AS THE GRID GETS CLEANER, WILL MICROGRIDS LOWER EMISSIONS IN NEW YORK?

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Executive Summary

In the fall of 2012, Hurricane Sandy struck the New York metro area, knocking out power for more than 8.5 million people.[1] More than 50,000 utility workers from around the nation and Canada were recruited to assist the utility company Consolidated Edison[2] in getting the power back on, but some New Yorkers were left without power for weeks.[3] Natural disasters are one of several factors driving a recent surge in interest in microgrids, a local source of power that can disconnect from the grid and continue serving a single building, or an entire campus, in the event of a blackout.

Combined heat and power, or CHP, is one technology that has been used in microgrids in New York. CHP is similar to a combustion natural gas plant, but it uses the heat left over from making electricity to provide thermal energy needed in buildings. When used under ideal conditions, the system's efficiency can be upwards of 60-80%, making better use of fossil fuel resources.[4]

Since Hurricane Sandy, New York State has moved aggressively on renewable energy and climate goals. In 2015, the Governor's Office issued the State Energy Plan, which called for goals of 50% electricity production from renewable resources by 2030, and a 40% reduction in greenhouse gas (GHG) emissions from 1990 levels, also by 2030. In this context, if microgrids are going to receive state support, they will need to contribute to these climate goals.

As emissions from grid electricity decrease with added renewable generation, how will a microgrid need to be designed to contribute to these goals? Can a CHP microgrid deliver an emissions savings? If so, under what operating conditions?

To address these questions, a community microgrid using CHP is modeled for a fictional town in Westchester County, New York. Energy demands for five buildings are simulated and the electric and thermal operations of the CHP microgrid is modeled for every hour between 2018-2030.

Traditionally, diesel generators have been used to provide backup power. But diesel has some important downsides: it's more expensive to operate than the grid, fuel can be hard to come by in an extended emergency, and the nitrogen oxide emissions from burning diesel have been linked to 38,000 premature deaths a year worldwide.[5]

While the value of reliability is hard to quantify, there are microgrids that have proven themselves when the grid failed, and likely saved lives. In September of 2014, during Hurricane Sandy, every installed microgrid in the New York City area remained operational,

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[1] *Office of Electricity Delivery and Energy Reliability, U. D. (2012). Hurricane Sandy Situation Report #19. Situation Report.*
[2] *Webley, K. (2012, November 26). Hurricane Sandy By the Numbers: A Superstorm's Statistics, One Month Later. TIME.com.*
[3] *Riddell, R. (2013, January 23). The 10 Longest Power Outages of 2012. UtilityDive.com*
[4] *Howard, B. (2014). Combined heat and power's potential to meet New York City's sustainability goals. Energy Policy, V.65*
[5] *New Scientist Staff. (2017, May 15). Diesel Fumes Lead to Thousands More Deaths Than Thought . New Scientist.*

including those at Co-Op City in the Bronx, Princeton University, Goldman Sachs, and New York University.[6]

Microgrids might also provide economic benefits through everyday operations. When the microgrid can make more electricity than the "load" it's serving requires, and when the price for electricity on the grid is higher than it costs to produce, the microgrid can export additional electricity to the grid and make a profit. Increasingly, selling electricity back to the grid is being hailed as a way to pay for the high initial capital costs of microgrid infrastructure.

Both the reliability and the economic benefits of microgrids are clear and getting clearer. But as we will see in this report, the emissions benefit of a CHP microgrid is less obvious.

Today, electricity in New York is generated mostly by natural gas (40%), nuclear (31%), and hydro power (20%). New York's average emissions factor, is 467.88 lbs CO_2/MWh, the eighth lowest in the country. An emissions factor is determined by taking the total source emissions produced and dividing it by the total energy used.

Three future scenarios are modeled showing how the electricity mix in New York might change between 2018-2030. These changes in the electricity mix lead to differences in average emissions factors over this period. These scenarios are used as a background against which to compare the model community's microgrid performance.

Using these scenarios, it's determined that before a microgrid is put in place in the model town, the community's average emissions factor between 2018-2030 would range between 484.34 lbs CO_2/MWh to 387.36 lbs CO_2/MWh. This establishes a lower bound.

When the CHP microgrid is operating on its own, without a grid connection, its average emissions factor is 948.31 lbs CO_2/MWh. This establishes an upper bound.

When the microgrid is connected to the grid, sometimes buying electricity from the grid and sometimes selling it, the average emissions factor is 777.91 lbs CO_2/MWh – 743.06 lbs CO_2/MWh, which is 61%-92% higher than the baseline. This suggests that a CHP microgrid can raise emissions.

A sensitivity analysis shows that the price for electricity that the microgrid receives from the grid affects the way the microgrid operates, with higher prices causing higher emissions factors. As the CHP system makes more electricity to sell, the waste heat cannot always be used.

A microgrid does not in and of itself provide an environmental benefit. CHP is a technology that can be used to increase reliability, provide heat, and potentially lower costs. But optimizing its operations by using least-cost economic dispatch can lead to a higher average emissions factor over the baseline. When planning for new distributed generation, this report offers three conclusions: 1) Microgrids must match or beat future emissions factors, not today's emissions factors, 2) a community using CHP should have a higher demand for heat than electricity, 3) microgrid operations can be greatly affected by even small price signals from the grid.

[6] *Morgan, E., Valentine, S., Blomberg, C., Limpaecher, E., & Dydek, E. (2016, April 5). Boston Community Energy Study - Zonal Analysis for Urban Microgrids.*

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Introduction

In the fall of 2012, Hurricane Sandy struck the New York metro area, knocking out power for more than 8.5 million people.[7] More than 50,000 utility workers from around the nation and Canada were recruited to assist the utility company Consolidated Edison[8] in getting the power back on, but some New Yorkers were left without power for weeks.[9]

And, according to the National Climate Assessment, storms such as Hurricane Sandy will likely increase in intensity, frequency, and duration over the coming decades.[10]

Storms like Sandy, that caused extended electric outages, have led many communities to search for backup generation options that would provide added resiliency. This situation is one of several factors driving the recent surge in interest in microgrids, local sources of power that can disconnect from the grid and continue serving a single building, or an entire campus, in the event of a blackout. Accordingly, over the last decade, microgrids have been studied extensively by public agencies in New York State for their potential to improve the reliability of electricity.

In 2013, the New York Energy Research and Development Authority (NYSERDA) started a competition called the New York Prize, offering funding for specific regions that wanted to explore building a microgrid. Across the state, 83 communities submitted feasibility studies, many of which relied on a common microgrid technology called combined heat and power (CHP).[11] CHP uses a fuel, typically natural gas, to make electrical energy and then uses the waste heat produced during that process to condition a building's air and hot water. During Hurricane Sandy, all CHP microgrids in the New York City area remained operational, including those at Co-Op City in the Bronx, Princeton University, and New York University.[12] This level of demonstrated engagement with microgrids, and proof of performance, makes New York a particularly appropriate focus for a study.

As New York, and the world, face a future in which electric resiliency is more important than ever, people are looking for solutions. The grid of the future will not look the same as it does today.

At the same time, however, recognizing that the climate and the demand for resiliency in the face of extreme weather are not independent, there is also a desire to reduce the greenhouse gas (GHG) emissions that brought us to this position in the first place.

New York has also committed to reducing its carbon dioxide (CO_2) emissions. In 2016, New York's Public Service Commission adopted the Clean Energy Standard (CES), which

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[7] Office of Electricity Delivery and Energy Reliability, U. D. (2012). Hurricane Sandy Situation Report #19. Situation Report.
[8] Webley, K. (2012, November 26). Hurricane Sandy By the Numbers: A Superstorm's Statistics, One Month Later.
[9] Riddell, R. (2013, January 23). The 10 Longest Power Outages of 2012.
[10] National Climate Assessment. (2014). Climate Change Impacts in the United States.
[11] New York State Energy Research and Development Authority. (2017). Evaluation of New York Prize Stage 1 Feasibility Assessments.
[12] Morgan, E., Valentine, S., Blomberg, C., Limpaecher, E., & Dydek, E. (2016, April 5). Boston Community Energy Study - Zonal Analysis for Urban Microgrids.

established the goal that by 2030, the state would derive 50% of its electricity from renewable generation resources.[13] "One of the primary benefits of the CES," the order states, "will be a reduction in total emissions of air pollutants resulting from fossil fuel combustion." This increase in generation from renewables will likely result in lower emissions of CO_2, a greenhouse gas that represented 81% of all GHG emissions in the US in 2016.[14]

In this context, if microgrids are going to receive state support, they will need to contribute to these climate goals. And the challenge to microgrid designers is more difficult than creating a system design that will bring emissions down below what the baseline is today. Over the next 12 years, New York's electricity supply will increasingly come from renewable and zero-carbon resources. Each kWh of electricity produced in the state between now and 2030 will be cleaner than the previous kWh. As the grid gets cleaner, each unit of energy from a microgrid will also need to get cleaner, at least on average, in order for the microgrid to help the state reach its climate goals. Since most CHP systems run on natural gas, they may have a higher emissions factor than the grid average today, and certainly higher than a renewable-centric future average.

This situation raises several questions. Can a CHP deliver this level of emissions savings? Under what operating conditions? As emissions from grid electricity decrease, how will a microgrid need to be designed to contribute to these goals? How do the goals of increasing grid reliability and reducing GHG emissions interact?

Though the resiliency and economic effects of microgrids have been studied extensively in New York — as shown in the literature review that follows — some of the environmental side effects have not. The impact that CHP microgrids would have on emissions has not been fully addressed.

This project addresses the question of how the average emissions factor (CO_2 emitted per unit of energy used) for a community microgrid in New York that uses CHP will compare, between the years 2018 and 2030, to a baseline scenario of not building a microgrid.

Project Outline

Microgrids are long-term assets, with predicted lifetimes of 20-30 years. Decisions about which technologies are used in microgrids today could have lasting environmental impacts or result in large stranded costs if underutilized, or retired, for environmental reasons. The goal of this project is to better understand how microgrids are incentivized to operate, and how that might impact CO_2 emissions in the future.

This paper begins with a background on current literature about microgrids, and how they have been studied in New York. I will then discuss how this project provides needed analysis about the relationship between CHP microgrids and future emissions scenarios. Next, I will discuss the current mix of resources on the New York electric grid and create scenarios for how those resources might change over time. Next, I outline the methods of this project and the details of the model. Finally, I will highlight my results, show how a microgrid's operations are sensitive to the price of electricity on the grid, and discuss how

[13] *State of New York Public Service Commission. (2016). Order Adopting A Clean Energy Standard.*
[14] *Environmental Protection Agency . (n.d.). Overview of Greenhouse Gases.*

these results might change how policy-makers think about emissions from distributed energy resources.

Current Literature

There are many resources available on how microgrids work, their history, what sorts of technologies are being used, and what market trends are driving new developments. Here are a few examples that were helpful to me:

- "Massachusetts Microgrids: Overcoming Legal Obstacles," Harvard Law School[15]
- "Resilient Microgrids for Rhode Island Critical Services," Celtic Energy[16]
- "Microgrids: Benefits, Models, Barriers and Suggested Policy Initiatives for the Commonwealth of Massachusetts"[17]
- "Combined Heat and Power's Potential to Meet New York City's Sustainability Goals" 2014[18]
- "Year in Review: Growth of Microgrids for Resilience," Energy Manager Today[19]

I chose to focus my research on New York State government reports so that I could better understand how policy makers might be thinking about microgrids. These are the four reports to which I referred often in my research:

1. "Microgrids: An Assessment of the Value, Opportunities, and Barriers to Deployment in New York State," NYSERDA[20]
    - Describes the regulatory barriers to microgrids and distributed generation resources.
    - Cites two potential "environmental value streams" from microgrids: CO_2 reduction through increased efficiency and reduced emissions of criteria pollutants.
2. "Microgrids for Critical Facility Resiliency in New York State," NYSERDA[21]
    - Finds economic barriers to microgrids in critical facilities due to operational risk of new systems.
    - Cites the potential value to public health of lower air pollutant emissions.
3. "Distributed Energy Resources Roadmap for New York's Wholesale Electricity Markets," NYISO[22]
    - Frames microgrids in the larger context of distributed energy resources.
    - Describes how behind-the-meter dispatchable generators could be paid by the New York Independent Systems Operator.

