: An Initial Assessment of the Regional Population, Control Technology Options and Air Quality Policy Issues

appropriate emissions factors were not available, the project team sought the advice of industry experts and gathered information from manufacturer specification literature as well as published data from peer reviewed academic journals. The emissions matrix in this analysis is far more inclusive. The 2003 study utilized highly averaged emission factors for diesel engines only and for just three pollutants; NOx, PM10, and VOCs. This study has developed an emission factors database for three fuel types: diesel, natural gas and gasoline. This report encompasses emissions rates for the three pollutants covered in the NESCAUM study, NOx, PM_{10}, and VOCs and expands coverage to include PM_{10}, $PM_{2.5}$, CO, as well as CO_2[5]. The superior depth and breadth of coverage of the emissions factors database in this report should yield policy scenario estimates that are more accurate and capable of generating a more comprehensive set of outcomes across pollutant types.

I.5 Uniqueness of this Approach

This study is unique in several aspects. Central to the project is its utilization of a proprietary estimated engine generator inventory from PSR that is disaggregated by 7 power size class, 3 fuel types, date of engine installation, and i imputed geographical location. The PSR estimated inventory provides a window into the population of engine generators that is inaccessible with state and local permit data alone.

This database, in our estimation, is a powerful tool for assessing important policy issues pertaining to distributed fossil fuel generators. PSR combines this database with information from its quarterly telephone surveys, its knowledge of the generator manufacturing and parts industries, and data from the U.S. Census Bureau. PSR uses a methodology similar to the methodology it uses for breaking out the state-level inventory from national sales figures, to segment the estimated in-service generator population for New York State into estimated generator populations for New York City and Westchester County.

To create an effective tool for understanding air emissions, we joined the PSR estimated inventory with a matrix of air emissions factors which were collected from data sources including federal regulatory agencies, academic institutions, and engine manufacturers (as described in Section II.3). The emissions factors matrix contains entries for certain criteria air pollutants (NO_X, PM_{10}, $PM_{2.5}$, CO, and VOCs)[6] as well as a CO_2 emission rate for every fuel type (diesel, natural gas, and gasoline), seven power size class (1-25kW, 25-150kW, 150-300kW, 300-450kW, 450-560kW, 560-1MW, 1MW-2MW) and year (from 1990 – 2016).

An entry, or cell, in the PSR estimated engine generator inventory is defined by its fuel type, its power size class and its year of installation. For example, the number of diesel engines in the 1MW – 2MW size class, installed in 1990, that are still in operation in New York City, would represent a “cell.”

This cell will have associated with it a set of air emissions characteristics. That is, for 1990 diesel engines sized at 1MW to 2MW there will be an emission rate for each pollutant. All emission rates are expressed in grams per kWh of electrical production.

[5] See Appendix 3. List of Defined Terms
[6] See Appendix 3. List of Defined Terms

I.6 Potential Scenarios of Concern

The study team proposed the development of three detailed scenarios. One scenario would be a reference or base case scenario. A key determinant of the level of emissions from fossil-fired DG units is the number of run-hours of these units. The reference case establishes a lower bound for the expected value of run-hours.

There are several plausible scenarios which may warrant regulatory intervention, including the reference scenario of current operation. One potential future scenario could be increased proliferation and run-time of residential and commercial emergency generators in response to natural disasters, such as Superstorm Sandy that impacted New York City, Long Island, and New Jersey in 2012. This would be especially harmful to communities that are located in existing non-attainment zones for air quality and exacerbated if the long-term outage was coincident with high cooling degree days. Another potential scenario is the possible increase in the deployment of demand-response or the introduction of critical peak electricity pricing. Large numbers of commercial or emergency generators could increase run time if demand-response or critical peak pricing makes it sufficiently economically beneficial.

I.6.a Reference Case Scenario

Our analysis begins with construction of a "reference case" that is based upon a set of key assumptions regarding the annual hours of operation of generators in the estimated inventory. This set of assumptions, when embedded[7] in an Excel Tool that combines an estimated engine generator inventory and air emissions matrix, will provide the capability of creating a variety of scenarios, that can estimate the changes in the annual air emissions (expressed in tons per year) that result from changes in the hours of operations from the reference case.

The reference case scenario assumes that non-emergency DG units are only run for their intended use, and that emergency DG units are run solely for regular testing and emergency events. This scenario is operationalized within the model by first creating a set of assumptions on the duty cycle of the generators by size and fuel type. We determined stationary generator use typically falls into three categories: emergency backup, baseload, and peaking. Emergency generators typically only operate in the event of a grid outage or for testing. Baseload generators are used the majority of the time, with some variation based on daily or weekly operating hours, or seasonal energy needs. Peaking generators are any non-emergency engine with intermittent use, whether that is enrollment in an official demand-response program, in load-following operation without enrollment in a formal program, or used on a site with a varying electric demand. We then assigned expected hours of operation associated with each duty cycle. Section II.4 of the report provides a detailed description of the development of the reference case.

[7] As explained in greater detail in Section III. the tool is designed so that scenario analysis can be readily conducted by user made changes to key assumptions, such as the run-hours by duty cycle of the generators (emergency, peaking, baseload) or by the proportion of engines within each fuel type, that are estimated to operate as either emergency, peaking or baseload generators

I.6.b. Outages of Extended Duration Due to Weather Events

According to a 2015 study by Lawrence Berkeley National Laboratory and Stanford University, the duration of outages due to catastrophic weather events is likely to increase in the future.[8] According to the same study, a 5% increase in the average wind speed resulted in a 56% increase in the number of hours a utility's customer went without power. Taken together, a plausible scenario for model testing is an increase in total hours of DG operation as a consequence of an increase in the frequency and the duration of weather events that result in power outages of extended duration.

To construct a *proof of concept* model demonstration utilizing this case, we incorporated empirical information on outages from the New York Department of Public Service (NY DPS), advice and guidance from experts, and reference to research and reports from interested parties and stakeholders. The precise methodology for how the power outages in NY State and its sub-regions are translated into a revised set of assumptions is elaborated more thoroughly in Section III of the report. The model is run with the base set of assumptions, and then run a second time with the revised assumptions that represent a change in frequency and severity of storms that reflect a potential increase in grid outages from historical averages.

I.6.c. Potential Gross Increased DG Emissions Due to Economic Incentives

In this scenario, we considered economic incentives to operate fossil-fired DG units under 2 MW that may result from time of use or time variant pricing. The Project Team, in consultation with subject matter experts and regulators, determined that this would be most likely to affect commercial generators through an expanded demand-response ("DR") program, and most likely to affect emergency generator operation through critical peak pricing.[9]

Historically regulators have been able to exercise oversight and control of local generation in part because the generators were large in size and small in number. While some customers have had emergency and backup generators, under average pricing there are few opportunities to gain economic advantage by running them. DR programs have been in existence for some time, but the participation of fossil-fuel-fired distributed generation has been tightly controlled in these DR programs.[10] A move to time-variant pricing or an increase in the need for DR may encourage non-trivial increases in the run-hours of fossil-fuel-fired DG, potentially during the hottest days of the year.[11]

To construct a *proof of concept* model demonstration utilizing this case, we estimated the potential response to an expanded DR program, as well as the potential response to the implementation of statewide critical peak pricing. We calculated the effect on average run-hours for certain engines both programs may have, and modeled operation under both programs to determine the range of both programs' potential impact on emissions from fossil-fired DG.

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[8] Larsen, P., LaCommare, K., Eto, J., Sweeny, J. "Assessing Changes in the Reliability of the U.S. Electric Power System." Lawrence Berkeley National Laboratory, August 2015.

[9] These are specified fully in the Section III.2, Scenario 2 Analysis.

[10] 6-NYCRR III A 222; 40 CFR 60 Subpart IIII

[11] NYISO system peak is on high heat days due to the need for air conditioning. These are the days when central-generation peaker plants are most likely to be running, as well as DG peakers. High heat days are also when ground-level ozone is most likely to form as a matter of atmospheric chemistry, making the increased emissions of CO, NOx and VOCs especially harmful.

II. The Essential Components of the Study (Engine Inventory, Emissions Matrix, Excel Tool)

II.1. Describing the Estimated Engine inventory

The foundation of this analysis is the PSR Engine Generator Estimated Inventory. It estimates the existing in service population of stationary engine generators in New York by power size class (7), fuel type (3), year of installation or "vintage" (27), and geographic location (7).

The 7 power size class include the following:

1kW to 25kW

25kW to 150kW

150kW to 300kW

300kW to 450kW

450kW to 560kW

560kW to 1,000kW

1,000kW to 2,000kW

The 3 fuel types associated with the estimated generator inventory are:

Natural gas,

Diesel, and

Gasoline

There are 27 distinct dates of installation, or "vintage" characteristics associated with the estimated generator inventory:

In service year of installation 1991, 1992, …, 2015, 2016 (26 distinct categories), and

In service year of installation – 1990 and before (one distinct category)

The geographic location of the estimated generator inventory is estimated for 7 areas:

Bronx, Kings, New York, Queens, and Richmond counties (comprising New York City),

Westchester county, and

Rest of New York State (the remaining 61 counties of New York State: excluding the 5 counties of New York and Westchester County)

For purposes of scenario analysis, the geographic locations are aggregated into the following 3 categories:

New York City (the sum of the 5 counties)

New York City plus Westchester (Con Ed Service Territory)

Rest of New York State

II.1.a Methodology for Constructing Estimated Generator Inventory

This is an explanation of the methodology used by Power Systems Research (PSR) to develop an estimate for the 2016 installed base of generators in New York State, New York City, and the six counties in the Con Ed Service Area, by generator power range, fuel type, and vintage. Power Systems Research is a respected leader in market intelligence for the power equipment industry. As the foundation, PSR used its PartsLinkTM database, an estimated national inventory of installed generators based on decades of data collection, market research and industry experience.

PartsLinkTM provides a national overview of the estimated total number of in-service generators by each power range and fuel type. Seven power ranges are included in the estimate, ranging from less than 25 kilowatts at the low end to 1-2 megawatts at the high end. The three fuel types are gasoline, diesel and natural gas. PartsLinkTM also contains data on generator retirement and average generator lifespan by power range and fuel type, enabling PSR to allocate the installed number of generators in each power range and fuel type to each vintage. In order to determine New York State's share of the national PartsLinkTM inventory, PSR combined PartsLinkTM data with data from quarterly PSR telephone surveys, PSR's knowledge of the generator manufacturing and parts industries, and data from the U.S. Census Bureau, all as described in more detail below. PSR then used a similar methodology (described briefly below) to segment the in-service generator population for New York State into estimated generator populations for New York City (further broken down by each of the five New York City counties), the Con Ed Service Area (the five counties of New York City plus Westchester County) and the balance of New York State.

Methodology for Determining Generator Vintages

PSR tracks generator retirement at the national level in PartsLinkTM. This estimate of the distribution of generator vintages by size class and fuel type is based on manufacturers' anticipated useful life for their generators, and PSR's decades-long collection of data on generator retirement rates. PSR has performed many studies for industry clients on product lifespans and replacement intervals. As a result PSR is able to produce an estimate of the national installed generator database by vintage as well as by power range and fuel type.

Methodology for Installed Commercial Generator Base

(a) Separating Commercial and Residential Generators

PSR started with its national database of in-service generators from PartsLinkTM, then allocated the national total between commercial and residential use for each combination of power range and fuel type. Commercial generators have a range of uses including providing base load, peaking, and as emergency back-up. Residential generators are currently used as emergency back-up only. Based on PSR's industry knowledge, it estimated that 73% of gasoline generators under 25kW and almost all natural gas generators under 25kW are residential emergency generators.

(b) Determining New York State's Share of National Commercial Generator Inventory

PSR disaggregated its national inventory of commercial generators to the New York State level by relying on U.S. Census data and data acquired from past studies, surveys, and market experience. First, PSR used its knowledge of generator usage in relation to U.S. Census business statistics to create two correlation tables. The first correlation table allocates generators within each power range by business size. The second correlation table estimates the likelihood of a business in a certain industry using a generator of one of the three fuel types.

