Combined Heat and Power Potential for Carbon Emission Reductions

National Assessment 2020-2050

Prepared for
Energy Solutions Center

July 2020

IMPORTANT NOTICE: This is an Energy Solutions Center (ESC) commissioned study prepared for ESC by ICF. The study used 2018 eGRID emission rates (average fossil fuel and non-baseload) to estimate marginal emissions for the U.S. and each eGRID subregion. ICF applied assumptions based on market modeling from ICF's Integrated Planning Model (IPM®) and legislated clean energy targets to estimate the average marginal emissions in 2050 for each subregion. ICF did not include assumptions related to the timing of grid resource changes, applying a linear progression from 2018 eGRID data to 2050 estimates. This report and information and statements herein are based in whole or in part on information obtained from various sources. The study is based on public data on energy costs, cost trends, future commitments to clean or renewable energy sources, and ICF modeling and analysis tools to estimate future grid emissions and potential for emission reductions with combined heat and power (CHP) systems. Neither ICF nor ESC make any assurances as to the accuracy of any such information or any conclusions based thereon. Neither ICF nor ESC are responsible for typographical, pictorial or other editorial errors. The report is provided AS IS. No warranty, whether express or implied, including the implied warranties of merchantability and fitness for a particular purpose is given or made by ICF or by ESC in connection with this report. You use this report and the results contained within at your own risk. Neither ICF nor ESC are liable for any damages of any kind attributable to your use of this report.

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Executive Summary

Combined heat and power (CHP) systems, which operate at high efficiency, have the potential to reduce carbon emissions from grid electricity across the entire country. For all states in the continental U.S., fossil fuel generators are used as marginal grid resources to serve incremental customer loads. When CHP is installed, grid requirements for these marginal resources are reduced, and emissions are avoided, even when the CHP system is operating on natural gas.

In the future, as coal plants are retired and utilities shift towards efficient combined cycle gas power plants and renewable generation, the gap between carbon emissions from CHP and the grid will be narrowed. When renewable or zero-carbon resources are used on the margin, CHP could become a net carbon emitter, requiring biogas or renewable natural gas (RNG) to be incorporated into the CHP fuel supply to maintain a carbon emissions advantage.

In this study, ICF showed that CHP systems fueled by natural gas are expected to continue reducing carbon emissions for most of the country through 2050. Additionally, RNG has the potential to be introduced to the gas supply in many U.S. regions over the study period, which could improve CHP emission reductions even further.[1] CHP installations provide the added benefit of resilient heat and power for host sites, allowing them to continue critical operations during extended grid outages. The study's findings indicated that CHP can play a role in decarbonization efforts well into the future for most U.S. locations.

Marginal Grid Generation

Power generation in the United States generally follows a "dispatch order", which can be thought of as a stack of resources to meet required loads at any point in time. Nuclear, hydroelectric, and renewable resources are generally used as available -- at the bottom of the stack -- while fossil fuel resources with higher variable costs are used to meet additional loads. First, coal and combined cycle gas plants to meet baseload customer requirements, and then intermediate and peaking gas/oil plants are dispatched to meet peak loads. The last resource to be deployed at any given point in time – the one at the top of the stack – is considered the marginal resource. This is the grid resource that is first to be reduced or turned off when no longer needed.

For a distributed energy resource (DER) such as CHP, the avoided grid emissions will correspond to the emission characteristics of the grid resource at the top of the stack. During daytime hours, these are the intermediate and peaking grid resources, while at night when electricity demand is low, some baseload resources – including coal plants – may be at the top of the stack. For a CHP system that operates 24/7, marginal emissions currently consist of a mix of fossil fuel resources in most locations.

Figure ES-1 shows an example load duration curve for a hypothetical vertically integrated utility with a 10 GW peak and a mix of generation resources. In this example, if 1 GW of CHP that operates 24/7 were to come online, the power from CHP would not displace any renewable or zero-emission resources – only fossil fuel resources would be displaced.