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[15] *Emmett Environmental Law and Policy Clinic. (2014). Massachusetts Microgrids: Overcoming Legal Obstacles. Cambridge: Harvard Law School.*
[16] *Celtic Energy. (2017). Resilient Microgrids for Rhode Island Critical Services. State of Rhode Island Office of Energy Resources.*
[17] *KEMA, Inc. (2014). Microgrids: Benefits, Models, Barriers, and Suggested Policy Initiatives for the Commonwealth of Massachusetts.*
[18] *Howard, B. (2014). Combined heat and power's potential to meet New York City's sustainability goals. Energy Policy, V.65*
[19] *Danigelis, A. (2017, December 15). Year in Review: Growth of Microgrids for Resilience.*
[20] *New York State Energy Research and Development Authority. (2010). Microgrids: An Assessment of the Value, Opportunities and Barriers to Deployment in New York State. Albany, NY: NYSERDA.*
[21] *New York State Energy Research and Development Authority. (2014). Microgrids for Critical Facility Resiliency in New York State. Albany, NY: NYSERDA.*
[22] *New York Independent Systems Operator. (2017). Distributed Energy Resources Roadmap for New York's Wholesale Electricity Markets. NYISO.*

4. "Evaluation of New York Prize Stage 1 Feasibility Assessments," NYSERDA[23]
    - Describes 83 communities' Stage 1 NY Prize microgrid submissions.
    - Frames CHP systems as the preferred design of a microgrid.

The primary role of a microgrid, in these reports, is to provide better resiliency through local generation. There is also an assumed environmental benefit through: 1) improved efficiency of CHP plants over grid-level power plants, 2) lower local emissions, 3) less line loss from not having to transmit as much power over long distances on the grid.

However, I was interested in learning more about the potential environmental benefits of CHP systems, since they were the ones most commonly referred to in reports. New York State has been a leader on many environmental issues, with a policy community that might be interested in these results. But, the available literature, while addressing environmental concerns, does not perform hourly dispatch models for CHP systems and compare it to lowering emissions factors on the grid over time. To fill this gap, I decided to model a CHP system sited in New York to quantify potential CO_2 emissions factor impacts.

[23] *New York State Energy Research and Development Authority. (2017). Evaluation of New York Prize Stage 1 Feasibility Assessments.*

Today In New York

Key Definitions

What Is a Microgrid and How Does It Work?

A microgrid is any electric system—from any power source—that serves a smaller portion of the electric demand and can disconnect, or "island," from the greater electric infrastructure around it. A microgrid creates a redundant source of energy, which dramatically lowers the chances of ever losing power completely.

A microgrid is traditionally made up of a generation source, a controller, and a distribution network to deliver energy to one or multiple buildings. The generation source can be a fossil fuel, or a renewable resource like solar or wind, and it may include some type of energy storage, such as chemical batteries. The distribution network delivers electricity, through wires, but there could also be heat generated that would be distributed as steam. In a basic design, a microgrid only operates when grid power is interrupted. This form of a microgrid provides backup power, but it is expensive relative to the amount it is used.

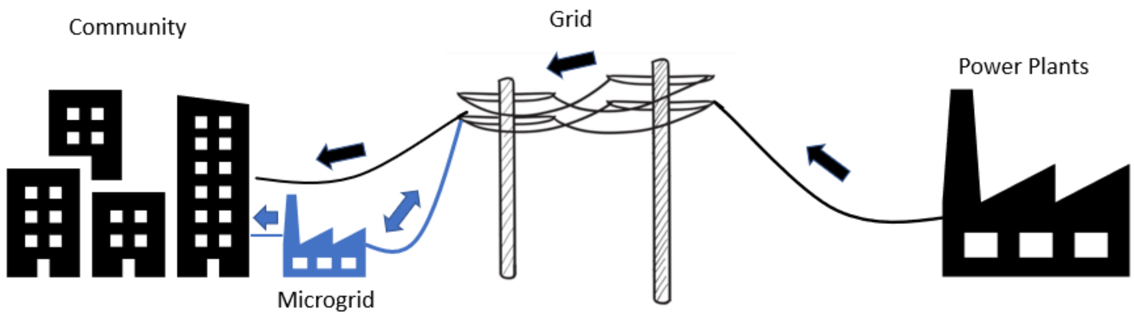

Figure 1. A microgrid can provide electricity locally or push it to the grid.

Another way microgrids can be designed is to operate at certain times to maximize a customer's utility savings. Electric customers are charged based on how much they consume, when they consume, and their peak demand for power. Microgrids can save an owner money by reducing the amount of electricity purchased from the grid, shifting the timing of the customer's demand for grid electricity, or reducing the owner's peak power demand for electricity.

In this design, electricity is sometimes purchased from the grid and other times it's sold to the grid. Microgrid operating software is designed to maximize customer returns through "optimal dispatch," choosing when to sell and when to buy power.

Microgrids can be designed to serve any size building, from a single home up to entire campuses. Princeton University's microgrid, for example, uses a 4.5 MW solar array, 15 MW gas-fired combined-heat and power plant, and thermal storage.[24]

[24] *Barter, P., & Borer, E. T. (2015, June 8). Case Study: Microgrid at Princeton University.*

What Is CHP?

In a typical natural gas power plant, natural gas is combusted with high-pressure air and that gas is used to spin a turbine, which in turn spins a generator, which makes electricity. The hot gas is usually then discarded, making a combustion natural gas plant only about 30% efficient.[25] A CHP has a similar design (Figure 2.) but it uses the waste heat to provide thermal energy needed in buildings. Moreover, when used under ideal conditions, the system's efficiency can be upwards of 60-80%, making better use of fossil fuel resources.[26]

In New York, with its long winters, a building's annual heating demands are considerable. This factor has given CHP some clear advantages in microgrid designs. After Hurricane Sandy, the New York State Energy and Research Development Authority [NYSERDA] created the NY Prize, a chance for communities around the state to apply for a microgrid feasibility study. Within the 83 feasibility studies in Stage 1, the majority involved using CHP. Of the 11 communities that were selected for Stage 2, 10 proposed using a CHP system.[27]

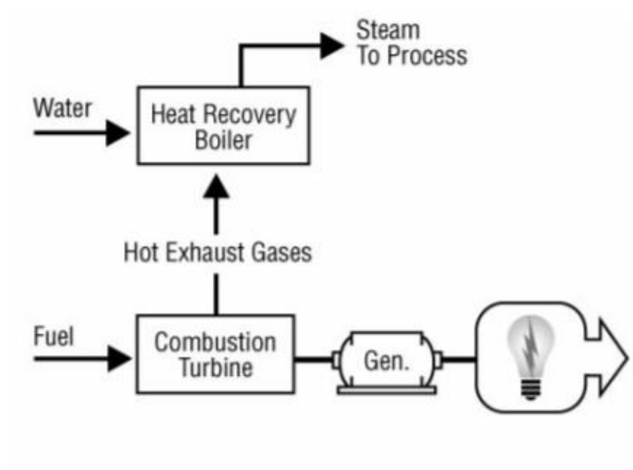

Figure 2. In CHP thermal energy is recovered after electricity generation.[28]

While there are other ways of configuring a CHP system, for industrial processes for example, the most commonly used system for commercial buildings is shown above.

Energy Demand from Buildings

Of all the energy used in the US, including fuels for transportation and industry, roughly 40% is used by residential and commercial buildings.[29] There are three primary ways that buildings use energy: supplying electricity for appliances, conditioning air, and making hot water. The proportion of the total energy use represented by each of these categories varies considerably depending on the type of building and its location. In New York, there is a

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[25] Webber, M. (2017). Chapter 19: Generation. In M. Webber, Energy 101: Energy Technology and Policy. Austin: University of Texas.
[26] Howard, B. (2014). Combined heat and power's potential to meet New York City's sustainability goals. Energy Policy, V.65
[27] New York State Energy Research and Development Authority. (2017). NY Prize: Stage 2 Winners. NYSERDA.
[28] GHG Protocol Initiative. (2006). Allocation of GHG Emissions from a Combined Heat and Power (CHP) Plant: Guide to Calculation Worksheets. World Resources Institute.
[29] U.S. Energy Information Administration. (April 2018). Monthly Energy Review, Table 2.1 Energy Consumption by Sector.

significant demand for heating, and heat production, as discussed above, is one of the advantages of using a CHP system.

What Is an Emissions Factor and Why Does It Matter?

CO_2 is produced whenever fossil fuels are combusted. The amount of CO_2 released per unit of fuel depends on the type of fuel being used. For natural gas, 117 lbs of CO_2 is produced for every million British thermal units (MMBtu) that are burned.[30] The amount of energy produced in combustion is constant. But the amount of energy that is actually *used* can change.

One way to think about emissions when it comes to energy use is an emissions factor. An emissions factor is determined by taking the total source emissions produced and dividing it by the total energy used.

$$Emissions\ Factor = \frac{All\ CO_2\ Produced, lbs}{All\ Electric + All\ Thermal\ Energy\ Used, MWh}$$

This means that the more energy that's actually used, the higher the denominator, and the lower the emissions factor. When referring to power plants, emissions factor only considers the CO_2 produced per MWh, since electricity is the only energy that usually used. For context, Table 1. shows average emissions factors for different types of power plants in New York.

Power Plant	Emissions Factors, lbs CO_2/MWh
Natural gas	**1,042.84**
Petroleum	**2,139.62**
Coal	**2,672.56**

Table 1. Average emissions factors for fossil fuel plants in New York State, 2016.[31]

When electricity is made in a modern CHP plant, there is between 1-2 times as much heat energy generated as electrical energy.[32] If all the heat from this process is recovered, a CHP plant's emissions factor could be half or even a third that of a combustion natural gas plant.

[30] *U.S. Energy Information Administration. (n.d.). How much carbon dioxide is produced when different fuels are burned?*
[31] *U.S. Energy Information Administration. (2017, July 20). New York: State Profile and Energy Estimates.*
[32] *GHG Protocol Initiative. (2006). Allocation of GHG Emissions from a Combined Heat and Power (CHP) Plant: Guide to Calculation Worksheets. World Resources Institute.*

The Case for Microgrids

Advantages for Back-up Power

Traditionally, diesel generators have been used to provide backup power. A diesel generator could be considered a microgrid since it can “island.” Diesel fuel can be stored onsite and contains more energy per gallon than gasoline.