PSR used two U.S. Census business statistics to construct its national correlation tables for power range and fuel type, and a third U.S. Census business statistic to determine the number of generators in each power range and of each fuel type that should be allocated to New York State.

To construct the first correlation table matching generator power range to business size, PSR used U.S. Census business size categories defined by number of employees. The U.S. Census has nine size classes ranging from one employee at the smallest to 1,000 employees and over at the largest. The U.S. Census data identifies the total number of businesses in each size class nationally. This enables PSR to estimate the portion of each generator power range attributable nationally to each of the nine business size classes.

To construct the second correlation table matching generator fuel type to business type, PSR used U.S. Census data which classifies all U.S. businesses into one of eighteen categories (manufacturing, health care, multi-family housing, etc.). Combined with their industry and survey data, this enables PSR to estimate the demand for generators of each fuel type among the eighteen business types at the national level. Combining this estimate with results from the first correlation table matching power range to business size and with its own industry knowledge, PSR is able to create an estimated national commercial generator inventory by power range, fuel type, vintage, business size, and business type.

Finally, in order to determine New York State's share by power range and fuel type of this estimated national commercial generator inventory, PSR used U.S. Census annual gross pay figures for each business size and business type. The U.S. Census tracks annual gross pay in each state by business size and business type. Comparing annual gross pay data by business size and business type nationally to annual gross pay data by business size and business type for New York State enables PSR to estimate New York State's share of the estimated national commercial generator inventory broken down by power range, fuel type and vintage.

Methodology for Installed Residential Generator Database

As with commercial generator installations, PSR started with a national installed, in-service base of generators from its national PartsLinkTM database. PSR then referred to its quarterly PowerTrackerTM phone survey of generator owners, conducted since 2002, which captures the percentage of residential generator ownership among single-family households in each state. When the percentage of residential generator ownership among single-family households in New York State is combined with U.S. Census data on the number of single-family homes in New York State, the result is an estimate of the number of residential generators in New York State, as well as an estimate of New York State's percentage share of the national inventory of residential generators.

Methodology for Installed Generator Databases for New York City, the Con Ed Service Area and the Balance of New York State

(a) Commercial Generators

In order to create an estimated commercial generator inventory for New York City (consisting of the five counties of New York, Kings, Queens, the Bronx and Richmond), and an estimated commercial generator inventory for the Con Ed Service Area (consisting of the 5 New York City counties plus Westchester County), PSR used the same methodology described above that was used to create an estimated commercial generator inventory for New York State, but on a county-by-county basis, then added together the results for the 5 counties (to create the estimated inventory for New York City) and the 6 counties (to create the estimated inventory for the Con Ed Service Area).

In order to create the estimated commercial generator inventories on a county-by-county basis, PSR used the same correlation tables (matching power range to business size, and matching fuel type to business type) described above.

To complete the estimated commercial generator inventory on a county-by-county basis, PSR compared annual gross pay by business size and business type in each of the six counties to annual gross pay be business size and business type in New York State. This enabled PSR to estimate the installed base of generators in each of the six counties by fuel type, power range, and vintage.

(b) Residential Generators

PSR used a methodology similar to the methodology for the New York State residential emergency generator installations estimate (described above) to develop its estimate of residential emergency generator installations in New York City and in the Con Ed Service Area.

Starting with the New York State estimate of residential emergency generator installations, PSR used PowerTrackerTM quarterly phone survey data along with U.S. Census Bureau data concerning the number of single-family homes in each of the six counties (New York, Brooklyn, Queens, Bronx, Staten Island, Westchester) to develop an estimate for the number of residential generators in each of the six counties. Summing the results for the five counties of New York City provides the estimated residential emergency generator installations in New York City by power range, fuel type and vintage. Summing the results for all six counties (the five counties of New York City plus Westchester County) provides the estimated residential emergency generator installations in the Con Ed Service Area by power range, fuel type and vintage.

(c) Commercial and Residential Generators in the Balance of New York State

For commercial generators, both the New York State and county-level estimated installed generator inventories are based on the same correlation tables matching power range to business size and matching fuel type to business type. The U.S. Census data is consistent as well, as New York State census data is an aggregate of individual county level census data. Therefore, the difference between the estimated New York State commercial generator inventory and the estimated commercial generator inventory for the six counties constituting the Con Ed Service Area equals the estimated commercial generator inventory for the balance of New York State.

For residential emergency generators, both the New York State-level census data on single-family homes and the PowerTrackerTM quarterly phone survey results are based on individual county-level data and are therefore consistent. Accordingly, PSR estimated the installed residential emergency generator base for the balance of New York State by subtracting the installed residential emergency generator base for the six counties constituting the Con Ed Service Area from the installed residential emergency generator base for New York State.

II.1.b External Corroboration of the Estimated Generator Inventory

The Project Team conducted initiatives to cross check the estimated generator inventory with data on the existing stock of generators in New York City, each of the five counties constituting New York City, and New York State. The team identified and vetted with EDF several outside experts associated with key state and City regulatory authorities or interested agencies, as well as knowledgeable staff at Con Edison.

The Project Team engaged in numerous interactions, by e-mail and phone, with experts at NYC DEP, NYS DEC and to a lesser extent with Con Edison, NYSERDA, and the City of New York.

There was sufficient information available to us from NYC DEP that we were able to conduct some comparisons, shown in Table 3. The NYC DEP data records could be configured to conform with 5 of the 7 power size classes in the PSR estimated inventory. For those 5 power size classes, and, on an all New York City basis, with just one exception, the PSR estimated inventory was considerably greater than the NYC DEP data. In the 150-300kW range, the NYC DEP generator count was 26% of those in the PSR estimated generator inventory. In the next power size class, 350-450kW, the NYC DEP count was 29% of the PSR estimated inventory in that size class. The next size class represents an anomaly in the trend and magnitude of the other power size classes. The NYC DEP data in the 450 – 560kW range, exceeds the PSR estimates by a small amount (7% greater). In the remaining size class, the pattern found before is maintained (ie. that PSR estimates are greater than NYC DEP estimates, and, that as the engine generators get larger, the NYC DEP estimates get closer to the PSR estimates). Thus, in the 560-1,000kW range, NYC DEP data is 42% of the PSR estimated inventory, and in the next and last power size class, 1,000 to 2,000kW, that difference narrowed to 58% of the PSR estimated inventory.[12]

[12]. The confidence level bounding the estimates based on the national sales totals from Power Systems Research (PSR) were not developed in this analysis. However, the difference between all estimates and permitted data aside from the 450kW-560kW size class are well outside any reasonable margin of error.

Comparison of PSR Estimated Inventory to NYC DEP Data

		Generators in DEP Database	Generators in PSR Database	NYC DEP Generators as a Percentage of the PSR Estimated Inventory
All New York City	150 - 300 kW	**1,245**	**4,776**	**26%**
	300 - 450 kW	**726**	**2,479**	**29%**
	450 - 560 kW	**429**	**402**	**107%**
	560 - 1000 kW	**776**	**1,836**	**42%**
	1000 - 2000 kW	**1,036**	**1,789**	**58%**
New York City	**Total**	**4,212**	**11,282**	**37%**

Table 3, Comparison of NYCDEP Permits and PSR Estimated NYC Inventory

On average, across all 5 counties of New York City, for those power size classes where the NYC DEP data can be configured into similar size classes as the PSR data, we find that the generators identified in the NYC DEP electronic records database are about 37% of the total in the PSR estimated generator inventory. Though, with the exception of the 450-560kW, the larger the size class, the smaller the discrepancy is between the DEP permit data and the PSR estimated inventory. However, the difference is still quite high.

This outcome re-confirms a finding of the 2003 NESCAUM study: that the count of smaller-scale engine generators in the permit records of the Northeast states, fell far short of the total engine generators in the PSR estimated inventory. At that time, the analysis found, that on average, across the nine NESCAUM states, the number of engine generators in the state permit files were about 34% of the PSR estimated inventory. In the NESCAUM study, there was one anomaly among the 9 states. The State of Maine reported 18 (3%) more generators in their State Permit records, than were estimated by PSR. For the other 8 states the count of generators in the PSR estimated inventory as compared to those listed in state permit records, ranged from just 11% of the PSR generator estimate for New York State to 69% of the PSR estimate for the state of New Jersey. The results from the NESCAUM Report are reproduced in Table 4.

Table III-3

Comparison of PSR Estimated Generators and State Permit Records

DATA SOURCE	CT	ME	MA	NH	NJ	NY	RI	VT	Total
PSR Estimated Generators	3,223	560	5,027	743	8,415	15,037	363	310	33,678
Generators in State Permit Records	1,721	578	1,104	360	5,823	1,662	72	66	11,386
% of PSR Estimates in Permitting Records	53%	103%	22%	48%	69%	11%	20%	21%	34%

Table 4, Comparison of 2003 PSR Data and State Permits. Source: NESCAUM report Page 17

The NESCAUM report identified several reasons for the discrepancy between generators in state permit records as compared with PSR estimated generators. One is that the present size threshold for reporting fails to capture many of the smaller stationary engine generators, particularly at the state level (NYS DEC). In the case of stationary engine generators operating under Emergency exemptions, the State does not have electronic records for each individual unit. In fact, during this project we were told that NYS DEC has electronic records for approximately 700 sites that are either Title V or State Facility Permit sites.[13]

Another reason for discrepancy with permit data is that some small generators are included in the permits of larger facilities (Title V / State Facility permits). However, the number of small generators that are required to register if they are located at a larger facility account for a very small fraction of the sites with generators. The NYS DEC registrations for smaller emissions sources include another 9,000 or so sites, though not all are stationary generators. In our conversations with air regulatory experts at NYS DEC we were told that a large proportion of these records are not accessible electronically.

The New York City DEP was extremely generous with their time and assistance in providing information from their databases for our review and comparison. They performed several analyses comparing the engine generators on file in their database, vis-à-vis the PSR estimated inventory. NYC DEP configured their records into power size classes that were congruent with those provided by PSR. The NYC DEP filing threshold is 40kW. Therefore the information requested omitted the <25kW power size class, and the 25kW to 150kW power size class for which PSR provided an estimated inventory. As noted above, the count of generators in the NYC DEP database, as compared with the number of generators that PSR estimated for the same geographic area, was found to be about 37% (4,212 permitted by DEP compared to 11,282 in the PSR estimated inventory) for engines in power size classes from 150kW up to 2,000 kW.

II.2. The Emissions Factors Matrix

As a descriptive tool, the generator estimated inventory can provide insights into the stock of engine generators in service within particular geographic areas. To convert this descriptive tool into an instrument for policy analysis requires further steps.

Policy questions can be addressed by associating with each observation in the engine generator estimated inventory a set of air emissions rates. The project team developed a detailed matrix of air pollution emissions rates unique for each size class, fuel type, and vintage of generator in the PSR estimated inventory. The air emissions included are NO_X, PM_{10}, $PM_{2.5}$, CO, CO_2, and VOCs. These are the regulated criteria pollutants for generators and greenhouse gasses.[14]

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[13] Title V and State Facility Permits are given on a site-wide potential to emit NOx. These permits include potentially many sources of emission at a given site, including boilers, machinery, and generators. Because only the total site potential to emit is considered, this leaves large information gaps in sites that do not meet this overall emission level. It also does not reveal the portion of permitted emissions attributable to the generators installed at these sites.

[14] Appendix 3, List of Defined Terms

II.2.a Methodology for Constructing the Emissions Matrix

We created the emission factor matrix from EPA generator certification data, California Air Resource Board (CARB) emission factors from their EMFACS 2007 model, EPA New Source Performance Standards, and New York State Chapter III part 227-2 NO_X regulations. We used the following methodology to produce emissions factors for New York City non-emergency generators, New York State non-emergency generators, and for emergency generators from these sources.