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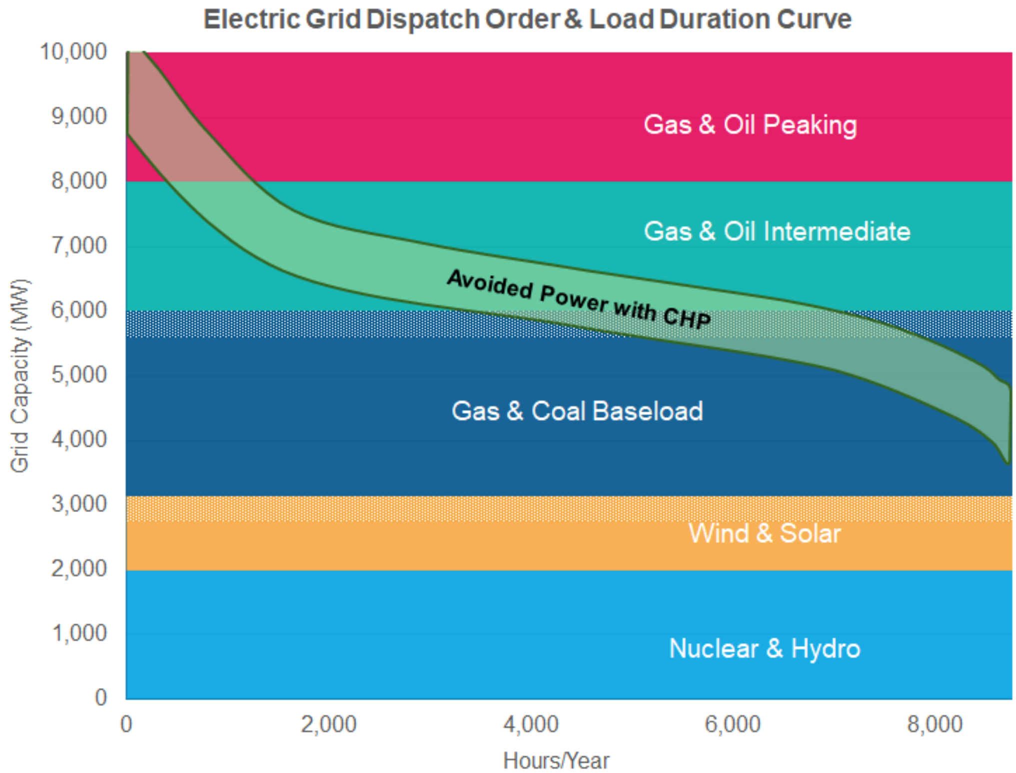
[1] American Gas Foundation, *Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment*, prepared by ICF, December 2019, https://gasfoundation.org/wp-content/uploads/2019/12/AGF-2019-RNG-Study-Full-Report-FINAL-12-18-19.pdf

Figure ES-1. Avoided Power with CHP for an Example Utility



Currently, the average fossil fuel emissions from the grid provides a reasonable representation of the marginal grid emissions displaced by a behind-the-meter CHP system operating 24 hours a day. As described in the methodology for the EPA CHP Emissions Calculator[2], the eGRID[3] *Average Fossil Fuel* emissions factors can be used to estimate displaced grid emissions from 24/7 CHP systems, while the eGRID *Non-Baseload* emissions factors can be used to estimate grid emissions displaced by CHP systems that operate during daytime hours. These systems would primarily be displacing intermediate and peaking resources.

CHP Emission Reduction Analysis

The starting point for the emission savings potential estimates in ICF's analysis are the 2018 eGRID *Average Fossil Fuel* emissions factors for the savings estimations of 24/7 CHP systems and the 2018 eGRID *Non-Baseload* emissions factors for the savings estimates of CHP systems that operate during daytime hours. This methodology is consistent with the EPA CHP Emissions Calculator and further described in ICF's 2019 white paper.

The grid mix is evolving in response to changing fuel prices, technology costs, and state policies, among other drivers, so it is unlikely that the emission rates today will be representative of emission rates in

[2] U.S. Environmental Protection Agency, CHP Partnership, CHP Energy and Emissions Savings Calculator, https://www.epa.gov/chp/chp-energy-and-emissions-savings-calculator
[3] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

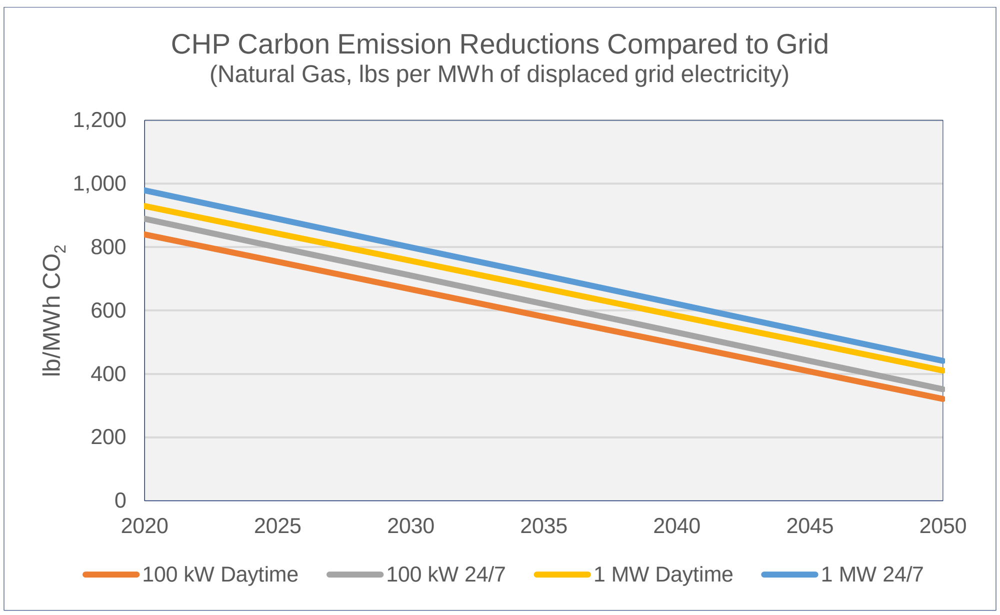
2050. ICF used a combination of eGRID data and modeling to develop a set of 2050 emission rates for this study.