But diesel has some important downsides. First, it’s expensive. The average price for retail electricity in New York State is $0.17/kWh, which is about half of what it might cost using a diesel generator.[33] Second, diesel biodegrades quickly and must be used within 6-12 months, adding to costs.[34] Third, after severe weather events, fuels can be in short supply if roads are inaccessible. After Hurricane Sandy, pumps at gas stations didn’t work because they relied on electricity to operate. Ports and refineries were also affected, limiting supply just when hospitals were most reliant on backup generation.[35] Finally, when diesel is burned, the exhaust contains fine particulate matter, nitrogen oxides, and potentially sulfur dioxide, which can cause lung irritation, headaches, nausea, and lung-tissue damage. Emissions of nitrogen oxide alone have been linked to 38,000 premature deaths a year worldwide, in addition to the 3.7 million deaths caused by outdoor air pollution.[36] Burning a gallon of diesel also produces roughly 22.4 lbs of CO_2, the largest contributor to climate change.[37]

The cost to provide onsite backup power will likely be greater than the costs of a grid connection alone—meaning the extra expense can only be justified in special cases. Yet backup generation is critical, and often mandated, for hospitals and other emergency facilities. And certain types of businesses, such as grocery stores, suffer significant economic losses when they lose power for long durations. Backup generation has traditionally only been used in buildings that need to stay on, for legal or economic reasons, in an emergency.

But several trends have started to impact where microgrids are being considered. First, there is a greater awareness of the changes in our climate that are leading to more weather events that impact the power system.

These events will likely become more frequent and more severe.[38] Second, the costs of technologies that can generate electricity on-site, while also producing fewer emissions than burning diesel fuel, have seen incredible cost declines. Just since 2009, the levelized cost of electricity for solar has fallen 85%, and 66% for onshore wind. Lithium-ion battery prices have dropped from $1,000/kWh in 2010 to $209/kWh in 2017.[39] When accounting for fossil fuel plant retirements, renewables made up 94% of new net capacity installations across the country in 2017.[40] Non-critical facilities such as housing developments, office

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[33] *$3 per gallon / ((144,000 Btu per gallon / 3412 Btu per kWh) * 20% efficiency) = $0.36/kWh*

[34] *BP Australia Limited. (2005, February 10). Long Term Storage of Deisel.*

[35] *Zernike, K. (2012, November 1). Gasoline Runs Short, Adding Woes to Storm Recovery. New York Times.*

[36] *New Scientist Staff. (2017, May 15). Diesel Fumes Lead to Thousands More Deaths Than Thought . New Scientist.*

[37] *U.S. Energy Information Administration. (2017, May 19). How much carbon dioxide is produced from burning gasoline and diesel fuel?*

[38] *National Climate Assessment. (2014). Climate Change Impacts in the United States. GlobalChange.gov.*

[39] *Bloomberg New Energy Finance. (2018, March 28). Tumbling Costs for Wind, Solar, Batteries Are Squeezing Fossil Fuels.*

[40] *Weaver, J. F. (2018, January 12). More than 94% of Net New Electricity Capacity in the USA from Renewables in 2017 – Emissions down 1%. . Electrek.co.*

buildings, and even wine vineyards have been willing to invest in microgrids because they can achieve greater reliability at a reasonable cost.[41]

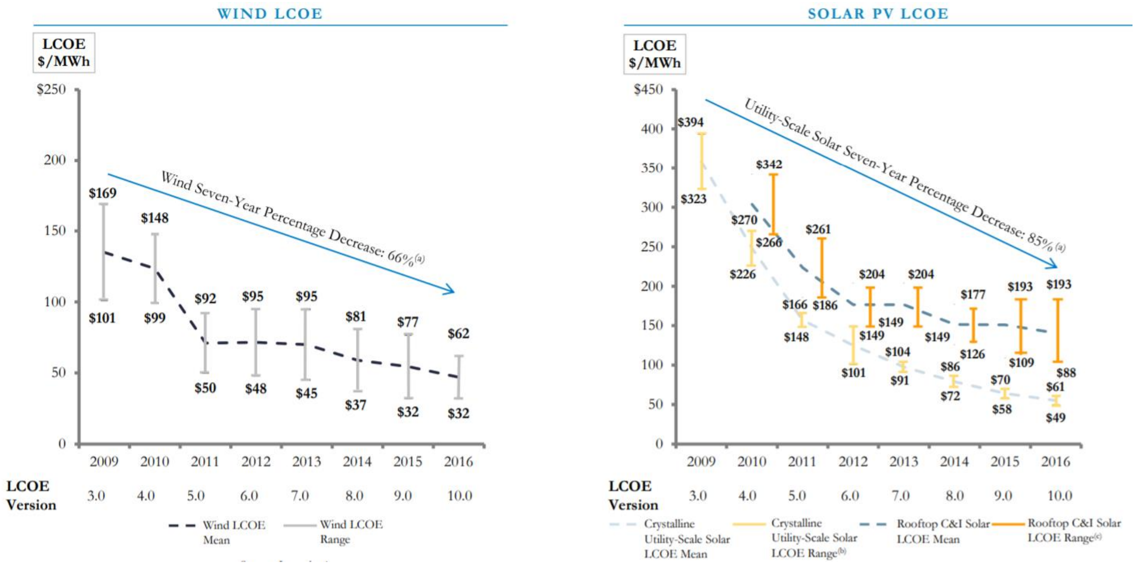

Figure 3. Levelized costs of electricity trends for solar and onshore wind, Lazard.[42]

While the value of reliability is hard to quantify, there are microgrids that have proven themselves when the grid failed, and likely saved lives. In 2013, a severe summer storm brought down the transmission line serving Borrego Springs, CA. With temperatures above 100° F, the community's microgrid stayed on and kept certain zones air conditioned, giving residents needed relief.[43] In September of 2014, during Hurricane Sandy, every installed microgrid in the New York City area remained operational, including those at Co-Op City in the Bronx, Princeton University, Goldman Sachs, and New York University.[44]

Microgrids also have the potential to provide backup power while also emitting less air pollution than the grid. As the technologies used in microgrids shift away from traditional diesel generators, and toward technologies like CHP, solar and battery storage, and fuel cells, microgrids have the potential to lower emissions, reduce costs and improve health, all while providing the reliability on which we have come to depend.

Advantages on the Energy Market

Microgrids might also provide economic benefit through everyday operations. When the microgrid can make more electricity than the "load" it's serving requires, and when the price for electricity on the grid is higher than it costs to produce, the microgrid can export additional electricity to the grid and make a profit.

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[41] *Bebon, J. (2016, October 21). Napa Valley Winery Installs Solar+Storage Microgrid. Solar Industry Mag.*
[42] *Lazard. (2016). Lazard's Levelized Cost of Energy Analysis - Version 10. Lazard.*
[43] *San Diego Gas and Electric. (2018, January 5). Borrego Springs' Claim to Energy Fame: A Microgrid That Enhances Reliability. SDGE.com.*
[44] *Morgan, E., Valentine, S., Blomberg, C., Limpaecher, E., & Dydek, E. (2016, April 5). Boston Community Energy Study - Zonal Analysis for Urban Microgrids.*

Increasingly, selling electricity back to the grid is being hailed as a way to pay for the high initial capital costs of microgrid infrastructure. The Carlyle Group, one of the largest private equity firms in the world, announced in January of 2018 that it was setting aside at least $500 million to start a new business unit that would finance and operate microgrids.[45] Further, frequent operation of certain types of microgrid technologies, like combined-heat and power, can actually make them more reliable during an emergency.[46]

Advantages of Aggregating Demand

A building's demand for electricity will change over the course of a day and year. As people wake up, go to work, turn on equipment, and then go home again, the electric demand of the building rises and falls. The more the demand changes, the more the generation must adjust, because supply and demand for electricity have to stay in sync. This changing demand stresses the resources providing power. It also means that the generation resource must be sized to meet the customer's peak demand, while not being used as much as it could be the rest of the day. For example, to provide electricity to the building in Figure 4., a generator will need to be able to deliver about 450 kW of power for a few hours in the middle of the day.

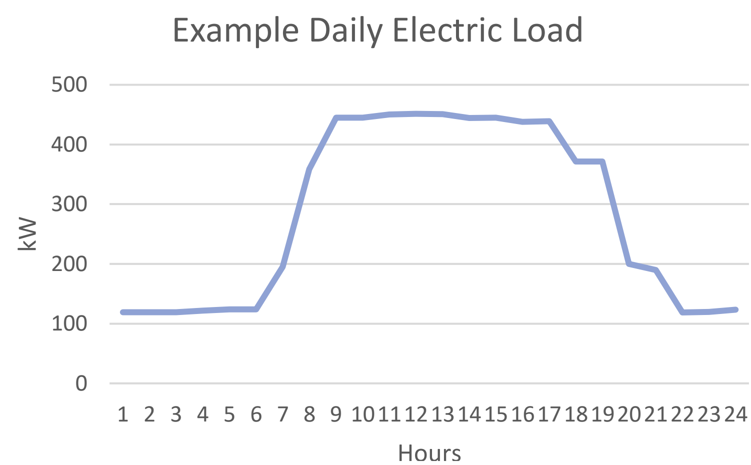

Figure 4. An example electric load for a large high school.

The variation in demand for power effects microgrid economics in two ways. The first is that the higher the peak demand, the bigger the upfront investment will be for the generation resource. One way to reduce upfront costs in a microgrid is to carefully size the generation resource to only meet the expected peak. Another way is to try to decrease the peak through energy efficiency measures or to separate out some of the building's critical load and only connect that load to the microgrid. The second way in which load variation affects microgrid economics is that whatever size the generation resource, it only earns revenue (or saves money) when it's actually operating. A 450 kW generation resource that only produces 100 kW for half the day will not be earning as much as it could. A less variable, or flatter, load curve means that the generation resource that's serving the load is being utilized more often relative to its capacity.

In a microgrid, different types of buildings can be integrated into one "load," or demand. This aggregation can offer several advantages for lowering costs. First, a more diverse group of buildings can mean that the demand for energy will be more consistent throughout a day, or even season. A school will use a lot of energy in the winter, but much less in the summer. Meanwhile, a grocery store, which requires a lot of refrigeration, might use a lot of energy in the summer. Aggregating loads across buildings means that whatever generating

[45] *Wood, E. (2016, August 29). US Microgrid Market Growing Faster than Previously Thought: New GTM Research. Microgrid Knowledge.com*

[46] *ICF. (2013, March). Combined Heat and Power: Enabling Resilient Energy Infrastructure for Critical Facilities. ICF.*

power source is serving them will stay in use for more of the year overall. For a microgrid or a power plant, the more it's used, the sooner it pays for itself.

Second, aggregating loads means that the total load is less "peaky." In a single building, one piece of equipment being turned on can lead to a rapid ramp up of generation, to meet that sudden demand. Ramping quickly can shorten the lifetime of natural gas turbines in a CHP system, and increase emissions.

And finally, joining different buildings together spreads the considerable capital expenses needed for a microgrid across several customers. A bigger system also takes advantage of economies of scale to bring down costs: each new kW of power added is typically cheaper than the previous.

Current Implementation

While this is not a new technology or concept, the rate of microgrid adoption has increased in recent years. The U.S. currently has about 160 microgrids, with 1.6 GW of capacity. This is expected to grow to 4.3 GW of capacity by 2020.[47]

Both the reliability and the economic benefits of microgrids are clear and getting clearer. But as we will see in this report, the emissions benefit is less obvious.

[47] *Wood, E. (2016, August 29). US Microgrid Market Growing Faster than Previously Thought: New GTM Research. Microgrid Knowledge.com*

New York's Electricity

New York has the lowest per capita GHG emissions in the country.[48] This is in part because a quarter of all residents use public transportation, five times the national average.[49] In terms of the power sector, emissions of pollutants have been falling for decades, largely because of the Clean Air Act. In New York, between 2000 and 2016, emissions of sulfur dioxide (SO_2) fell 98%, nitrogen oxides (NO_x) fell 87%, and carbon dioxide (CO_2) fell 43%.[50] Today, coal generation makes up only a small fraction of total electricity generation in the state, while natural gas generation has grown to over 40%, followed by nuclear at 31%, and hydro power at 20%. This generation mix led to an average emissions factor in 2016 of 467.88 lbs CO_2/MWh. This is the eighth lowest in the country, and the average emissions factor in the U.S. is 998.4 lbs CO_2/MWh.