First, we compiled EPA emissions certification data for all years, power classes, and fuel types available. For diesel, data is from 1996-2016, with CO_2 data from 2011-2016. For natural gas and gasoline, data is for under 25kW engines only from 1997-2016, with CO_2 data from 2011-2016. Emissions for each fuel type, size class, and year are averages of emissions certifications for each year, with the raw data trimmed of outliers. Because of the high amount of negative, zero, missing, or order-of-magnitude too high data in the certifications, we performed a 25% trimmed mean for years with sufficiently large numbers of certifications. The 25% trimmed mean excluded the top and bottom 12.5% of the certifications from the average emission rate for each size class and year. Erroneous data points were manually removed for years without a sufficient quantity of certifications.

Second, for years or pollutants with data not available through EPA certifications, we used emissions factors from CARB's EMFACS 2007 model. Because EMFACS emissions factors are available across all years prior to 2007, but not individually for each year, we assumed years without specific emissions factors to be equal to the last available year. This includes diesel CO_2 emissions prior to 2011, CO_2 emissions for gasoline and natural gas engines over 25kW, and particulate matter emissions for natural gas and gasoline engines.

Third, we incorporated EPA New Source Performance Standards (NSPS). Corroborating with current-model Caterpillar generator emissions data, NSPS are treated as equivalent to emissions factors for natural gas and gasoline engines over 25kW. We compared diesel certification data to the tiered diesel emissions regulations, finding that the slightly higher emissions factors from the certification data were consistent with the phased implementation of the emissions regulations.

The EPA implemented specific emergency generator emissions standards in 2009 for natural gas and gasoline engines over 19kW, and diesel engines in 2010. We created specific emergency generator emissions factors using the emergency NSPS instead of the standard NSPS for natural gas and gasoline engines. For diesel engines, we held emissions constant from 2010 forward, consistent with the diesel emergency generator regulations.

Fourth, we applied New York-specific emissions regulations. The Chapter III part 227-2 NO_X regulations are the only generator emissions regulations in New York State, and do not apply to emergency generators. Part 227-2 NO_X regulation sets limits for existing diesel and natural gas generators installed between 1995 and 2005, as well as emissions standards from 2005 to present. These standards apply to engines over 150kW in New York City and engines over 300kW in New York State, which is the differentiating factor between New York City and the rest of New York State. Part 227-2 NO_X standards were applied as emissions factors for years and sizes where EPA certifications, CARB EMFACS factors, or federal NSPS standards otherwise exceeded Part 227-2 NO_X standards for non-emergency engines.

II.2.b External Corroboration of the Emissions Matrix

The Project Team conducted a review process on the methods, assumptions, and results in the development of the emissions matrix. We conducted online research, identified and interviewed experts at air regulatory agencies (e.g. California Air Resources Board, Environmental Protection Agency, New York Department of Environmental Conservation); spoke with trade associations, engine manufacturers, and academics specializing in the analysis of emissions from fossil fuel fired stationary engine generators.[15]

II.3. Describing the Excel Tool

The Excel Tool calculates the gross[16] output of estimated distributed generators' criteria pollutants across NYS, with subtotals by fuel type and geographic region. User inputs are shaded in a light-yellow color with black text: 135%

Duty Cycle is the first sheet and is shown below in Figure 1.[17] Most of the model's user inputs are entered here. These form the baseline case, which is prepopulated but can be altered, and an alternative scenario's conditions ("Scenario 3") allowing for a free-form modification of the generation mix. Scenarios 1 & 2 are across-the-board fixed percentage increases in run-hours that are set in the following *Total* sheet.

The figures in this sheet allow the user to view and edit the generator inventory usage mix and their annual run-hours. The number of generators in each size class, and of each fuel type, is fixed according to the PSR estimates and cannot be altered by the user. The figures entered on this sheet assign the relevant number of generators in the inventory, for each size class, to either the Emergency, Peaking, or Baseload categories.[18] The user can then enter the respective number of run-hours for those categories below.

The user can also select a low, middle, or high average size assumption for size classes. This feature allows the selection of an average size of 25, 50, or 75 percent of the difference between the high and low boundaries of each size class. For example, the average value for the 1000-2000kW size class would be set at 1250kW, 1500kW, or 1750kW respectively.

[15] Full citation of contacts found in Appendix 2.1.
[16] Appendix 3, List of Defined Terms
[17] Graphics and screen shots in this document are intended for illustrative purposes only. They may contain test values or other "dummy" data and should not be interpreted by the user as viable data.
[18] Appendix 3, List of Defined Terms

GENERATOR DUTY CYCLE - DATA INPUT

Average Generator Output in Size Range: MIDDLE

BASELINE

DIESEL

Size	Emergency	Peaking	Baseloac
1-25 kW	100.0%	0.0%	0.0%
25-150 kW	100.0%	0.0%	0.0%
150-300 kW	98.0%	0.0%	2.0%
300-450 kW	80.0%	18.0%	2.0%
450-560 kW	80.0%	18.0%	2.0%
560-1000 kW	77.0%	20.0%	3.0%
1000-2000 kW	77.0%	20.0%	3.0%
ANNUAL HOURS	51	100	6,000

NATURAL GAS

Size	Emergency	Peaking	Baseload
1-25 kW	100.0%	0.0%	0.0%
25-150 kW	100.0%	0.0%	0.0%
150-300 kW	97.0%	0.0%	3.0%
300-450 kW	78.0%	19.0%	3.0%
450-560 kW	77.0%	19.0%	4.0%
560-1000 kW	75.0%	20.0%	5.0%
1000-2000 kW	75.0%	20.0%	5.0%
	15	100	6,000

GASOLINE

Size	Emergency	Peaking	Baseload
1-25 kW	100.0%	0.0%	0.0%
25-150 kW	100.0%	0.0%	0.0%
150-300 kW	100.0%	0.0%	0.0%
300-450 kW	100.0%	0.0%	0.0%
450-560 kW	100.0%	0.0%	0.0%
560-1000 kW	100.0%	0.0%	0.0%
1000-2000 kW	100.0%	0.0%	0.0%
	2	-	-

SCENARIO 3

Size	Emergency	Peaking	Baseloac
1-25 kW	100.0%	0.0%	0.0%
25-150 kW	100.0%	0.0%	0.0%
150-300 kW	98.0%	0.0%	2.0%
300-450 kW	80.0%	18.0%	2.0%
450-560 kW	80.0%	18.0%	2.0%
560-1000 kW	77.0%	20.0%	3.0%
1000-2000 kW	77.0%	20.0%	3.0%
ANNUAL HOURS	51	110	6,000

Size	Emergency	Peaking	Baseload
1-25 kW	100.0%	0.0%	0.0%
25-150 kW	100.0%	0.0%	0.0%
150-300 kW	97.0%	0.0%	3.0%
300-450 kW	78.0%	19.0%	3.0%
450-560 kW	77.0%	19.0%	4.0%
560-1000 kW	75.0%	20.0%	5.0%
1000-2000 kW	75.0%	20.0%	5.0%
	15	110	6,000

Size	Emergency	Peaking	Baseload
1-25 kW	100.0%	0.0%	0.0%
25-150 kW	100.0%	0.0%	0.0%
150-300 kW	100.0%	0.0%	0.0%
300-450 kW	100.0%	0.0%	0.0%
450-560 kW	100.0%	0.0%	0.0%
560-1000 kW	100.0%	0.0%	0.0%
1000-2000 kW	100.0%	0.0%	0.0%
	2	-	-

Figure 1, Duty Cycle Sheet

On the *Duty Cycle* sheet, some of data input cells also have blue color bars to highlight their respective percentages of the group's total amount. All groups of size class cells should total to 100% to match the PSR estimated inventory. If any do not meet this constraint, the adjoining cell off to the right will be shaded red to indicate an error in need of correction. The model will still function and calculate totals, but the user should be aware that these results will be skewed until this condition is rectified.

Total, the second sheet (shown in Figure 2), has four user inputs. They allow the user to scale up the criteria pollutant levels, based on run-hours, from the baseline case by a fixed percentage via the in-cell drop down. Note that Scenario 3 is based on the previous, more specific inputs from the *Duty Cycle* sheet, and is not alterable here.

The tables display the sum of each of the seven criteria pollutants for each scenario the user has created, from generators of all sizes and fuel types. These are subtotaled by geographic region: New York City, Westchester (which together with NYC forms the ConEd service territory), and the remaining areas of NYS for non-emergency (baseload and peaking) generators. Emergency generators, which are subject to different pollution constraints common to all NYS counties, are shown across all of New York State as a single total.

TOTAL Criteria Pollutants

BASELOAD AND PEAKING OUTPUT (metric tons)

		Escalation v. Baseline:	135%	80%	CUSTOM
	Polutant	Baseline	Scenario 1	Scenario 2	Scenario 3
NYS TOTAL	CO	6,497.4	8,771.5	5,197.9	6,545.7
	Nox	11,412.9	15,407.4	9,130.3	11,514.9
	PM	427.9	577.7	342.3	431.8
	PM 10	32.4	43.8	26.0	32.7
	PM 2.5	395.4	533.9	316.4	399.0
	CO2	1,839,752.1	2,483,665.4	1,471,801.7	1,855,709.7
	VOC	1,805.6	2,437.5	1,444.5	1,821.2
NYC	CO	2,636.7	3,559.5	2,109.4	2,657.2
	Nox	5,415.5	7,310.9	4,332.4	5,465.2
	PM	206.7	279.0	165.3	208.6
	PM 10	15.9	21.5	12.7	16.1
	PM 2.5	190.8	257.5	152.6	192.5
	CO2	863,522.1	1,165,754.8	690,817.6	871,210.0
	VOC	834.7	1,126.8	667.7	842.1
Westchester	CO	163.3	220.4	130.6	164.6
	Nox	507.8	685.5	406.2	512.4
	PM	19.7	26.6	15.7	19.9
	PM 10	1.5	2.1	1.2	1.6
	PM 2.5	18.1	24.5	14.5	18.3
	CO2	82,030.5	110,741.1	65,624.4	82,762.8
	VOC	72.3	97.7	57.9	73.0
Remaining NYS	CO	3,697.5	4,991.6	2,958.0	3,723.9
	Nox	5,489.6	7,411.0	4,391.7	5,537.4
	PM	201.5	272.1	161.2	203.3
	PM 10	15.0	20.2	12.0	15.1
	PM 2.5	186.6	251.9	149.2	188.2
	CO2	894,199.6	1,207,169.5	715,359.7	901,736.9
	VOC	898.6	1,213.1	718.9	906.1

EMERGENY OUTPUT (metric tons)

		Escalation v. Baseline:	135%	80%	CUSTOM
	Polutant	Baseline	Scenario 1	Scenario 2	Scenario 3
NYS TOTAL	CO	8,531.2	11,517.1	6,825.0	8,531.2
	Nox	3,888.5	5,249.5	3,110.8	3,888.5
	PM	144.0	194.3	115.2	144.0
	PM 10	11.2	15.1	9.0	11.2
	PM 2.5	132.7	179.2	106.2	132.7
	CO2	487,604.0	658,265.4	390,083.2	487,604.0
	VOC	1,182.1	1,595.8	945.7	1,182.1

Figure 2, Total Pollutants Sheet

The other three sheets, *Diesel*, *NatGas*, and *Gasoline*, show the total gross emissions by fuel type and are structured identically to the *Total* sheet. Each of the fuel type sheets displays the total emissions for each of the seven criteria pollutants for each scenario for all sizes and vintages of that fuel type. This is broken down for New York City, Con Ed Service Territory, and all of New York State for non-emergency generators, and shown for all of New York State for emergency generators. A sample sheet for diesel is shown below in Figure 3. These sheets display the fuel-specific components which are summed up to create the figures show on the *Total* sheet. Note that the scaling factors for Scenarios 1 & 2 are linked to the *Total* sheet and cannot be altered independently.