In 2008, the state issued a moratorium on hydraulic fracturing, a way of producing natural gas from shale rock. New York's Governor, Andrew Cuomo, signed an executive order in 2014 banning hydraulic fracturing in the state, citing environmental and public health concerns.[51] New York, despite having significant shale reserves, is now one of three states, along with Vermont and Maryland, that has banned "fracking", as it's called. The state today imports most of the natural gas needed for power generation and heating, largely from Pennsylvania.[52]

In terms of solar, roughly 753 MW of the 785 MW of installed solar capacity in New York State is connected at the distribution level.[53] There is only one grid-scale solar project operating in New York, the 32 MW Long Island Solar Farm, at Brookhaven National Laboratory. Distributed solar generation has historically not been accounted for in state power generation totals because electric utilities do not necessarily know how much electricity is generated by distributed systems.[54]

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[48] *U.S. Energy Information Administration. (2017, July 20). New York: State Profile and Energy Estimates.*
[49] *Ibid.*
[50] *New York Independent Systems Operator. (2017). Power Trends: New York's Evolving Electric Grid. Retrieved from NYISO.com.*
[51] *McGeehan, P. (2017, January 9). Cuomo Confirms Deal to Close Indian Point Nuclear Plant. NYTimes.com.*
[52] *U.S. Energy Information Administration. (2018, March 30). Natural Gas. International & Interstate Movements of Natural Gas by State.*
[53] *New York Independent Systems Operator. (2017). Power Trends: New York's Evolving Electric Grid. NYISO.com.*
[54] *U.S. Energy Information Administration. (2017, July 11). EIA adds small-scale solar photovoltaic forecasts to its monthly Short-Term Energy Outlook.*

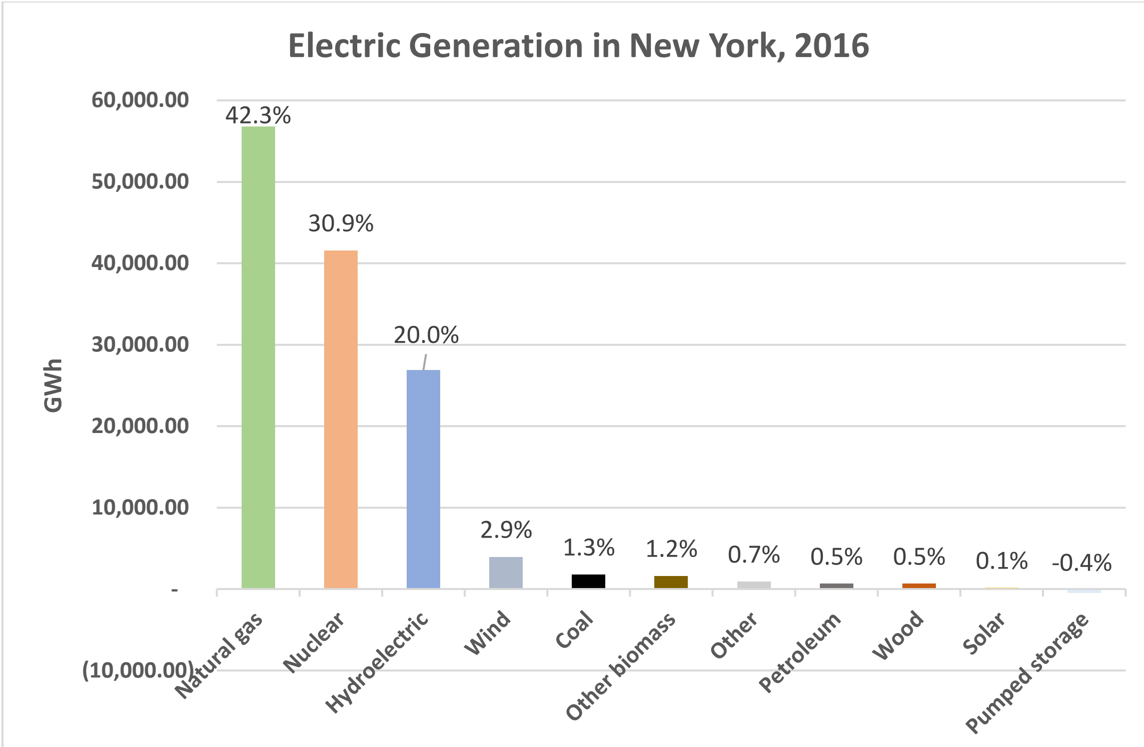

Figure 5. In 2016, natural gas plants provided 42.3% of all generation, but the rest was almost entirely from zero-carbon emitting resources.[55]

[55] *U.S. Energy Information Administration. (2017, July 20). New York: State Profile and Energy Estimates.*

Projecting the Future

Three Futures for New York State

In 2014, the Public Service Commission (PSC) launched an initiative called Reforming the Energy Vision (REV). Among REV's many ambitious goals was to reverse the trend of rising residential electricity prices of the previous years.[56] One of strategies the PSC took was to begin an aggressive campaign to increase energy efficiency investments and diversify the electricity fuel source. In 2015, the Governor's Office issued the State Energy Plan, which called for goals of 50% electricity production from renewable resources by 2030, and a 40% reduction in GHG emissions from 1990 levels, also by 2030. A year later, the PSC adopted the Clean Energy Standard, making these goals a part of statute.

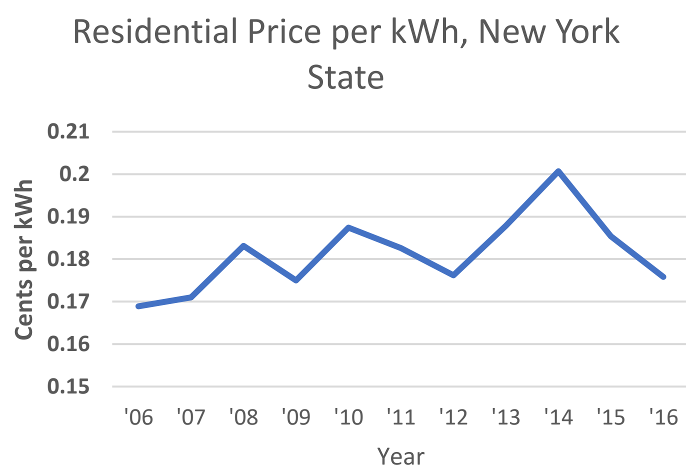

Figure 6. Rates have fallen since 2014.

However, increasing levels of renewables in the electricity mix does not necessarily mean that emissions will decrease. Nuclear power is not considered a renewable resource, but it's responsible for more than a quarter of the state's low-carbon electricity. Yet in 2017, the Governor Cuomo announced plans to close the last two reactors at Indian Point, one of the three nuclear plants in New York, citing safety concerns at having a nuclear plant operating less than 30 miles from Midtown Manhattan.[57] Regardless of the fate of Indian Point, or any given low-carbon resource, the exact make-up of the future electricity mix is impossible to know. Policies are changing quickly, and New York's energy future might turn out in any number of ways.

In trying to model how a CHP microgrid would affect emissions, I created three potential futures for the electricity mix in New York through 2030. In each scenario, I take it for granted that the state will achieve its goal of getting to 50% renewable electricity. What changes in each scenario is other 50%, the rest of the electricity mix. For all scenarios, the emissions factor for fossil fuels is assumed to be 1103.5 lbs CO_2/MWh for every year to 2030. This is a weighted average of the emissions factor from all fossil fuel resources from 2016.[58]

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[56] *State of New York Public Service Commission. (2014, August 22). DEVELOPING THE REV MARKET IN NEW YORK: DPS STAFF STRAW PROPOSAL ON TRACK ONE ISSUES.*
[57] *McGeehan, P. (2017, January 9). Cuomo Confirms Deal to Close Indian Point Nuclear Plant. NYTimes.com.*
[58] *U.S. Energy Information Administration. (2017, July 20). New York: State Profile and Energy Estimates.*

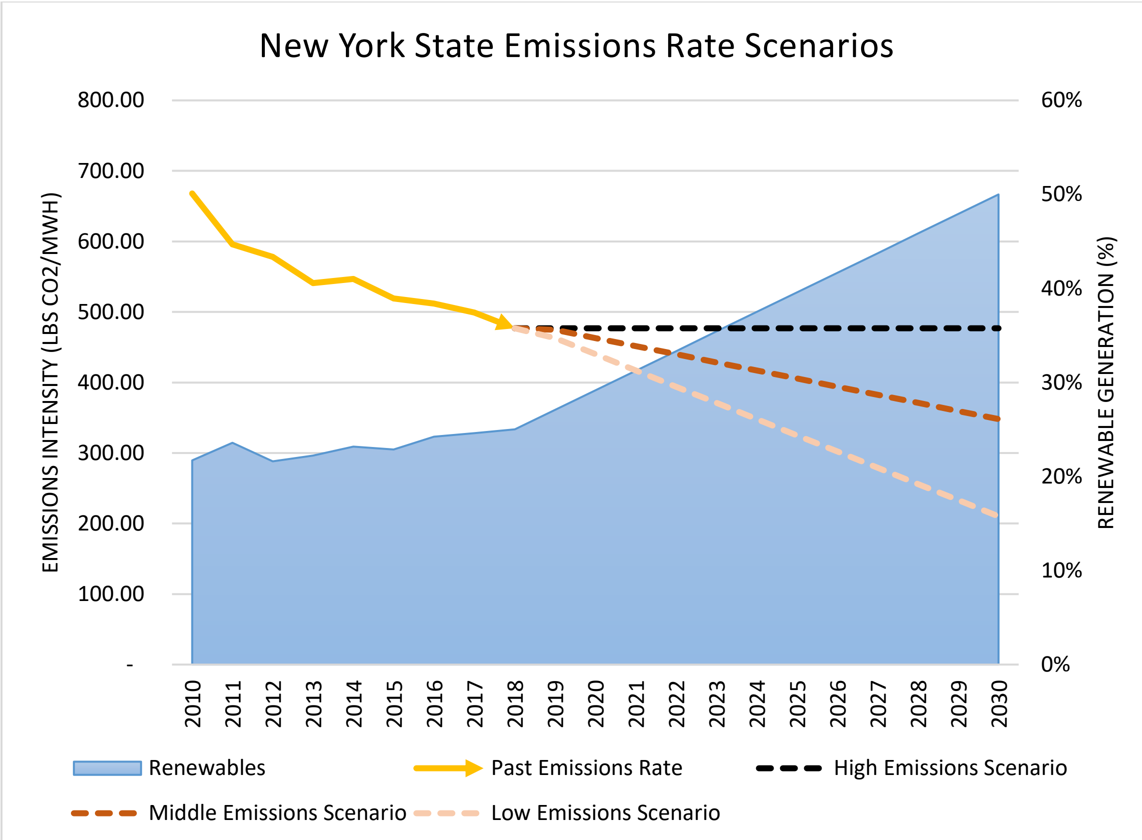

Figure 7. Potential changes in emissions factor as New York State reaches 50% renewable electricity.

High-Emissions Scenario

- **Average Emissions Factor, 2018-2030 = 476.88 lbs CO_2/MWh**

In this scenario, every new unit of renewable electricity replaces a unit of existing low-carbon electricity. This means that the grid in 2030 in New York will have same percentage of low-carbon resources on the grid as it did in 2016. The average annual emissions factor remains the same for every year between 2018-2030.

Middle-Emissions Scenario

- **Average Emissions Factor, 2018-2030 = 416.38 lbs CO_2/MWh**

In this scenario, new renewable generation replaces half a unit of fossil fuels and half a unit of low-carbon resources. The emissions factor in 2030 is 27% lower than it was in 2018.

Low-Emissions Scenario

- **Average Emissions Factor, 2018-2030 = 347.41 lbs CO_2/MWh**

In this scenario, every unit of renewable generation added to the grid displaces a unit of fossil fuel resources. This results in an emissions factor in 2030 that is 56% lower than the 2016 emissions factor.

See Appendix for complete annual data.

The Model City: Welcome to Atlantis

Modeling a Community Microgrid

The first step to simulating a community's energy load was to establish a physical location, because the surrounding climate has a big impact on a building's energy consumption. The Department of Energy describes 16 different building types in its Commercial Reference Buildings database, which represent 70% of all commercial buildings in the US.[59] Of the 16 climate zones in the US, there are two in New York.[60] I sited my community, nicknamed Atlantis, at 41°12.5' N, 73°53.6' W, roughly the location of the small town of Croton-On-Hudson. This is within climate zone 5A, which covers much of the southern part of the state. This region was chosen because the area has many characteristics that make it suitable for a microgrid, such as high electric prices and a history of reliability concerns.

Next, I used two pieces of software, HOMER Pro and eQuest, to model electric and thermal loads for five buildings in this location. HOMER Pro is a microgrid optimization tool that is widely used within the industry.[61] It is a bi-level optimization software that simulates energy demands in specific time intervals, and then minimizes both the costs for capacity planning (upfront capital) and operations and maintenance costs. Minimizing capacity means that the microgrid generation resources will be built using the least amount of power possible to meet demand. Operating costs will be limited by using the electric grid at times when it would be more expensive to operate the microgrid.

eQuest is a tool funded by the California Public Utilities Commission that provides model simulations of how a building might use energy, based on comprehensive data specific to the building's materials, mechanical systems, and occupancy.[62] The software offers users the ability to change variables such as the insulation value of the roof, the lighting technology, fenestration, heating and cooling systems, and occupancy schedules. eQuest also provides 42 building types that can be used to start a baseline model.

The types of buildings I modeled were a small municipal office, a walk-in health clinic, a large high school, a police station, and a supermarket. These types of buildings were chosen because they represented a range of facilities that a community might consider joining together under a microgrid because of their importance in an emergency. A large high school might be used as a temporary shelter and meeting place, a police station and a municipal office could be used by emergency personnel, a health clinic could treat those who have been injured, and a supermarket would preserve food supplies during extended outages.

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[59] *Data.gov. (2017, August 29). Commercial Reference Building: Large Office.*

[60] *National Renewable Energy Laboratory. (2011, February). U.S. Department of Energy Commercial Reference Building Models of the National Building Stock. NREL.gov*

[61] *Homer Energy. (n.d.). The HOMER Pro Microgrid Software. Software, V. 3.11.3 (Pro Edition).*

[62] *DOE-2. (n.d.). The Quick Energy Simulation Tool. Software, V.3.65.*

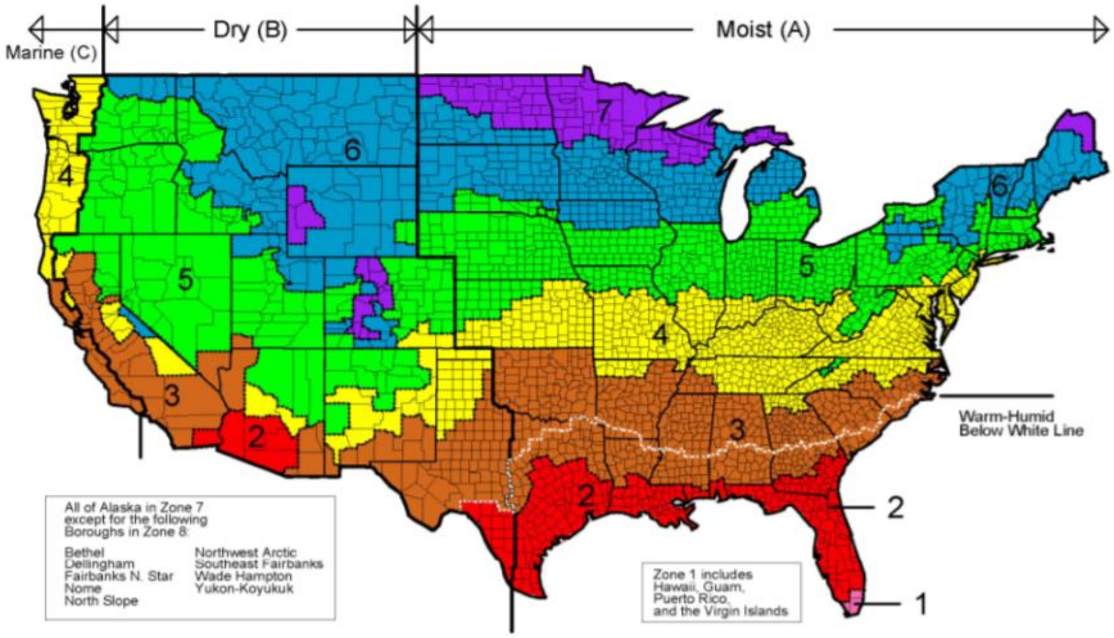

Figure 8. Climate zones used in DOE's Commercial Reference Buildings.[63]

Electric Loads

HOMER Pro can import data from the Department of Energy's Commercial Reference Buildings database[64] to generate electricity load profiles based on the location of the building. The software imports Typical Meteorological Year (TMY)[65] data specific to the location of the electricity load. The TMY data used for this model comes from New York City's Central Park, which was the closest reference point, 30 miles away.

Electric Load Summary			
	Peak Load, kW	Annual Total, kWh	Area, ft^2
Municipal	20.06	64,649.18	5,500
Clinic	110.62	317,278.95	24,962
High School	1243.31	2,905,170.62	210,886
Police Station	103.40	482,578.77	24,962
Supermarket	377.73	1,668,434.36	45,000

Table 2. Total community electric load.[66]

[63] *National Renewable Energy Laboratory. (2011, February). U.S. Department of Energy Commercial Reference Building Models of the National Building Stock.*
[64] *Office of Energy Efficiency and Renewables. (n.d.). Existing Commercial Reference Buildings Constructed In or After 1980. Energy.gov.*
[65] *National Renewable Energy Laboratory. (2008, May). Users Manual for TMY3 Data Sets. Retrieved from NREL.gov.*
[66] *Office of Energy Efficiency and Renewables. (n.d.). Existing Commercial Reference Buildings Constructed In or After 1980. Energy.gov.*

For each building, the hourly electric loads for each building were generated separately then added to one another, so that the modeled microgrid would be able to serve the combined load of all five buildings when islanding.

Figure 9. Locating Atlantis in Westchester County.

Thermal Loads

Next each building was then modeled in eQuest to simulate the expected thermal demands of each facility.

In order to model a building in eQuest, the user has to provide a full range of design parameters in order to account for the building's anticipated thermal heating and hot water needs. Default parameters were selected for the building's design, with the exception of the occupancy schedule of the police station, which was made to operate 24 hours a day, and the square footage of the health clinic and the grocery store, which were made to match the square footage of these buildings as they exist in the Commercial Reference Building database. Each building's thermal demands were assumed to be met with natural gas. Natural gas is the most common fuel for heating and hot water in New York State, and it produces about 40% fewer CO_2 emissions than fuel oil, which is the second most common fuel source.[67]

	Westchester Space Heating	NY Space Heating
Natural Gas	47%	58%
Electricity	11%	11%
Fuel Oil	38%	23%

Table 3. Space heating demand is mostly met by natural gas boilers.

The thermal loads for each building were converted from kBtu to kWh and then added together to create a community level peak thermal demand. While it's unusual to see

[67] *Environmental Protection Agency. (2014, April 4). Emissions Factors for Greenhouse Gas Inventories. EPA.gov.*

heating demand expressed in kWh, putting energy consumption figures in the same units makes it easier to make comparisons later between electric and thermal energy use.

Thermal Load Summary			
	Peak Load, kW	Annual Total, kWh	Area, ft^2
Municipal	119.47	31,175.44	5,500
Clinic	379.29	432,670.03	24,962
High School	3,282.53	684,014.77	210,886
Police Station	139.89	137,890.61	24,962
Supermarket	671.16	470,954.03	45,000

Table 4. Total community thermal load.

Putting the electric and thermal demands for these buildings together, we can compare their energy demands for electricity and heat and see how their aggregate loads change over the course of a year (Figures 9 and 10.)

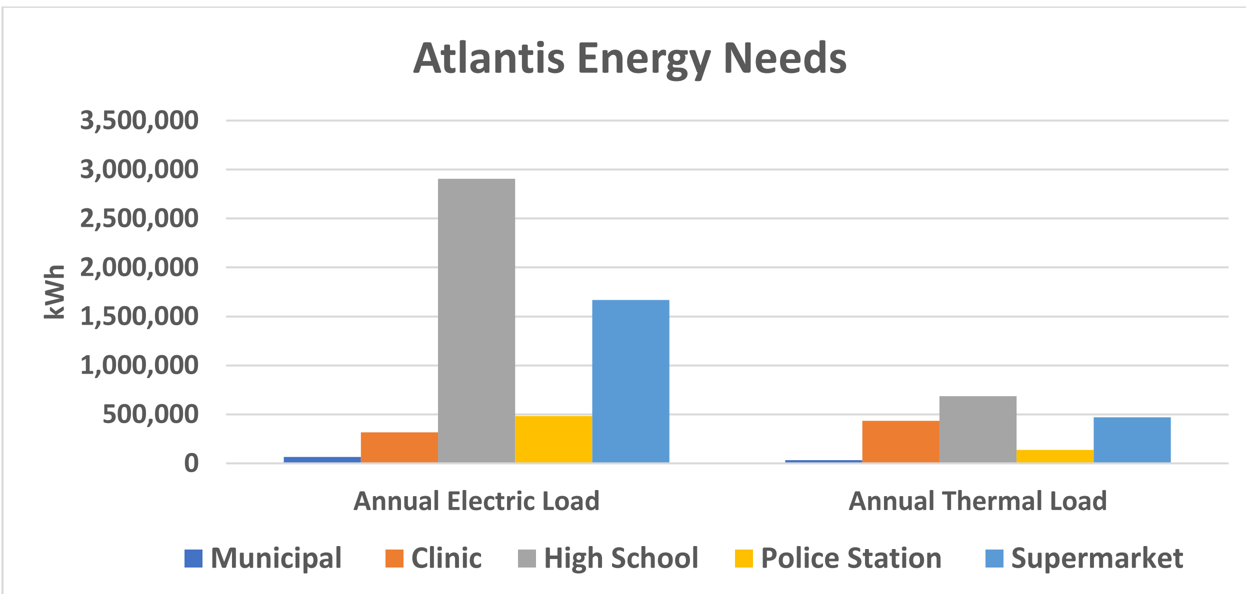

Figure 9. The electric load and thermal loads for each building in the Atlantis microgrid.

The demand for electricity at the high school and the supermarket are much larger than their heating demands. Collectively, the demand for electric energy is three times larger than the demand for thermal energy, across all five buildings.