Criteria Pollutants - Diesel

BASELOAD AND PEAKING OUTPUT (metric tons)

	Escalation v. Baseline:		135%	80%	CUSTOM
	Polutant	Baseline	Scenario 1	Scenario 2	Scenario 3
NYS TOTAL	CO	2,980.5	4,023.7	2,384.4	3,008.1
	Nox	10,519.9	14,201.9	8,416.0	10,616.9
	PM	405.6	547.6	324.5	409.3
	PM 10	32.4	43.8	26.0	32.7
	PM 2.5	373.1	503.8	298.5	376.6
	CO2	1,589,018.5	2,145,175.0	1,271,214.8	1,603,603.4
	VOC	1,491.0	2,012.9	1,192.8	1,504.9
NYC	CO	1,454.9	1,964.2	1,164.0	1,468.6
	Nox	5,126.7	6,921.0	4,101.4	5,174.7
	PM	198.8	268.4	159.1	200.7
	PM 10	15.9	21.5	12.7	16.1
	PM 2.5	182.9	246.9	146.3	184.6
	CO2	775,494.2	1,046,917.2	620,395.4	782,707.1
	VOC	726.1	980.2	580.9	732.9
Westchester	CO	142.0	191.7	113.6	143.3
	Nox	501.5	677.1	401.2	506.2
	PM	19.4	26.1	15.5	19.5
	PM 10	1.5	2.1	1.2	1.6
	PM 2.5	17.8	24.0	14.2	18.0
	CO2	78,285.4	105,685.3	62,628.3	79,004.0
	VOC	68.7	92.7	54.9	69.3
Remaining NYS	CO	1,383.6	1,867.9	1,106.9	1,396.3
	Nox	4,891.7	6,603.8	3,913.4	4,936.1
	PM	187.4	253.0	149.9	189.1
	PM 10	15.0	20.2	12.0	15.1
	PM 2.5	172.4	232.8	137.9	174.0
	CO2	735,238.9	992,572.5	588,191.1	741,892.3
	VOC	696.2	939.9	557.0	702.7

EMERGENY OUTPUT (metric tons)

	Escalation v. Baseline:		135%	80%	CUSTOM
	Polutant	Baseline	Scenario 1	Scenario 2	Scenario 3
NYS TOTAL	CO	910.2	1,228.8	728.2	910.2
	Nox	3,603.1	4,864.1	2,882.4	3,603.1
	PM	129.4	174.8	103.6	129.4
	PM 10	10.4	14.0	8.3	10.4
	PM 2.5	119.1	160.8	95.3	119.1
	CO2	431,291.5	582,243.5	345,033.2	431,291.5
	VOC	440.2	594.2	352.1	440.2

Figure 3, Diesel Pollutants Sheet

II.3.a Methodology for Constructing the Excel Tool

To construct the model, we formatted the PSR estimated generator inventory into a set organized by location, fuel type, size, and vintage (*Master Gen Inv* sheet). Classifications with estimated quantities of zero were removed to increase the efficiency of calculations and data matching algorithms.

We subdivided this data set into three separate sheets by geography: NYC, Westchester, and the remainder of NYS ("*Other*" sheets). Each geography's inventory was then subdivided into separate sheets by fuel type (Diesel, NatGas, and Gasoline). Specific emissions factors were matched to the inventory by size and vintage for each fuel type. NYC and Westchester, ConEd's territory, have one set of (identical) factors, the remainder of NYS has another set.

We assumed usage to be identical across vintage and geography. The quantity of generators used is also influenced by the type: Emergency, Peaking, and Baseload. Emergency generators are kept separate and aside because they are regulated uniformly across New York State as compared to emissions from generators working in non-emergency scenarios. Inputs from the *Duty Cycle* sheet are used to calculate the relevant run-hours for each fuel type, and the proportion of peaking, baseload, and emergency use for each size class and fuel type. This assigns percentages of the total estimated inventory for each geography to the corresponding geography-specific sheet or emergency sheet based on the percentage of emergency or non-emergency use, to be paired with the respective emissions factors.

Once the percent of estimated inventory is assigned to each sheet and matched with emissions data, each size and vintage of the inventory are paired with run times to calculate the total emissions for each fuel type. The total kWh, and resulting quantity of emissions, will also depend on the user-selected toggle for 25/50/75 within-size class average engine size.

The methodology described above calculates the generator and emissions data for each geography, fuel type, vintage, and use type. For each geography, the tool performs the following calculation for each size class, fuel type, and vintage:

> Emission factor (g/ kWh) * generator size (kW) * average run time (hours/year) * number of generator (scalar) * 0.000001 (metric tons/g) = Metric tons emitted per year (MT/year)

This is calculated, line by line, for each size class, fuel type, and vintage in each geography and again for emergency generators. Total values are in the total rows of tables on the respective geography and fuel type calculation sheets. These are then summed to the fuel type total sheets, and those are in turn summed to the *Total* sheet.

II.4. Constructing the Excel Tool's Reference Case Conditions

To construct the baseline scenario, we determined the best estimate of the use type (Emergency, Peaking or Baseload)[19] and yearly operation pattern of generators in New York State by fuel type and size class. We then determined the best estimate of the average existing run-hours for each use type and fuel type.

We apportioned the three use types for each size class and fuel type based on consultation with PSR, Director of Air Engineering at NYC DEP Kit Liang, and Manager of Distributed Resources Operation at NYISO Vijaya Ganugula. Based on these discussions, as well as the professional insight of Dr. Venkataraman and Dr. Amar, we arrived at an estimate for the distribution of generator use types, shown in Figure 4.

BASELINE

DIESEL			
Size	Emergency	Peaking	Baseload
1-25 kW	100.0%	0.0%	0.0%
25-150 kW	100.0%	0.0%	0.0%
150-300 kW	98.0%	0.0%	2.0%
300-450 kW	80.0%	18.0%	2.0%
450-560 kW	80.0%	18.0%	2.0%
560-1000 kW	77.0%	20.0%	3.0%
1000-2000 kW	77.0%	20.0%	3.0%

NATURAL GAS			
Size	Emergency	Peaking	Baseload
1-25 kW	100.0%	0.0%	0.0%
25-150 kW	100.0%	0.0%	0.0%
150-300 kW	97.0%	0.0%	3.0%
300-450 kW	78.0%	19.0%	3.0%
450-560 kW	77.0%	19.0%	4.0%
560-1000 kW	75.0%	20.0%	5.0%
1000-2000 kW	75.0%	20.0%	5.0%

GASOLINE			
Size	Emergency	Peaking	Baseload
1-25 kW	100.0%	0.0%	0.0%
25-150 kW	100.0%	0.0%	0.0%
150-300 kW	100.0%	0.0%	0.0%
300-450 kW	100.0%	0.0%	0.0%
450-560 kW	100.0%	0.0%	0.0%
560-1000 kW	100.0%	0.0%	0.0%
1000-2000 kW	100.0%	0.0%	0.0%

Figure 4, Baseline Duty Cycle Apportionment

Next, we determined the baseline run-hour assumptions for each use type and fuel type. To estimate the baseline of emergency run-hours, we assume that engines under 25kW will run only during grid outages, but that engines over 25kW will run approximately 50 hours per year for testing in addition to any grid outages. We weighted the 50 hour run time by the proportion of emergency engines above and below 25kW for each fuel type to find the average testing run time for each fuel type. Then, we

[19] Appendix 3, List of Defined Terms

identified the 4 year average (2013-2016) outage length per customer in New York State of 1.8 hours per NY Department of Public Service. [20] Combined, this gives baseline run-hours of 51 hours for diesel, 15 hours for natural gas, and 2 hours for gasoline.

To find the run-hours for peaking and baseline generators, we held discussions with industry and academic contacts, and with the New York ISO. We estimated that currently peaking engines run on average 100 hours per year, and that only diesel and natural gas engines over 300kW are used for peaking. We estimated that baseload engines run 6000 hours per year, or 16 hours per day, on average. Some will run more, providing power to residential buildings or campuses with 24-hour use, while some may run less, such as in a manufacturing plant only running one shift for eight hours a day. Some facilities may also only run in the summer and winter, but be inactive for portions of the spring and fall shoulder seasons.

The run-hour assumptions for all use types are shown in Figure 5.

SCENARIO 3

Size	Emergency	Peaking	Baseload
1-25 kW	100.0%	0.0%	0.0%
25-150 kW	100.0%	0.0%	0.0%
150-300 kW	98.0%	0.0%	2.0%
300-450 kW	80.0%	18.0%	2.0%
450-560 kW	80.0%	18.0%	2.0%
560-1000 kW	77.0%	20.0%	3.0%
1000-2000 kW	77.0%	20.0%	3.0%
ANNUAL HOURS	-	110	6,000

Size	Emergency	Peaking	Baseload
1-25 kW	100.0%	0.0%	0.0%
25-150 kW	100.0%	0.0%	0.0%
150-300 kW	97.0%	0.0%	3.0%
300-450 kW	78.0%	19.0%	3.0%
450-560 kW	77.0%	19.0%	4.0%
560-1000 kW	75.0%	20.0%	5.0%
1000-2000 kW	75.0%	20.0%	5.0%
	-	110	6,000

Size	Emergency	Peaking	Baseload
1-25 kW	100.0%	0.0%	0.0%
25-150 kW	100.0%	0.0%	0.0%
150-300 kW	100.0%	0.0%	0.0%
300-450 kW	100.0%	0.0%	0.0%
450-560 kW	100.0%	0.0%	0.0%
560-1000 kW	100.0%	0.0%	0.0%
1000-2000 kW	100.0%	0.0%	0.0%
	-	-	-

Figure 5, Baseline Duty Cycle and Run-Hour Assumptions

III. Test Scenario Analyses and Results

III.1. Scenario Analysis #1: Climate Event

The impact of large storms, most recently Hurricane Florence and Hurricane Maria, and still fresh in the mind of New Yorkers from Hurricane Irene in 2011 and Superstorm Sandy in 2012, can have a dramatic effect on the usage of emergency generators. Damage from flooding and wind to the electric grid created widespread, sustained power outages, necessitating increased operation of emergency generators many times above yearly averages. Accordingly,, a plausible scenario for model testing is an increase in total hours of DG operation as a consequence of an increase in the frequency and the intensity of weather events that result in power outages of extended duration.

The model is run with the base set of assumptions, and then run a second time with the revised assumptions that represent changes in frequency and severity of storms that depart significantly from historical norms.

[20] New York State Department of Public Service 2016 Electric Reliability Performance Report, Appendix pp. 4-6

III.1.a. Scenario Specification

To construct a model for this scenario, we used outage data from New York State Department of Public Service (NY DPS) for 2012[21], the year of Superstorm Sandy, to estimate the impact of a potential future climate event on New York State generator emissions. We found the difference between the average annual customer outage length in 2012 compared to the average annual customer outage length from 2013-2016. We used the increase in average annual outage time as a measure for increased run time per generator. Modeling this increase in average annual emergency engines run-hours with the Excel Tool gives an estimate of yearly generator emissions resulting from a climate event. This analysis provided an estimate of an additional 22 hours of average run time per generator statewide.

Additionally, a recent study by Lawrence Berkeley National Laboratory and Stanford University found the duration of outages due to catastrophic weather events is likely to increase.[22] According to this study, a 5% increase in the average wind speed resulted in a 56% increase in the number of hours a utility's customer went without power. An article in Geophysical Research letters estimated that another Hurricane Sandy could have 50%-80% more destructive power due to increased ocean temperatures.[23] Benjamin Horton, Ph.D., of Rutgers University found that intense storms and flooding could happen at three to 17 times their current frequency,[24] and stated in an interview with CBS that "Events like Hurricane Sandy, which currently occur approximately every 400 years — the frequency that those events will occur may be as much as once every 20 years… Oceans are the heat sources for hurricanes, so a warmer ocean means more intense hurricanes and also a potential increase in their frequency".[25]

To account for the likelihood of increased storm frequency and severity, we also estimated the generator emissions of storm years with outages 150% and 200% that of 2012. These annual outage results can be interpreted as the results of several intense storms, such as multiple hurricanes or superstorms, or inclusive of a severe ice storm. They can also be interpreted as a concentrated outage from one severe storm.