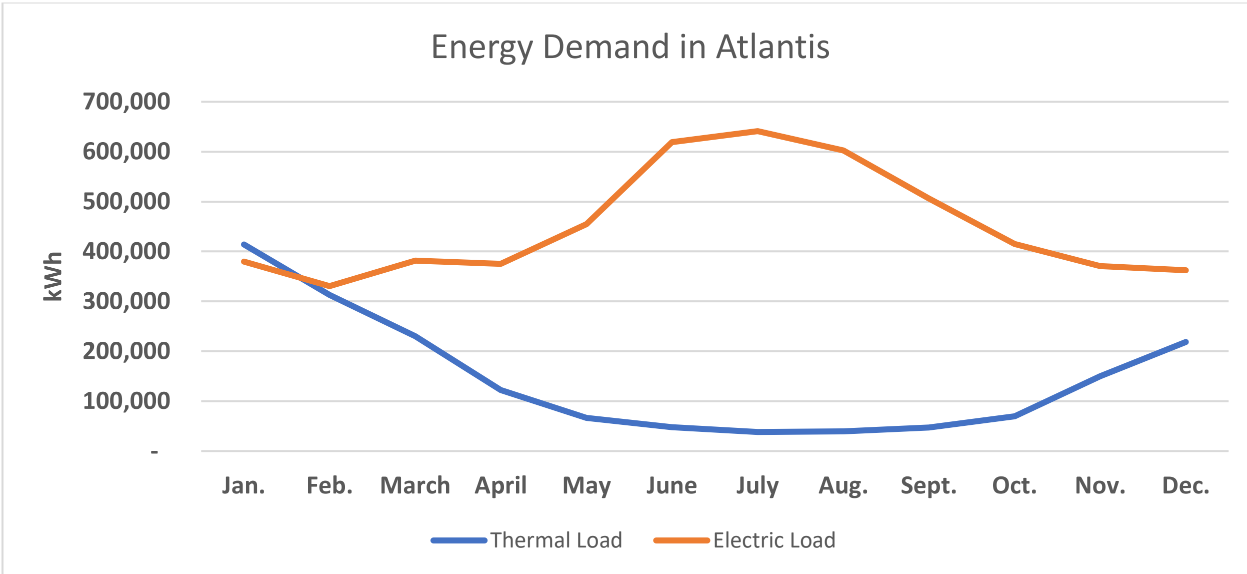

Figure 10. Total monthly demands for electric and thermal energy.

Figure 10. shows how electric and thermal demands change over time. Electric demand peaks in the summer, from an increased need for cooling which using electricity, while heating demand peaks in the winter.

Future Emissions Factors - Results

To understand the potential emissions impacts of a CHP microgrid for a community in New York, I first needed to establish a baseline: what would the community's emissions be if they didn't build a microgrid? To find out, I ran an hourly simulation of the community's demand for both electricity and thermal energy between 2018 and 2030, for each of the three statewide emissions scenarios described earlier. I then averaged the emissions factors over the entire period.

The following are some important assumptions I made when considering how prices and consumption patterns will change overtime. These assumptions are consistent across all simulations.

Variables/Attributes	Data/Assumptions	Reason
Community Peak Electric Load	1,761 kW	Load data based on DOE 16 Building Types
Community Peak Thermal Load	3,771 kW	Load Data based on eQuest modeling
Annual Electric Load Growth	-0.27%	NYISO Power Trends Report 2017
Thermal Load Growth	0%	Lack of data showing thermal load growth patterns
Emissions Factor in Year 1, CO_2 lbs/MWh	476.875	Weighted average of 2016, EIA

Emissions factor, annual change	-3%	Took the weighted average of the change in emissions for each grid region
Natural gas price	$6.58/Mcf	NYSERDA, average commercial price, November '17
Natural gas price increase	0.5% Annually	Estimate
Price per kWh	$0.17	EIA Average for New York State, 2016
Wholesale price, sell back	$0.05	Estimate
Annual price increase for grid power	$0.0005	Estimate

Baseline Emissions

Baseline, Grid only:

- **Electricity source: Electric grid**
- **Building heating source: Boiler, natural gas**
- **Hot water source: Hot water heater, natural gas**

In the baseline simulation, without a microgrid, Atlantis' average emissions factor will go down over time. This is because the demand for electricity in the state is estimated by the New York Independent Systems Operator to drop by 0.27% a year, due to efficiency gains, while grid emissions stay the same or go down. At the same time, their thermal demand, which is supported by natural gas, is not projected to grow.

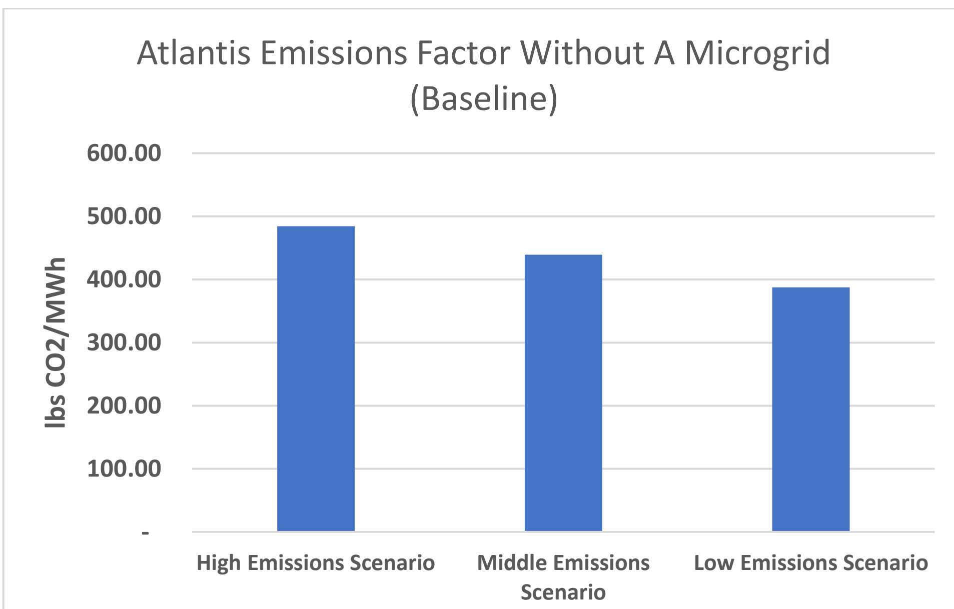

Figure 11. Baseline emissions factors for Atlantis, under three scenarios.

In this baseline case, Atlantis' average emissions factor would be between 484.34 lbs CO_2/MWh to 387.36 lbs CO_2/MWh. The community's emissions factor in 2030 would be between 0% - 20% lower than it was in 2016, depending on the statewide emissions scenario moving forward.

Microgrid-Only Emissions

Microgrid only:

- **Electricity source: CHP microgrid**
- **Building heating source: Microgrid, backup boiler**
- **Hot water source: Microgrid, backup hot water heater**

The next step was to add a CHP system and simulate what would happen to Atlantis' emissions if all its energy demand was supplied by the microgrid. Microgrids are not designed to be a community's only source of energy, but this simulation creates an upper bound, establishing the highest possible emissions factor with a community microgrid using CHP. A CHP system's emissions factor will depend on how much of the waste heat is utilized. But even if all the waste heat is used, the emissions factor will be higher than the emissions factor of the grid because all the energy in this CHP system is generated by burning natural gas, whereas less than half of the electricity from the grid comes from fossil fuels.

The results of this simulation show that Atlantis' emissions factor rises considerably over the baseline (non-microgrid) simulation for the community. The emissions factor, 948.31 lbs CO_2/MWh, remains the same regardless of the statewide emissions scenario (high, middle, or low) because this system is not connected to the grid. Changes happening on the grid do not affect a fully islanded microgrid system.

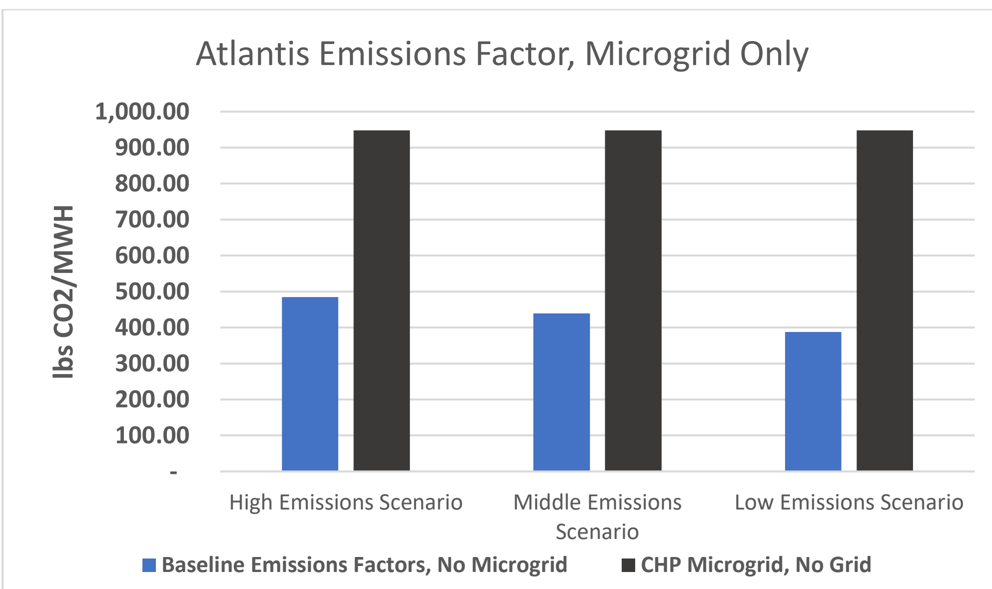

Figure 12. Microgrid only simulation produces much higher average emissions factors in all three scenarios over the baseline case.

When fully islanded for the entire 13 years, the emissions factor was 96% - 145% higher than the baseline.

Microgrid and Grid Emissions

Microgrid – Grid Connected:

- **Electricity source: Electric grid, CHP microgrid**
- **Building heating source: Microgrid, backup boiler**
- **Hot water source: Microgrid, backup hot water heater**

Finally, I connected the Atlantis microgrid to the grid and simulated hourly operations from 2018 – 2030. In this simulation, it's important to understand that HOMER, the microgrid simulation software, is making an economic decision at every hour as to whether or not to generate electricity. In this simulation, the microgrid in Atlantis receives $0.05 per kwh to sell its electricity to the grid. (This price was selected to represent a reasonable wholesale market price in current conditions, but the model would work at any price.) This is a simplified description of how a microgrid controller works, but it serves the purposes of this study.

The results of this simulation show that Atlantis' emissions factor is between 777.91 lbs CO_2/MWh – 743.06 lbs CO_2/MWh, 61%-92% higher than the baseline, with no microgrid (Figure 13.). For reference, the average emissions factor for all natural gas plants in New York in 2016 was 1042.84 lbs CO_2/MWh and is represented by the red line in the figure.