To construct the climate event scenario, we used the NY Department of Public Service average customer outage length for 2012, the year of Superstorm Sandy. The average outage length per customer in 2012 was 24 hours, an increase of 22 hours over the 2013-2017 period. We added 22 hours to the run time of each fuel type, giving scenario run-hours of 73, 37, and 24 hours for diesel, natural gas, and gasoline, respectively. The 150% case added 33 run-hours to emergency engines for all fuel types, and the 200% case added 44 run-hours to emergency engines of all fuel types.

[21] New York State Department of Public Service 2016 Electric Reliability Performance Report, Appendix pp. 4-6
[22] Larsen, P., LaCommare, K., Eto, J., Sweeny, J. "Assessing Changes in the Reliability of the U.S. Electric Power System." Lawrence Berkeley National Laboratory, August 2015.
[23] Lau, W., Shi, J., Tao, W., Kim, K. "What would happen to Superstorm Sandy under the influence of a substantially warmer Atlantic Ocean?" Geophysical Research Letters 43(2).
[24] Horton, B., Lin, N. "Hurricane Sandy's flood frequency increasing from year 1800 to 2100." Proceedings of the National Academy of Sciences 113(43).
[25] https://newyork.cbslocal.com/2016/10/11/superstorm-sandy-could-happen-again/

III.1.b. Scenario Results

Table 5 - Impact of 22 Hour Climate Event on Emergency Generator Emissions, Metric Tons per Year

Emergency Engines Rest of NY State						
	Natural Gas Engines		Diesel Engines		Gasoline Engines	
	Baseline	**Scenario 1**	**Baseline**	**Scenario 1**	**Baseline**	**Scenario 1**
CO	1,580.8	3,899.2	443.8	635.2	4,080.3	48,962.5
NO_X	167.7	413.6	1,725.0	2,468.9	36.8	441.3
PM	2.8	6.9	63.0	90.4	7.8	94.0
PM_{10}	0.0	0.0	5.1	177.7	0.7	7.5
$PM_{2.5}$	2.8	6.9	58.0	81.6	7.2	86.5
CO_2	28,056.0	69,204.8	208,669.3	298,683.5	12,629.0	151,547.6
VOC	43.6	107.5	214.0	306.2	502.3	6,028.4
Emergency Engines NYC						
	Natural Gas Engines		Diesel Engines		Gasoline Engines	
	Baseline	**Scenario 1**	**Baseline**	**Scenario 1**	**Baseline**	**Scenario 1**
CO	369.7	911.9	421.8	603.8	1,139.2	13,670.6
NO_X	56.3	139.0	1,700.6	2,434.3	10.6	127.2
PM	0.9	2.1	60.0	85.8	2.2	26.2
PM_{10}	0	0	4.8	6.9	0.2	2.1
$PM_{2.5}$	0.9	2.1	55.2	79.0	2.0	24.1
CO_2	9,080.1	22,397.7	201,386.6	288,259.3	3,596.7	43,160.5
VOC	13.4	33.1	204.6	292.9	140.0	1,679.6
Emergency Engines Westchester						
	Natural Gas Engines		Diesel Engines		Gasoline Engines	
	Baseline	**Scenario 1**	**Baseline**	**Scenario 1**	**Baseline**	**Scenario 1**
CO	130.3	321.5	44.6	63.9	320.7	3,848.9
NO_X	11.2	27.6	177.5	254.1	2.9	34.6
PM	0.2	0.5	6.4	9.1	0.6	7.4
PM_{10}	0	0	0.5	0.7	0	0.6
$PM_{2.5}$	0.2	0.5	5.9	8.4	0.6	6.8
CO_2	1,960.7	4,836.4	21,235.6	30,396.0	990.0	11,880.5
VOC	3.1	7.7	21.6	30.9	39.5	473.9

Table 6 - Impact of 33 Hour Climate Event on Emergency Generator Emissions, Metric Tons per Year

Emergency Engines Rest of NY State						
	Natural Gas Engines		Diesel Engines		Gasoline Engines	
	Baseline	**Scenario 1**	**Baseline**	**Scenario 1**	**Baseline**	**Scenario 1**
CO	1,580.8	5,058.5	443.8	731.0	4,080.3	71,403.6
NO_X	167.7	536.6	1,725.0	2,841.0	36.8	643.6
PM	2.8	9.0	63.0	103.9	7.8	137.0
PM_{10}	0.0	0.0	5.1	8.4	0.7	10.9
$PM_{2.5}$	2.8	9.0	58.0	95.5	7.2	126.1
CO_2	28,056.0	89,779.1	208,669.3	343,690.5	12,629.0	221,007.0
VOC	43.6	139.5	214.0	352.5	502.3	8,791.3
Emergency Engines NYC						
	Natural Gas Engines		Diesel Engines		Gasoline Engines	
	Baseline	**Scenario 1**	**Baseline**	**Scenario 1**	**Baseline**	**Scenario 1**
CO	369.7	1,183.0	421.8	694.7	1,139.2	19,936.3
NO_X	56.3	180.3	1,700.6	2,801.1	10.6	185.5
PM	0.9	2.8	60.0	98.8	2.2	38.3
PM_{10}	0	0	4.8	7.9	0.2	3.1
$PM_{2.5}$	0.9	2.8	55.2	90.9	2.0	35.2
CO_2	9,080.1	29,056.5	201,386.6	331,695.6	3,596.7	62,942.3
VOC	13.4	42.9	204.6	337.0	140.0	2,449.4
Emergency Engines Westchester						
	Natural Gas Engines		Diesel Engines		Gasoline Engines	
	Baseline	**Scenario 1**	**Baseline**	**Scenario 1**	**Baseline**	**Scenario 1**
CO	130.3	417.0	44.6	73.5	320.7	5,613.0
NO_X	11.2	35.8	177.5	292.4	2.9	50.4
PM	0.2	0.6	6.4	10.5	0.6	10.8
PM_{10}	0	0	0.5	0.8	0	0.9
$PM_{2.5}$	0.2	0.6	5.9	9.7	0.6	9.9
CO_2	1,960.7	6,274.3	21,235.6	34,976.3	990.0	17,325.7
VOC	3.1	10.0	21.6	35.5	39.5	691.2

Table 7 - Impact of 44 Hour Climate Event on Emergency Generator Emissions, Metric Tons per Year

Emergency Engines Rest of NY State						
	Natural Gas Engines		Diesel Engines		Gasoline Engines	
	Baseline	**Scenario 1**	**Baseline**	**Scenario 1**	**Baseline**	**Scenario 1**
CO	1,580.8	6,217.7	443.8	826.7	4,080.3	93,844.7
NO_X	167.7	659.5	1,725.0	3,213.0	36.8	845.7
PM	2.8	11.0	63.0	117.5	7.8	180.1
PM_{10}	0.0	0.0	5.1	9.5	0.7	14.5
$PM_{2.5}$	2.8	11.0	58.0	108.1	7.2	165.7
CO_2	28,056.0	110,353.5	208,669.3	388,697.6	12,629.0	290,466.3
VOC	43.6	171.3	214.0	398.5	502.3	11,554.3
Emergency Engines NYC						
	Natural Gas Engines		Diesel Engines		Gasoline Engines	
	Baseline	**Scenario 1**	**Baseline**	**Scenario 1**	**Baseline**	**Scenario 1**
CO	369.7	1,454.1	421.8	785.7	1,139.2	26,201.9
NO_X	56.3	221.6	1,700.6	3,167.9	10.6	243.9
PM	0.9	3.4	60.0	111.7	2.2	50.3
PM_{10}	0	0	4.8	8.9	0.2	4.0
$PM_{2.5}$	0.9	3.4	55.2	102.8	2.0	46.3
CO_2	9,080.1	35,715.2	201,386.6	375,132.0	3,596.7	82,724.2
VOC	13.4	52.8	204.6	381.2	140.0	3,219.2
Emergency Engines Westchester						
	Natural Gas Engines		Diesel Engines		Gasoline Engines	
	Baseline	**Scenario 1**	**Baseline**	**Scenario 1**	**Baseline**	**Scenario 1**
CO	130.3	512.6	44.6	83.1	320.7	7,377.2
NO_X	11.2	44.1	177.5	330.7	2.9	66.3
PM	0.2	0.8	6.4	11.9	0.6	14.2
PM_{10}	0	0	0.5	0.9	0	1.1
$PM_{2.5}$	0.2	0.8	5.9	10.9	0.6	13.0
CO_2	1,960.7	7,712.2	21,235.6	39,556.5	990.0	22,770.9
VOC	3.1	12.3	21.6	40.2	39.5	908.4

Characterization of results

We can see from these results that a potential climate event leads to dramatic increases in emissions from emergency generators, especially among the hundreds of thousands of otherwise low or no use gasoline generators. Sustained emission of pollutants that do not disperse (CO, VOC, and PM) will have a cumulative effect on local air quality the longer generators in a specific area operate. The emissions of

CO and VOC are particularly troubling for sustained outages due to the high rate of emissions from otherwise very low-use gasoline generators, with potential increases in emissions of over 1000% over baseline emergency engine emissions. If a sustained outage coincides with high cooling degree days the increase in CO and VOCs could create large amounts of ozone. The generation of large quantities of PM near homes and urban areas would have serious health effects as well. Additionally, more severe storms will lead to longer and more widespread outages. This will have a greater impact on affected communities than several smaller storms spread throughout the year even if the annual outage hours are the same.

A possible climate event leads to gross annual increases in emergency generator emissions as follows:

- an annual increase in carbon dioxide emissions (CO_2) across the three study regions (from natural gas, diesel, and gasoline engines) by 432,762 metric tons (22 run-hours), 649,143 metric tons (33 run-hours) and 865,524 metric tons (44 run-hours). This is an increase of 88-178%, the equivalent of the annual emissions from 92,669 cars (22 run-hours), 139,003 cars (33 run-hours), and 185,337 cars (44 run-hours);
- an annual increase in carbon monoxide emissions (CO) across the three study regions (from natural gas, diesel, and gasoline engines) by 64,386 metric tons (22 run-hours), 96,579 metric tons (33 run-hours) and 128,772 metric tons (44 run-hours), an increase of 755-1500%;
- an annual increase in nitrogen oxide emissions (NOx) across the three study regions (from natural gas, diesel, and gasoline engines) by 2,452 metric tons (22 run-hours), 3,678 metric tons (33 run-hours) and 4,904 tons (44 run-hours), an increase of 63-126%;
- an annual increase in particulate matter emissions (PM) across the three study regions (from natural gas, diesel, and gasoline engines) by 179 metric tons (22 run-hours), 268 metric tons (33 run-hours) and 357 metric tons (44 run-hours), an increase of 124-248%;
- an annual increase in volatile organic compound emissions (VOC) across the three study regions (from natural gas, diesel, and gasoline engines) by 7,778 tons (22 run-hours), 11,667 metric tons (33 run-hours) and 15,556 metric tons (44 run-hours), an increase of 658-1,316%.

III.2. Scenario Analysis #2: Increased Demand-Response and Critical Peak Pricing

We explored two likely methods of implementing time-varying incentives for fossil-fired DG use. One is through an expanded NYISO demand-response program, the other would be through the roll-out of critical peak pricing (CPP) for residential and small commercial customers. The demand-response program would increase the average run-hours of non-emergency peaking engines, while the critical peak pricing could incentivize residential and small-commercial customers to operate their emergency engines to avoid peak electric prices.

III.2.a. Scenario Specification

Increased Demand-Response Analysis

Assuming that the population of generators remains constant, the introduction of an increased demand-response program would necessitate an increase in the average run time of existing peaking engines. We do not assume an increase in the run time of emergency or baseload engines.

Typically, there are two things that keep emergency generators from being used as peakers. The first is legality; emergency engines have less stringent emissions regulations, and engines with permits must log hours of operation. Second, many emergency generators are wired such that the site must disconnect from the grid to use electricity from the generator. Emergency power rarely meets peak demand, or even average demand, so the financial benefit of running the emergency engine would have to outweigh the consequences of the curtailment of electric use. In addition, discussion with experts and our research indicated that peaking units greater than 300kW are more likely to be used for load shifting as compared to other engines. Therefore, we assume that an expanded demand response programs will lead to an increased run time of peaking units.

After consulting with NYISO, we estimated up to 200 total hours of run time for generators enrolled in such a program, an increase of 100 hours over baseline. Given that not all peaking engines are likely to respond, and that demand-response will only be needed 5-7 days per year, we believe 100 additional hours across all engines engine would be unrealistic. Therefore, we believe 110, 125 and 150 average run-hours per peaking generator are realistic test cases. This accounts for a 50% enrollment rate of peaking generators, with an average increased run-time of 20, 50, or 100 hours from baseline. Tables 8-10 show the impact on gross emissions[26] for the baseline scenario (100 run-hours) and compares it with the emissions as a result an expanded demand response program for the three test cases (110, 125 and 150 average run-hours).

Critical Peak Pricing Analysis

A sub-condition we considered is the implementation of critical peak pricing in tandem with an increased demand-response program. Assuming the implementation of critical peak pricing, this makes the lowest 110-hour demand response scenario most likely, as the critical peak pricing will offset some of the need for load reduction through demand response.

However, under certain price conditions some generator owners may be incentivized to operate during a critical price period rather than pay to consume electricity from the grid. Because a CPP would impact customers on volumetric electric rates, the price signal would be limited to residential and small commercial customers. These customers would be highly unlikely to operate a generator over 25kW, so the increase in run-hours for the CPP events is limited to emergency generators under 25kW for all the three fuel types.

Assuming 5 to 10 CPP events per year, each lasting 2-3 hours in duration, and between 5% and 20% of owners of emergency generators under 25kW choosing to run their generators during these periods, we would expect an increase in average run-hours ranging from 0.5 hours to 6 hours. For the purposes of our analysis, we model the impact of an increase of 6 run-hours on the gross emissions in the scenario where the demand response program expands to 110 hours as a test case. The results of this demonstration analysis are displayed below in Tables 11-12.

III.2.b. Scenario Results

Increased Demand Response

Tables 8-10 shows the estimated impact of expanded demand response (110 hours, 125 hours and 150 hours) on emissions in the three study regions.

[26] Appendix 3, List of Defined Terms

Table 8 - Impact of 110 Hour Expanded Demand Response on Gross Emissions, Metric Tons per Year

New York City							
	Natural Gas Engines		Diesel Engines		Gasoline Engines		
	Baseline	Expanded DR at 110 Hours	Baseline	Expanded DR at 110 Hours	Baseline	Expanded DR at 110 Hours	Total Annual Incremental Increase
CO	1182.0	1189.00	1455.0	1469.0	0	0	21.0
NO_X	289.0	290.0	5127.0	5175.0	0	0	49.0
PM	8.0	8.0	199.0	201.0	0	0	2.0
PM_{10}	0	0	15.9	16.0	0	0	0.1
$PM_{2.5}$	8.0	8.0	183.0	184.9	0	0	1.9
CO_2	88028.0	88503.0	775494.0	782707.0	0	0	7866.0
VOC	109.0	109.0	726.0	733.0	0	0	7.0
Westchester County							
	Natural Gas Engines		Diesel Engines		Gasoline Engines		
	Baseline	Expanded DR at 110 hours	Baseline	Expanded DR at 110 hours	Baseline	Expanded DR at110 hours	Total Annual Incremental Increase
CO	21.0	21.0	142.0	143.0	0	0	1.0
NO_X	6.0	6.0	502.0	506.0	0	0	4.0
PM	0	0	19.0	20.0	0	0	0
PM_{10}	0	0	1.5	1.6	0	0	0
$PM_{2.5}$	0	0	17.4	18.4	0	0	0
CO_2	3745.0	3759.0	78285.0	79004.0	0	0	729.0
VOC	4.0	4.0	69.0	69.0	0	0	0
Rest of New York State							
	Natural Gas Engines		Diesel Engines		Gasoline Engines		
	Baseline	Expanded DR at 110 hours	Baseline	Expanded DR at 110 hours	Baseline	Expanded DR at 110 hours	Total Annual Incremental Increase
CO	2314.0	2328.0	1384.0	1396.0	0	0	26.0
NO_X	598.0	601.0	4892.0	4936.0	0	0	47.0
PM	14.0	14.0	187.0	189.0	0	0	2.0
PM_{10}	0	0	14.9	15.1	0	0	0.1
$PM_{2.5}$	14.0	14.0	172.0	173.88.0	0	0	1.8
CO_2	158961.0	159845.0	735239.0	741892.0	0	0	7537.0
VOC	202.0	203.0	696.0	703.0	0	0	8.0

Table 9 - Impact of 125 Hour Expanded Demand Response on Gross Emissions, Metric Tons per Year

New York City							
	Natural Gas Engines		Diesel Engines		Gasoline Engines		
	Baseline	Expanded DR at 125 Hours	Baseline	Expanded DR at 125 Hours	Baseline	Expanded DR at 125 Hours	Total Annual Incremental Increase
CO	1182.0	1199.0	1455.0	1489.0	0	0	51.0
NO_X	289.0	293.0	5127.0	5247.0	0	0	124.0
PM	8.0	8.0	199.0	215.0	0	0	16.0
PM_{10}	0	0	15.9	17.2	0	0	1.2
$PM_{2.5}$	8.0	8.0	183.0	197.8	0	0	14.7
CO_2	88028.0	89216.0	775494.0	793526.0	0	0	19220.0
VOC	109.0	110.0	726.0	743.0	0	0	18.0
Westchester County							
	Natural Gas Engines		Diesel Engines		Gasoline Engines		
	Baseline	Expanded DR at 125 Hours	Baseline	Expanded DR at 125 Hours	Baseline	Expanded DR at 125 Hours	Total Annual Incremental Increase
CO	21.0	21.0	142.0	145.0	0	0	3.0
NO_X	6.0	6.0	502.0	513.0	0	0	11.0
PM	0	0	19.0	20.0	0	0	1.0
PM_{10}	0	0	1.5	1.6	0	0	0.0
$PM_{2.5}$	0	0	17.4	18.4	0	0	0.9
CO_2	3745.0	3780.0	78285.0	80082.0	0	0	1832.0
VOC	4.0	4.0	69.0	70.0	0	0	1.0
Rest of New York State							
	Natural Gas Engines		Diesel Engines		Gasoline Engines		
	Baseline	Expanded DR at 125 Hours	Baseline	Expanded DR at 125 Hours	Baseline	Expanded DR at 125 Hours	Total Annual Incremental Increase
CO	2314.0	2348.0	1384.0	1415.0	0	0	65.0
NO_X	598.0	606.0	4892.0	5003.0	0	0	119.0
PM	14.0	14.0	187.0	192.0	0	0	5.0
PM_{10}	0	0	14.9	15.3	0	0	0.4
$PM_{2.5}$	14.0	14.0	172.0	176.6	0	0	4.6
CO_2	158961.0	161170.0	735239.0	751873.0	0	0	18843.0
VOC	202.0	205.0	696.0	712.0	0	0	19.0

Table 10 - Impact of 150 Hour Expanded Demand Response on Gross Emissions, Metric Tons per Year

New York City							
	Natural Gas Engines		Diesel Engines		Gasoline Engines		
	Baseline	Expanded Demand Response at 150 hours	Baseline	Expanded Demand Response at 150 hours	Baseline	Expanded Demand Response at 150 hours	Total Annual Incremental Increase
CO	1182.0	1216.0	1455.0	1523.0	0	0	102.0
NO_x	289.0	297.0	5127.0	5367.0	0	0	248.0
PM	8.0	8.0	199.0	226.0	0	0	27.0
PM_{10}	0	0	15.9	16.4	0	0	0.5
$PM_{2.5}$	8.0	8.0	183.0	189.5	0	0	8.4
CO_2	88028.0	90403.0	775494.0	811559.0	0	0	38480.0
VOC	109.0	112.0	726.0	760.0	0	0	37.0
Westchester County							
	Natural Gas Engines		Diesel Engines		Gasoline Engines		
	Baseline	Expanded Demand Response at 150 Hours	Baseline	Expanded Demand Response at 150 Hours	Baseline	Expanded Demand Response at 150 Hours	Total Annual Incremental Increase
CO	21.0	22.0	142.0	148.0	0	0	7.0
NO_x	6.0	6.0	502.0	525.0	0	0	23.0
PM	0	0	19.0	20.0	0	0	1.0
PM_{10}	0	0	1.5	1.6	0	0	0.0
$PM_{2.5}$	0	0	17.4	18.4	0	0	0.9
CO_2	3745.0	3814.0	78285.0	81878.0	0	0	3662.0
VOC	4.0	4.0	69.0	72.0	0	0	3.0
Rest of New York State							
	Natural Gas Engines		Diesel Engines		Gasoline Engines		
	Baseline	Expanded Demand Response at 150 Hours	Baseline	Expanded Demand Response at 150 Hours	Baseline	Expanded Demand Response at 150 Hours	Total Annual Incremental Increase
CO	2314.0	2451.0	1384.0	1447.0	0	0	100.0
NO_x	598.0	632.0	4892.0	5110.0	0	0	152.0
PM	14.0	15.0	187.0	196.0	0	0	10.0
PM_{10}	14.0	15..0	14.9	15.6	0	0	0.7
$PM_{2.5}$	14.0	14.0	172.0	180.3	0	0	9.2
CO_2	158961.0	167799.0	735239.0	768506.0	0	0	42105.0
VOC	202.0	214.0	696.0	726.0	0	0	42.0

From these tables, we can make some observations. First, diesel engines have a greater impact on gross emissions as compared to natural gas engines in all the three study regions viz., New York City, Westchester County, and the rest of New York State. This might be an indication of a higher number of older vintage diesel engines vis-a-vis the natural-gas engines. Second, that the gross emissions impact in New York City is almost comparable to the gross emissions impact in the rest of New York State (particularly the diesel engines) indicates that depending on the net emissions impact and other local factors, the concentration of pollutants over a smaller geographical area could imply more health risks. An expanded demand response program leads to increases in gross emissions as follows:

- a total annual increase in carbon dioxide emissions (CO_2) across the three study regions (from natural gas and diesel engines) by 16,132 metric tons (110 run-hours), 39,495 metric tons (125 run-hours) and 84,247 metric tons (150 run-hours). This is the equivalent annual emissions of 3,454, 8,457, and 18,040 passenger cars, respectively;
- a total annual increase in carbon monoxide emissions (CO) across the three study regions (from natural gas and diesel engines) by 48 tons (110 run-hours), 119 tons (125 run-hours) and 209 tons (150 run-hours);
- a total annual increase in nitrogen oxide emissions (NOx) across the three study regions (from natural gas and diesel engines) by 100 tons (110 run-hours), 254 tons (125 run-hours) and 423 tons (150 run-hours);
- a total annual increase in particulate matter emissions (PM) across the three study regions (from natural gas and diesel engines) by 4 tons (110 run-hours), 23 tons (125 run-hours) and 38 tons (150 run-hours);
- a total annual increase in volatile organic compound emissions (VOC) across the three study regions (from natural gas and diesel engines) by 15 tons (110 run-hours), 38 tons (125 run-hours) and 82 tons (150 run-hours).

Critical Peak Pricing

Tables 11-12 show the estimated impact of a CPP program increasing average under-25kW emergency generator runtime by 6 hours. This increase in runtime is considered as an addition to the lowest case (110 run-hours) expanded demand response in the three geographic study regions.