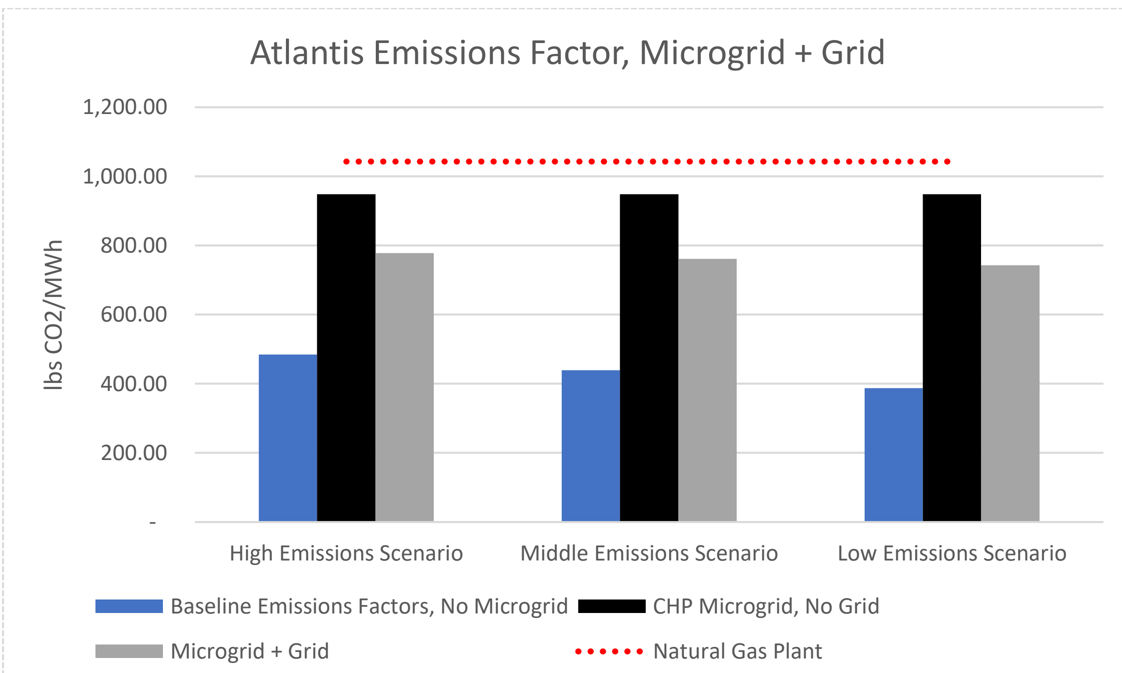

Figure 13. Microgrid and grid simulation produces an average emissions factor that is 61% - 92% higher than the grid emissions scenarios over the baseline case.

In this simulation, Atlantis purchased 36% of the total electricity it needed and the microgrid produced the rest.

However, the microgrid still sold an average of almost 180,000 kWh a year to the grid. During these hours, the microgrid would have been making electricity, which means it was also generating heat. If there wasn't a demand for the electricity at that time, it's also possible that there wasn't a demand for the heat, which would mean it was wasted. This wasted heat would cause the emissions factor to rise. In fact, over the course of the 13 years of operations, the microgrid generated an average of 2,880,251 kWh of thermal energy a year, but only used an average of 1,756,705 kWh a year. Only 37.88% of the heat generated was actually put to use by the buildings in Atlantis.

Sensitivity

Since the microgrid can sell electricity back to the grid, the next step was to conduct a sensitivity analysis to see how wholesale market prices affected microgrid operations. At \$0.05/kWh, Atlantis was a net consumer of electricity. At what price would Atlantis sell more electricity than it consumed? Figure 14. shows the average emissions factor for Atlantis as wholesale electricity prices change.

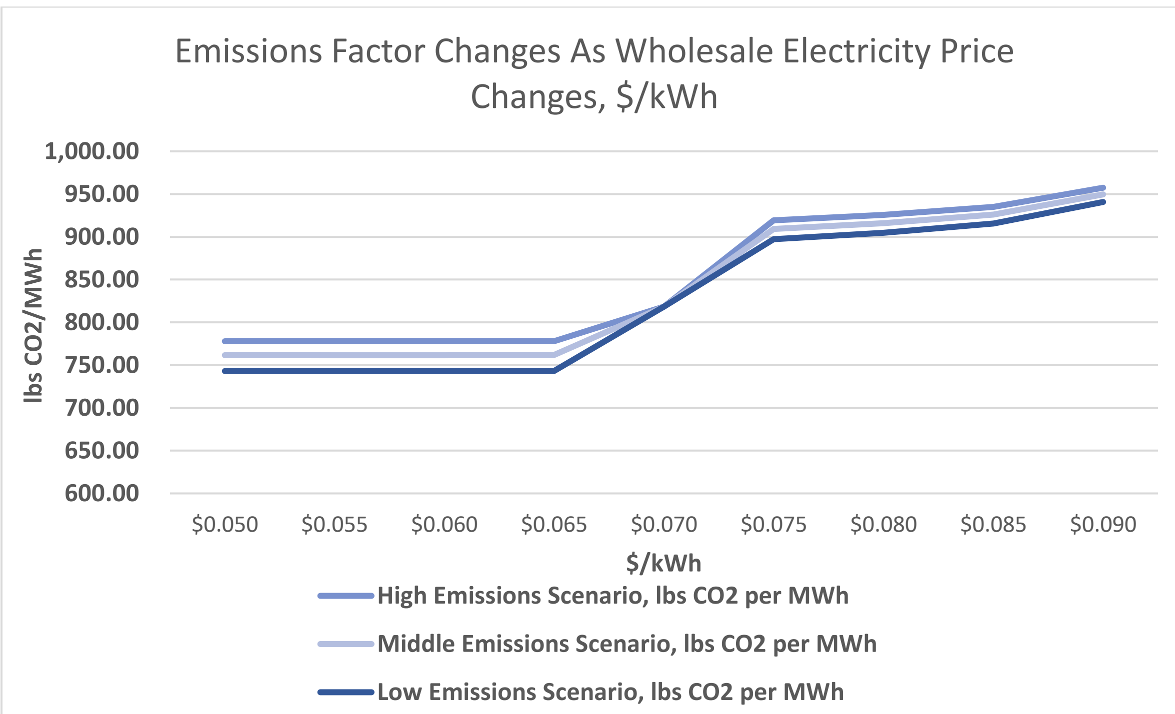

Figure 14. The emissions factor rises by 7.4% - 16.5% when the wholesale price of electricity changes from \$0.065/kwh to \$0.075/kWh.

Between \$0.065/kWh and \$0.075/kWh, the emissions factor rises by 7.4% - 16.5%. With this one-cent difference, Atlantis went from purchasing an average net of 1,770,511 kWh per year to selling an average net of 980,174 kWh per year.

At \$0.09/kWh—a high price that incentivizes creating more electricity to sell—Atlantis' emissions factor is between 940.77 – 957.43 lbs CO_2/MWh. In other words, at this price, the microgrid's grid-connected emissions factor could exceed even that of the microgrid-only scenario, working in islanding mode for the entire 13 years.

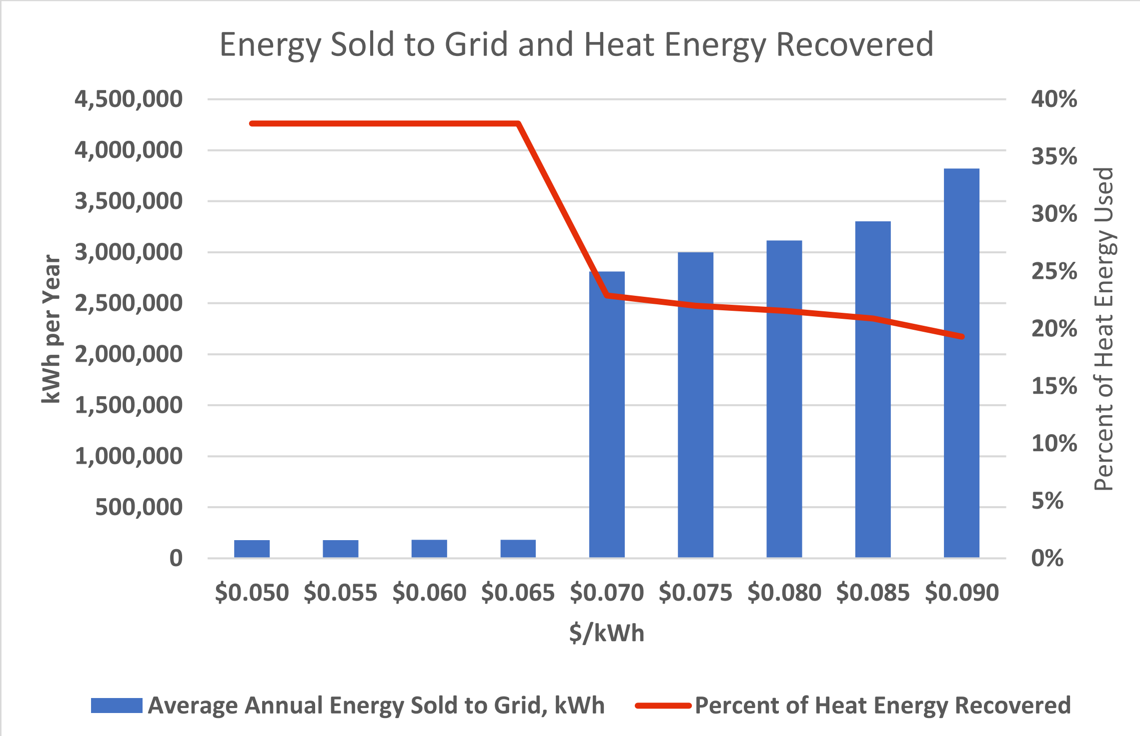

Figure 15. As more energy is sold to the grid, less heat energy is able to be used.

Figure 16. shows that the percentage of the heat produced that actually gets used decreases as the microgrid sells more electricity. That is because, as the software that runs the microgrid is incentivized by the high price to sell more energy back to the grid, it produces more than it would need on its own.

Electric Versus Thermal Demands

At this point it's important to go back and look at ways in which the simulated demands for electric and thermal loads of these five buildings in Atlantis may or may not reflect the real world. As noted on page 18, the community's total demand for electricity in three times larger than for heating. In a colder climate like New York, this might not reflect reality. It's possible that this is a result of assumptions made in eQuest that don't reflect the ways that these types of buildings operate. The process of building simulated load profiles in two separate softwares and then combining them may have led to this issue, though not all buildings modeled showed the same contrasting demands.

Regardless, the seasonal variation in demand is likely to be common across all kinds of buildings, with electricity demand being higher in the summer and heating demand higher in the winter. This difference in the need for each type of energy at any given time makes CHP a challenging technology to operate efficiently. Without a heat "sink," somewhere to put the additional heat generated from making electricity, the emissions factor in Atlantis would be impossible to control.

Discussion

As more renewable energy is used on the electric grid, electricity will likely get cleaner, meaning that it will emit less CO_2 per unit of electricity produced. That means that new technologies installed today must be able to compete not just with the current electricity mix, but also with the future electricity mix. For power generation installed today, including distributed assets like CHP microgrids, there is a risk that new assets will produce more emissions per unit of energy than the electric grid, or other alternatives.

Lenders think about this risk a lot when making economic decisions about what power generation projects to invest in. If a bank invests in a community's microgrid, it wants to be sure that the microgrid will recover its costs. Since CO_2 emissions don't currently have a direct cost associated with them, it's not clear how CO_2 emissions projections for a given asset affect investment decisions. Even when a metric like the social cost of carbon is included in an investment decision, CO_2 emissions could still be under-estimated because the subtleties of CHP microgrid dispatch drive the emissions and they are poorly understood.

For now, it remains up to policy makers to make projections about how an asset like a CHP microgrid will operate relative to emissions goals. It is important that all the other benefits of a CHP microgrid be recognized, including reliability, meeting thermal demand, and public health improvements over diesel backup power. But emissions impacts should be projected based on clear assumptions of how the CHP microgrid will operate. Fortunately, the costs for alternative microgrid designs that use renewable resources and batteries are dropping fast, potentially aligning the goals of both investors and policy makers. These falling costs make investment decisions in assets that depend on fossil fuels even more critical. It's possible that in only a few years, fossil fuel investments will not be operated as often as expected because they will be more expensive than cleaner alternatives.