Table 11 - Incremental Impact of 6 Hour Average Critical Price Peak Event on Emissions in Expanded Demand Response Scenario, Metric Tons per Year

New York City

	Natural Gas Engines		Diesel Engines		Gasoline Engines	
	110 Hours Demand Response	Incremental Increase due to 6 Hour CPP Event	110 Hours Demand Response	Incremental Increase Due to 6 Hour CPP Event	110 Hours	Incremental Increase due to 6 Hour CPP Event
CO	2658.0	91.0	1455.0	0	0	3398.0
NO_x	5465.0	3.0	5127.0	0	0	30.0
PM	209.0	0	199.0	0	0	7.0
PM_{10}	16.7	0	15.9	0	0	1.0
$PM_{2.5}$	192.2	0	183.0	0	0	6.0
CO_2	870735.0	550.0	775494.0	13.0	0	10285.0
VOC	842.0	1.0	726.0	0	0	419.0

Westchester County

	Natural Gas Engines		Diesel Engines		Gasoline Engines	
	110 Hours Demand Response	Incremental Increase due to 6 Hour CPP Event	110 Hours Demand Response	Incremental Increase due to 6 Hour CPP Event	110 Hours Demand Response	Incremental due to 6 Hour CPP Event
CO	164.0	41.0	142.0	0	0	960.0
NO_x	512.0	1.0	502.0	0	0	8.0
PM	20.0	0	19.0	0	0	2.0
PM_{10}	1.6	0	1.5	0	0	0.0
$PM_{2.5}$	18.4	0	17.4	0	0	2.0
CO_2	82763.0	249.0	78285.0	2.0	0	2904.0
VOC	73.0	0	69.0	0	0	118.0

Rest of New York State

	110 Hours Demand Response	Incremental Increase due to 6 Hour CPP Event	110 Hours Demand Response	Incremental Increase due to 6 Hour CPP Event	110 Hours Demand Response	Incremental Increase due to 6 Hour CPP Event
CO	3724.0	470.0	1384.0	0	0	12205.0
NO_x	5537.0	15.0	4892.0	0	0	106.0
PM	203.0	0	187.0	0	0	24.0
PM_{10}	15.1	0	14.9	0	0	2.0
$PM_{2.5}$	187.8	0	172.0	0	0	22.0
CO_2	905657.0	2830.0	735239.0	23.0	0	36946.0
VOC	906.0	7.0	696.0	0	0	1506.0

From the results of this analysis, we see that the incremental increase in gross emissions due to critical price events is mostly due to gasoline engines. The impact due to natural gas and diesel engines is much less significant. Due to critical price peak events, we estimate that there will be:

- an incremental increase in annual emissions of carbon monoxide (CO) by 17,183 tons;
- an incremental increase in annual emissions of nitrogen oxides (NOx) by 164 tons;
- an incremental increase in annual emissions of particulate matter (PM) by 34 tons;
- an incremental increase in annual emissions of carbon dioxide (CO_2) by 59,799 tons, or the annual emissions of 12,805 cars;
- an incremental increase in annual emissions of volatile organic compounds (VOC) by 2,067 tons.

Table 12 provides a total estimate of emissions of the pollutants in the expanded demand response scenario with a run of 110 hours and a 6-hour critical price peak event. We can see that when the expanded demand response program is accompanied by a 6-hour critical peak event, there is a significant increase in the gross emissions of CO by 17,183 metric tons and VOC by 2,067 metric tons. This is 261% and 112% respectively, relative to the demand-response alone.

Table 12 - Total Estimated Emissions in the Demand Response Scenario (110 Hours) + 6 Hour CPP Events, Metric Tons per Year

	Emissions in Demand Response Scenario at 110 Hours	**Incremental Emissions in 6 Hour CPP Event**	**Total Estimated Emissions (DR + 6 Hour CPP)**	**Percent Increase**
CO	6,546.0	17,183.0	23729.0	261.0
NO_x	11,514.0	164.0	11,668.0	1.3
PM	442.0	34.0	476.0	1.3
CO_2	1,855,710.0	59,799.0	1,91,5509.0	2.8
VOC	1,811.0	2,067.0	3,878.0	112.0

IV. Summary and Conclusions

This analysis provides several insights and re-confirms prior research conducted by NESCAUM more than a dozen years ago. One conclusion is the strong evidence of a significant data gap when comparing information available regarding the stock of smaller-sized stationary engine generators in the electronic records of New York State and New York City contrasted with an estimated inventory of stationary generators based on several decades of engine sales information.

IV.1. Number and Type of Generators in Estimated Inventory

The estimated stock of operating engine generators, in the 1kW to 2,000kW power size class, is quite significant, totaling nearly 750,000 units. As shown in Table 13, a very sizable share of that total are engines less than 25kW. However, even if one were to ignore the smallest power size class, 1kW to 25kW, there are estimated to be nearly 60,000 stationary engine generators in New York State between 25kW and 2,000kW, as shown in Table 14.

Power Range	Diesel	NatGas	Gasoline
<25 kW	553	51,028	633,845
25-150 kW	13,388	16,006	2,503
150-300 kW	10,521	1,074	120
300-450 kW	5,734	122	-
450–560 kW	893	190	-
560–1,000 kW	3,607	273	-
1,000–2,000 kW	3,133	274	-
Total by Fuel type	37,829	68,967	636,468
Grand Total			743,264

Power Range	Diesel	NatGas	Gasoline
25-150 kW	13,388	16,006	2,503
150-300 kW	10,521	1,074	120
300-450 kW	5,734	122	-
450–560 kW	893	190	-
560–1,000 kW	3,607	273	-
1,000–2,000 kW	3,133	274	-
Total by Fuel type	37,276	17,939	2,623
Grand Total			57,838

Tables 13 and 14, Estimated Generator Inventory by Size Class and Fuel Type.

The information that is currently available in electronic State and City records represents a very small percentage of this estimated stock. The confidence level bounding the estimates based on the national sales totals from PSR was not developed in this analysis. However, we conclude that for a variety of reasons discussed in Section II.1.b External Corroboration of the Estimated Generator Inventory, the information in the electronic records of the State and City falls markedly short of the actual stock of stationary engine generators.

IV.2. Distribution of Estimated Inventory by Size and Fuel Type

In the estimated inventory, diesel engines are the dominant type of stationary electric generators in the categories from 150kW up to 2MW. Natural gas engines are about ½ of the 25kW to 150kW category (and diesel is 42%). The smallest engine generators, those in the 1kW to 25kW are predominantly gasoline powered, though natural gas engines account for approximately 8% of that category. A full breakdown is shown in Table 15.

Power Range	Diesel	NatGas	Gasoline
<25kW	0.08%	7.44%	92.47%
25-150kW	41.97%	50.18%	7.85%
150-300kW	89.81%	9.17%	1.02%
300-450kW	97.92%	2.08%	0.00%
450–560kW	82.46%	17.54%	0.00%
560–1,000kW	92.96%	7.04%	0.00%
1,000–2,000kW	91.96%	8.04%	0.00%

Table 15, Percent Allocation of Estimated Inventory to each Fuel Type by Size Class

IV.3. Distribution of Estimated Inventory and Emission Factors by Vintage

PSR's estimated generator inventory sheds light on the stock of engines, their size, their vintage (age of installation) and their rough geographical distribution across New York State. The age of installation of these generators is a particularly important attribute of the estimated inventory. We know that the emissions rates for air pollutants for the older vintage engines can be orders of magnitude worse than today's models of like power size and fuel type.

For example, a non-emergency diesel engine between 150kW and 300kW installed in 1991 has a CO emission factor of 5.70 g/ kWh, and a $PM_{2.5}$ emission factor of 0.68 g/ kWh. By 2000, the emission factors for a new diesel engine of the same size had fallen to 0.72 g/ kWh of CO, an 87% reduction, and 0.14 g/ kWh of $PM_{2.5}$, a 79% reduction. By 2016 however, the emission factors had fallen even further to 0.17 g/ kWh of CO and less than 0.02 g/ kWh of $PM_{2.5}$. This is a reduction of 76% and 88% for CO and

$PM_{2.5}$, respectively, from 2000, and importantly a 97% reduction in both criteria pollutants compared to a 1991 engine.

Shown in Table 16, across all engine sizes and fuel types in the estimated inventory 42% are pre-2004 vintage, a cumulative total of 312,111 engine generators. Of those, 109,670 engine generators are pre 1997 vintage, 15% of the total inventory. If we focus on diesel engine generators we find that more than 1/3 of the diesel engine generators were installed prior to 2004. This represents an estimated total of 12,920 diesel generators in New York that were installed prior to 2004.

Vintage	Estimated Number of Generators	Percentage of total	Cumulative Percentage	Cumulative number
Engines Pre-1997	109,670	15%		
1997 - 2003	202,441	27%	42%	312,111
2004 - 2010	203,313	27%	69%	515,424
2011-2016	227,840	31%	100%	743,264
Total Engines				**743,264**
Diesel Pre-1997	4,689	12%		
1997 - 2003	8,231	22%	34%	12,920
2004 - 2010	11,476	30%	64%	24,396
2011 - 2016	13,433	36%	100%	37,829
Total Diesel Engines				**37,829**

Table 16, Distribution of Estimated Inventory by Vintage

The impact of the continued operation of old, high emitting fossil-fired engine generators can be quite substantial. The Excel Tool[27] provides a mechanism for examining and quantifying the air emissions impact of a State (or sub-state area) programmatic initiative that induces the "early retirement" of the stock of the oldest and highest emitting generators.

The Excel Tool provides the ability to investigate the gross emissions impacts of scenarios of generator usage patterns, regulation, or retirement across six types of air pollutants. The scenario analyses within this paper are merely illustrative of the many possible ways in with the tool can be used. In this study we have utilized the estimated generator inventory and the set of key exogenous assumptions (allocation of generator use type and run-hours) regarding the duty cycles in each power size class and fuel type. Subject to those key assumptions and the accuracy of the estimated generator inventory, this tool allows a user to estimate a benchmark for the quantity of the current gross emissions from these generators. Furthermore, as demonstrated in Section III. Test Scenario Analyses and Results, we have demonstrated usage of this model to estimate the potential impact on gross emissions from engine

[27] II.3. Describing the Excel Tool

generators resulting from changes in their operation that results from extreme weather events or price signals.

There are many opportunities for future work with the Excel Tool in areas including environmental policy applications, further refinements to the emissions matrix, sample survey or other means of external corroboration of the estimated generator inventory. The tool itself has been built with several avenues for users to alter key assumptions on use type allocation and run-hours, but this flexibility could be further extended. Another interesting area for enhancements would be attaching this tool to existing air quality models. This estimated inventory assists State and City air regulators by providing some insights into an important area where significant data gaps exist.

IV.4. Opportunities to refine PSR estimated inventory / methodology and emissions factors

Two areas of potential further study are further refinement of both the estimated generator inventory from PSR and the database of emissions factors. While the difference between permitted engines and PSR estimated engines in New York State is comparable to that in the 2003 NESCAUM report, one unexpected discrepancy with DEP permits arose. For the 450-560kW generator size class in Kings, Queens, Bronx, and Richmond Counties, than the number of permitted engines on record with DEP was larger than PSR's estimated inventory. Tracing the reasons why this occurred and what in the current PSR methodology would cause this result is a potential area for further refinement.

In general, the results of this analysis, which has yielded similar conclusions to the 2003 NESCAUM study, disclose a wide discrepancy between the estimated stock of engine generators based on permit data as compared with the estimate using the PSR methodology. This outcome was found in all but one of the 9 NESCAUM states and re-confirmed in this analysis. In the 2003 estimates of the generator stock based on New York State DEC permit records were just 11% of the estimate using the PSR method. In this study we found that the NYC DEP records were on average 37% of the estimated stock using the PSR approach. The agreement of the NYC DEP records with the PSR estimates were better in the two largest size classes, 58% agreement in the 1,000kW to 2,000kW size classes. We were unable to obtain similarly configured records from the New York State DEC, in order to make a similar comparison.

These results show a serious data gap and highlight the importance of developing a proper inventory. The PSR estimated inventory, which utilizes a top down approach allocating a national engine generator database to New York State, New York City and the Con Ed Service Area, provides one method for estimating the number, age, size and rough location of generators in New York. At a time when ownership of distributed generators is growing in New York State, it is critical that the air regulation agencies re-assess their data collection, electronic recording, and data access procedures to better assess the generator stock and its characteristics. This will give policy makers a sound foundation for assessing how policies and climate change may cause increased use of these resources, and potentially increase emissions.

For the emissions factor database, there is potential to identify more robust sources of quantitative engine testing data across all fuel types, size classes, and vintages. For many engines, especially smaller and older engines, the emissions factors are based on very small sample sizes. Finding more studies on more varied engines of the same size, vintage, and fuel type would strengthen the estimated emissions factors for these engines.