Finding the environmental benefits of using a grid-integrated CHP plant is a complicated calculation with plenty of uncertainty. Microgrids are generally being designed to operate when they can produce electricity for less than they would be able to buy it from the grid. But this economically optimized model is iterative. The electric and emissions output can change over time. They are factors of the number of hours the system operates, how quickly generation resources must ramp to meet demand, natural gas prices, grid prices for electricity at each time interval, and how well the emissions controls are operating, among others. This study does not attempt to forecast precise uncertainties about these issues. But it has shown that the price of electricity offered to a CHP microgrid will change its operations, and therefore its emissions impact, if there is not an outlet for thermal energy at every hour of potential operation.

Microgrids built today are likely to serve communities for 20 to 30 years. Given potential scenarios for future renewable development, we do not know the emissions impact of fossil fuel investments today. On the other hand, we know precisely the emissions rate of technologies that don't require combustion of hydrocarbons to generate power. There is a value to that certainty—though, like reliability, it's hard to quantify.

Potential for a geographic-specific study

Throughout this study, the average emissions factor used for the grid today was based on an average emissions factor throughout the entire state. Within the New York Independent Systems Operator territory (NYISO), the EPA divides the grid into three regions: NYUP (Upstate), NYCW (NYC and Westchester), and NYLI (Long Island). There is wide variation in emissions factors within these regions. A potential area of future study would be to measure the impacts of a CHP system located in different areas in the state.

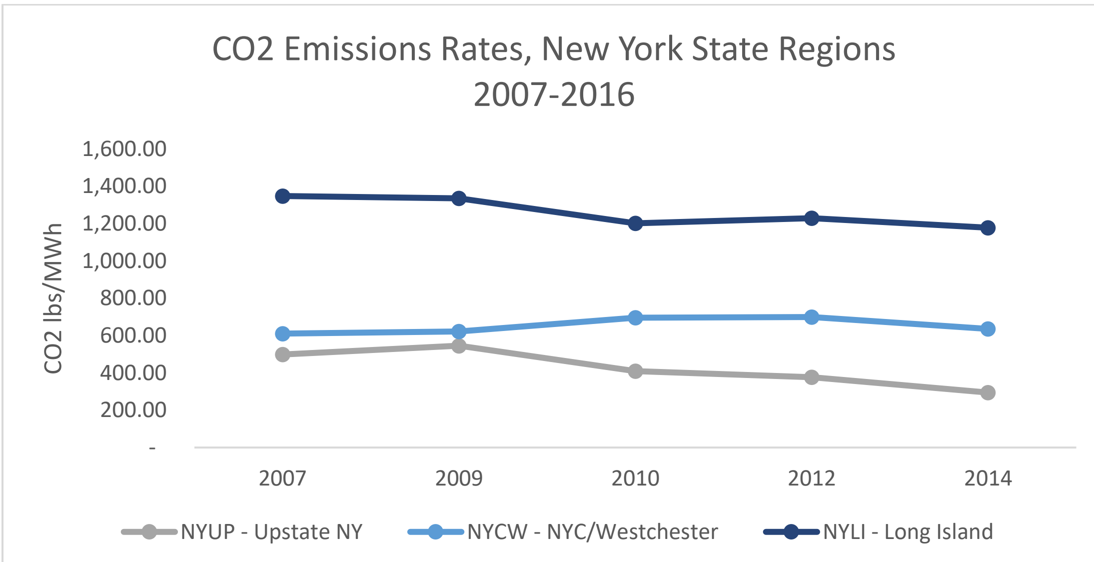

Figure 16. Emissions rate, lbs CO_2 per MWh, for each electric region in NY State. Source: eGRID 2007-2016.[68]

Communities in Long Island are particularly vulnerable to power outages due to weather. Combined with the region's high emissions factor, this might be a region to focus attention for further study.

Conclusion

There are three takeaways of this work. First, the grid will get cleaner. The costs for renewable generation are simply falling too fast for that not to be the case. The changes in emissions factor modeled in the three scenarios in this report might not come to fruition exactly as modeled. But investment decisions about assets that are expected to be operating for decades are converging with policy goals supporting renewable generation and lower emissions. Microgrids have to match or beat future emissions factors, not today's emissions factor, in order to limit the risk that they will be economically and environmentally obsolete before they reach the end of their expected life.

Using CHP as the only technology in a microgrid will likely not meet future emission standards in New York, if the load conditions for electric and thermal demand are similar to those modeled here. But a CHP system could be coupled with other technologies that would

[68] *Environmental Protection Agency. (2016). Emissions & Generation Resource Integrated Database (eGRID). EPA.gov.*

likely change this outcome. A building's demands for electric and thermal energy are not aligned through the day and year. This suggests that electric or thermal storage would be important to using as much of the energy produced in a CHP system as possible.

Second, a microgrid using CHP should have a greater energy demand for heat than for electricity. A CHP system will produce more heat energy than electric energy. Since emissions factor is determined by the total CO_2 produced per total energy used, a design should use as much thermal energy as possible in order to keep the emissions factor low.

Part of the reason there was so much waste in this model was because there was a demand for electricity that was three times higher than the demand for thermal energy. This ratio is an important metric for CHP microgrid designers, particularly if they are not using a storage technology.

Third, microgrid operations can be greatly affected by even small price changes on the grid. If policy makers incentivize all distributed resources equally, it could lead to unanticipated emissions impacts. There is currently no cost to emitting CO_2, so CHP systems are only driven by the economics of the demand for energy. Further, even if there were a cost of emitting carbon, distributed fossil fuel plants are harder and more expensive to monitor than large, centralized plants, so their actual emissions can be mischaracterized. These problems can be overcome, but only if each of them is well described.

By keeping these thoughts in mind, policy makers and microgrids designers using CHP for communities in New York—and around the country—can build energy solutions for their communities that will not only improve resiliency and improve public health but meet CO_2 emission reduction goals as well.

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Appendix

2016 Generation, EIA:

Total electric industry	134,417,107*	Percentage
Coal	1,770,238	**1.32%**
Hydroelectric	26,888,234	**20.00%**
Natural gas	56,793,336	**42.25%**
Nuclear	41,570,990	**30.93%**
Other	898,989	**0.67%**
Other biomass	1,604,650	**1.19%**
Petroleum	642,952	**0.48%**
Pumped storage	-470,932	**-0.35%**
Solar	139,611	**0.10%**
Wind	3,940,180	**2.93%**
Wood	638,859	**0.48%**

**MWh*

Carbon dioxide (thousand metric tons)	Thousand Metric Tons
Coal	2,146
Natural gas	26,865
Other	1,661
Petroleum	624
Total	31,295

Three Future Scenarios, Data

High-Emissions Scenario:

Fossil Fuel Scenario - All New Renewable Generation Replaces Non-Fossil Fuel Resources							
Year	**Projected State-Wide Generation, GWh**	**Renewable Generation**	**Fossil Generation**	**Other Generation**	**Fossil Generation, GWh**	**Emissions, Thousand Metric Tons CO_2**	**Emissions Factor of Grid, lbs per MWh**
2018	157,996.00	25.00%	44.05%	30.95%	69,592.29	34,833.45	476.88
2019	157,405.00	27.08%	44.05%	28.87%	69,331.97	34,703.15	476.88
2020	156,752.00	29.17%	44.05%	26.79%	69,044.35	34,559.18	476.88
2021	155,855.00	31.25%	44.05%	24.70%	68,649.25	34,361.42	476.88
2022	155,444.00	33.33%	44.05%	22.62%	68,468.21	34,270.81	476.88
2023	155,298.00	35.42%	44.05%	20.54%	68,403.91	34,238.62	476.88
2024	155,135.00	37.50%	44.05%	18.45%	68,332.11	34,202.68	476.88
2025	155,009.00	39.58%	44.05%	16.37%	68,276.61	34,174.90	476.88
2026	154,920.00	41.67%	44.05%	14.29%	68,237.41	34,155.28	476.88
2027	154,971.00	43.75%	44.05%	12.20%	68,259.87	34,166.53	476.88
2028	154,878.02	45.83%	44.05%	10.12%	68,218.92	34,146.03	476.88
2029	154,785.09	47.92%	44.05%	8.04%	68,177.98	34,125.54	476.88
2030	154,692.22	50.00%	44.05%	5.95%	68,137.08	34,105.06	476.88

Middle-Emissions Scenario

Middle Scenario - new renewable resources replace half fossil and half other generating resources.							
Year	**Projected State-Wide Generation, GWh**	**Renewable Generation**	**Fossil Generation**	**Other Generation**	**Fossil Generation, GWh**	**Emissions, Thousand Metric Tons CO_2**	**Emissions Factor of Grid, lbs per MWh**
2018	157,996.00	25.00%	44.05%	30.95%	69,592.29	34,833.45	476.88
2019	157,405.00	27.08%	43.01%	29.91%	67,692.34	33,882.45	474.55
2020	156,752.00	29.17%	41.96%	28.87%	65,778.68	32,924.60	463.06
2021	155,855.00	31.25%	40.92%	27.83%	63,778.78	31,923.58	451.57
2022	155,444.00	33.33%	39.88%	26.79%	61,991.38	31,028.92	440.07
2023	155,298.00	35.42%	38.84%	25.74%	60,315.47	30,190.07	428.58
2024	155,135.00	37.50%	37.80%	24.70%	58,636.17	29,349.52	417.08
2025	155,009.00	39.58%	36.76%	23.66%	56,973.87	28,517.48	405.59
2026	154,920.00	41.67%	35.71%	22.62%	55,327.41	27,693.36	394.09
2027	154,971.00	43.75%	34.67%	21.58%	53,731.34	26,894.47	382.60
2028	154,878.02	45.83%	33.63%	20.54%	52,085.79	26,070.81	371.10
2029	154,785.09	47.92%	32.59%	19.49%	50,442.19	25,248.14	359.61
2030	154,692.22	50.00%	31.55%	18.45%	48,800.55	24,426.43	348.11

Low-Emissions Scenario

Cleanest Scenario - All new renewable generation replaces units of fossil fuels							
Year	**Projected State-Wide Generation, GWh**	**Renewable Generation**	**Fossil Generation**	*Other Generation*	**Fossil Generation, GWh**	**Emissions, Thousand Metric Tons CO_2**	**Emissions Factor of Grid, lbs per MWh**
2018	157,996.00	25.00%	44.05%	30.95%	69,592.29	34,833.45	476.88
2019	157,405.00	27.08%	41.96%	30.95%	66,052.70	33,061.76	463.06
2020	156,752.00	29.17%	39.88%	30.95%	62,513.01	31,290.02	440.07
2021	155,855.00	31.25%	37.80%	30.95%	58,908.31	29,485.73	417.08
2022	155,444.00	33.33%	35.71%	30.95%	55,514.55	27,787.03	394.09
2023	155,298.00	35.42%	33.63%	30.95%	52,227.03	26,141.51	371.10
2024	155,135.00	37.50%	31.55%	30.95%	48,940.23	24,496.35	348.11
2025	155,009.00	39.58%	29.46%	30.95%	45,671.13	22,860.05	325.12
2026	154,920.00	41.67%	27.38%	30.95%	42,417.41	21,231.44	302.14
2027	154,971.00	43.75%	25.30%	30.95%	39,202.81	19,622.42	279.15
2028	154,878.02	45.83%	23.21%	30.95%	35,952.66	17,995.60	256.16
2029	154,785.09	47.92%	21.13%	30.95%	32,706.40	16,370.73	233.17
2030	154,692.22	50.00%	19.05%	30.95%	29,464.02	14,747.81	210.18