IV.5. Opportunities to refine Excel Tool functionality and baseline assumptions

The functionality of the tool can be augmented and expanded to tailor it to future policy research questions. A full geographic breakdown of emergency generator emissions, in addition to the geographic breakdown of peaking generator and baseload generator emissions can be added to the model. The ability to alter run-hours by size class, and not just fuel type and use type, would also allow more scenarios to be constructed in the model.

Another possibility is to add the ability to alter the vintage distribution of the generators within the estimated inventory for scenario analysis. This would allow examination of the potential impact of policies encouraging or requiring the retirement and replacement of older engines.

IV.6. Opportunities to integrate with air quality models

As stated from the outset, this Excel Tool is constructed to generate gross changes in emissions due to changes in operation of small fossil-fired DG. One opportunity is for larger-scale emissions and air quality models or frameworks to integrate the fossil-fired DG emissions results from this tool. Combining the gross emissions changes from this tool with a marginal emissions model could enable more accurate determination of net emissions changes from changes in DG usage or grid outages.

IV.7. Opportunities for further research in other jurisdictions

The methodology underlying this Excel Tool is readily portable to other geographic areas outside New York. Hurricanes Harvey and Maria devastated Texas, and especially Puerto Rico, in the Fall of 2017, causing lasting outages. In the case of Puerto Rico, nearly the entire grid for the island was incapacitated. Large parts of Puerto Rico relied on fossil-fired distributed generators to maintain or regain electric service for a very long period of time.

In Texas, in addition to the impact of Hurricane Harvey, there is reason to believe that evolving markets, new rate structures, and emerging business models may create incentives that encourage an increase in the operating hours of certain forms of DG that are run for reliability and/or peak shaving purposes. The Electric Reliability Council of Texas (ERCOT) runs two demand-response programs. The first is a traditional load-reduction based program, and the second is an Emergency Response Service that sells power directly back into the grid. Both of these programs are considered emergency use by Texas regulation and do not require stricter non-emergency emissions regulations.[28] With the lack of a capacity market in Texas, these demand-response programs are a lucrative market with a large potential for growth. Already, new businesses are being formed around Texas demand-response markets. One example is Enchanted Rock, an energy management company that installs, owns, and operates

[28] "Federal and State Air Regulations for Stationary Diesel-Fired Engines in Demand Response Programs." http://www.ercot.com/content/wcm/key_documents_lists/127793/TCEQ_Demand_Response_Memo_9-13-17_Updated.pdf

hundreds of megawatts of natural gas backup generators.[29] Its business model includes contracting with HEB supermarket stores to own and operate their emergency back-up power, while also bidding into ERCOT Emergency Response Service Demand-Response to increase their revenue.[30]

This Excel Tool can help to identify the potential impacts of climate events and an already-expanding, loosely regulated demand-response program on generator emissions. The effect on criteria pollutant and CO_2 emissions could be great, especially if the engines enrolling in demand response are of older vintage due to the differing emissions standards for demand-response eligibility in ERCOT from those in the Northeast.

India is another potential for study with the Excel Tool and DG inventory estimation technique developed in this study. Much of the country still relies on fossil-fired distributed generation for either grid stability or primary electric service, and air quality is notoriously poor. PSR maintains a detailed longitudinal database in India, somewhat similar in construction to the US engine generator database that underlies this analysis. One could attach to that information a detailed matrix of emissions factors relevant to the size class, fuel type, and vintage of generators in a region or state in India. Knowing what the in-service distributed generation stock looks like and how it is operated could give insight into how fossil-fired generator use could be modified through policy in India to provide cleaner air.

IV.8. Conclusion

The PSR Estimated Inventory, the detailed Emissions Matrix, and Excel Tool developed in this study provide a powerful analytical resource that can be utilized or adapted to address a variety of concerns pertaining to fossil-fired DG in New York State and elsewhere. This study has identified a significant data gap with regard to the tracking and permitting of fossil-fired DG under 2MW. We identified the potential current emissions from these generators, and how gross DG emissions could potentially increase under future economic conditions and climate events. The Excel Tool and estimated inventory developed in this study provides policy makers with the ability to assess a variety of options to address DG emissions. This unique analytical system offers regions and states a new ability to assess the current impacts and forecast the future consequences of changes in the usage of fossil-fired distributed energy resources.

[29] http://www.erockhold.com/

[30] http://www.erockhold.com/reliability/; http://www.erockhold.com/merchant-dg-sites/

Appendix

1. Illustrative Example of the Estimated Engine Generator Inventory: New York City

			Units aggregated over this period			Year of Installation				Total In-Service Population 2016
Geography	Fuel Type	Power Range	1981-1990	1991	1992	1993	2013	2014	2015	
NY City	Diesel	<25 kW	XX	XXX				XXX	XXX	XXXXX
NY City	Diesel	25 - 150 kW	XX	XXX				XXX	XXX	XXXXX
NY City	Diesel	150 - 300 kW	XX	XXX				XXX	XXX	XXXXX
NY City	Diesel	300 - 450 kW								
NY City	Diesel	450 - 560 kW								
NY City	Diesel	560 - 1000 kW								
NY City	Diesel	1000 - 2000 kW								
NY City	Natural Gas	<25 kW								
NY City	Natural Gas	25 - 150 kW								
NY City	Natural Gas	150 - 300 kW								
NY City	Natural Gas	300 - 450 kW								
NY City	Natural Gas	450 - 560 kW								
NY City	Natural Gas	560 - 1000 kW								
NY City	Natural Gas	1000 - 2000 kW								
NY City	Gasoline	<25 kW								
NY City	Gasoline	25 - 150 kW								
NY City	Gasoline	150 - 300 kW								
NY City	Gasoline	300 - 450 kW								
NY City	Gasoline	450 - 560 kW								
NY City	Gasoline	560 - 1000 kW								
NY City	Gasoline	1000 - 2000 kW								

2. Contacts and References

2.1 Emissions Matrix

We interviewed by phone and in person, staff at Engine Manufacturers Association (EMA) and the Institute of Clean Air Companies (ICAC). We interviewed Patrick Barrett of the Caterpillar Corporation, Americas Commercial Gas Territory Manager/Account Manager, Office 309 675-0172, cell 781 254-4231, BARRETT_PATRICK_J@cat.com. We requested from Mr. Barrett copies of the technical specification sheets for larger, natural gas fueled engines, made by Caterpillar. We contacted and received data from Scott Yappen, Director, Business Development, Foley Power Systems | Caterpillar Dealer. Mr. Yappen provided several technical specification sheets that were used in our analysis.

When faced with data needs, for example conversion factors for disaggregating total PM emissions into PM_{10} and $PM_{2.5}$ for each fuel type, Pace staff contacted experts, including staff at the New York Department of Environmental Conservation.

Our team reviewed relevant technical literature on this topic. In particular, we read the following as a means of corroborating missing and earlier period data:

> "Emissions of regulated pollutants from in-user diesel back-up generators". Atmospheric Environment. 40 (2006) 4199-4209 Sandip D. Shah, David R. Cocker III, Kent C. Johnson, John M. Lee, Bonnie L. Soriano, J. Wayne Miller
>
> "Case studies of stationary reciprocating diesel engines retrofit projects". Manufacturers of Emission Controls Association, August 2007.
>
> "Reduction of Particulate Matter Emissions from Diesel Backup Generators Equipped with Four Different Exhaust After treatment Devices". Sandip D. Shah, David R. Cockerill, Kent C. Johnson, John M. Lee, Bonnie L. Soriano, and J. Wayne Miller. Environ. Sci. Technol. 2007, 41, 5070-5076

We interviewed Dr. Sandip Shah, primary author of several reports on emissions from stationary diesel engines. We communicated and received advice from J. Wayne Miller, Department of Chemical and Environmental Engineering, UC-Riverside, Riverside, CA 95201. wayne@cert.ucr.edu

2.2 Scenario Analysis

Climate Event

a) New York State Department of Public Service 2016 Electric Reliability Performance Report, Appendix pp. 4-6

b) Larsen, P., LaCommare, K., Eto, J., Sweeny, J. “Assessing Changes in the Reliability of the U.S. Electric Power System.” Lawrence Berkeley National Laboratory, August 2015.

c) Lau, W., Shi, J., Tao, W., Kim, K. “What would happen to Superstorm Sandy under the influence of a substantially warmer Atlantic Ocean?” Geophysical Research Letters 43(2).

d) Horton, B., Lin, N. “Hurricane Sandy’s flood frequency increasing from year 1800 to 2100.” Proceedings of the National Academy of Sciences 113(43).

e) https://newyork.cbslocal.com/2016/10/11/superstorm-sandy-could-happen-again/

Demand-Response and Critical Peak Pricing

Persons Interviewed:

a) Cordero Butch, California Air Resources Board; E-mail: Butch.Cordero@arb.ca.gov

b) Nesamani Kalandiyur, Manager, California Air Resources Board, E-mail: ksnesa55@gmail.com

c) Michael Pope, Director of Education, Electrical Generating Systems Association. E-mail: m.pope@egsa.com

d) John Barnes, Chief, Division of Air Resources, NY Department of Environmental Conservation, E-mail: John.Barnes@dec.ny.gov

e) James Winebrake, RIT, E-mail: jjwgpt@rit.edu

f) Haley Armstrong, Institute of Clean Air Companies, E-mail: HArmstrong@icac.com

g) Michael Goo, Partner AJW Inc, E-mail: Mgoo@ajw-inc.com

h) Amengual Gilbert, Director of Marketing, Solar Turbines

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3. List of Defined Terms

Baseload Generators	Generators that operate in a steady-state for the majority of the year. For example, they may run continuously 24/7, 16 hours a day 5 days a week, or 24/7, but only during summer and winter months.
Con Ed Service Area	The five counties within New York City (Bronx, Kings, New York, Queens, and Richmond) plus Westchester County.
Criteria Pollutants	Pollutants used to set National Ambient Air Quality Standards under the Clean Air Act. The Pollutants relevant to generator emissions are NO_X, $PM_{2.5}$, PM_{10}, VOCs (due to their role in ozone formation), and CO.
Distributed Generation	Electric generation sourced near or at the site of its consumption. In contrast to a central generation facility, which is large and remote from those that consume its electricity, distributed generators are often much smaller and located at the end-points of a traditional electric distribution network.
Emergency Generators	Fossil-fired electric generators designed to provide on-site power in the event of a grid outage. They have less stringent emissions standards than non-emergency generators, but more stringent rules on how much they can be used outside of emergency situations.
Emissions Matrix	The average emissions, in grams per kilowatt-hour, of the criteria pollutants and CO_2 for a generator of each size class, vintage, and fuel type.
Estimated Generator Inventory	PSR's estimate of the population of fossil-fired electric generators under 2MW in New York State, the five counties of New York City, and Westchester County. It is disaggregated by year of installation, seven size classes, and three fuel types.
Excel Tool	The Excel Tool combines the Estimated Generator Inventory and the Emissions Matrix with run hour and usage data to provide estimates of changes in generator emissions under different use conditions.
Fossil Fuel Fired Generators	Generators fueled by gasoline, natural gas, or diesel fuel.
Gross Emissions	Emissions from the estimated installed generator inventory under various operating conditions. It does not include net impacts on other sources of emissions, such as offset grid emissions from fossil-fuel fired central station generation.
Peaking Generators	Non-emergency generators that run for short periods due to specific on-site energy needs or economic incentives.

Power Size Class	In the Estimated Generator Inventory, an estimate of the number of generators in each of a range of sizes was made. The categories are 1-25kW, 25-150kW, 150-300kW, 300-450kW, 450-560kW, 560-1000kW, 1000-2000kW.
Reference Case	The estimate of the current yearly run-hours and use type (baseload, peaking or emergency) for each size class and fuel type.
Run-hours	The average number of hours of operation for an engine of a certain size class and fuel type.
Stationary Engine Generator	A fossil-fired generator that is permanently attached to the site where it operates.
Vintage	The year that a generator was first installed.