To reflect the potential changes in emission rates through 2050, ICF used the Integrated Planning Model (IPM®), relying on public sources such as system operators, EIA, and EPA for assumptions such as electric load, natural gas prices, and technology costs, to develop projections of emission rates in 2050 on a regional basis. The projected changes in the generation mix and resulting emission rates are a function of the underlying assumptions and requirements imposed by existing state policies specific to renewable and clean energy penetration, such as renewable portfolio standards and clean energy standards.

According to the analysis, in most U.S. markets, CHP systems fueled by natural gas will continue to reduce carbon emissions through 2050 and beyond. Marginal generators in most regions are expected to remain reliant on fossil fuels, although there will be a shift towards efficient combined cycle gas power plants and away from coal, oil, and less efficient simple cycle gas generators.

Across the United States, CHP can be widely used to reduce carbon emissions over the next 30 years. The results of the analysis using estimated average U.S. grid emission factors are shown in Figure ES-2.

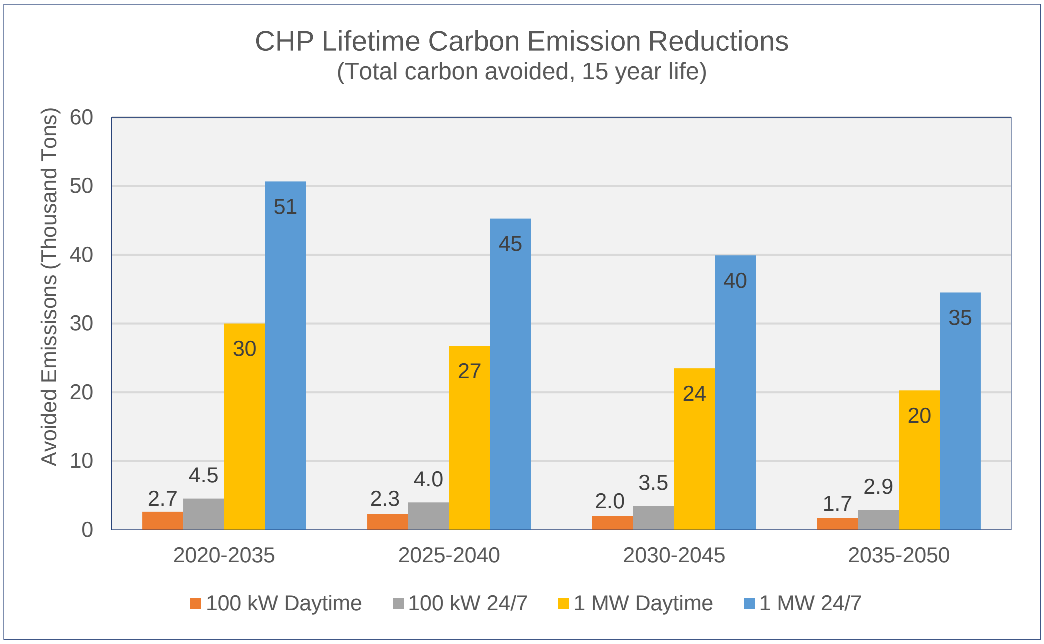
Figure ES-2. CHP Carbon Emission Reductions (lb/MWh) Compared to Average U.S. Marginal Grid Emissions



The estimated rate of carbon reduction for CHP in 2020 – on average across the U.S. – ranges from approximately 800 to 1,000 pounds for each MWh of displaced grid electricity. As we move to 2050, the rate of carbon reduction decreases, but even in 2050, CHP is estimated to reduce carbon emissions by approximately 300 to 450 pounds for each MWh of displaced electricity.

Figure ES-3 shows the average expected lifetime carbon emission reductions for a CHP engine with a 15-year life, installed in 2020, 2025, 2030, or 2035. Reductions are measured in tons (2,000 lbs).

Figure ES-3. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average U.S. Marginal Grid Emissions



ICF performed this evaluation for all of the eGRID subregions in the continental U.S. In every region except New York and California, CHP systems installed through 2035 and operating through 2050 are expected to cause a net reduction in carbon emissions over their system life. As a result, CHP has the potential to play a significant role in decarbonization efforts through 2050.

CHP Can Decarbonize as States Work Towards Renewable Targets

While many states have developed renewable targets for grid electricity, reaching zero carbon emissions will take decades to achieve. Additionally, as regional grids approach 100 percent clean energy, it is likely that fossil fuel resources will remain in use to serve marginal loads. If fossil generators operate on the margin, natural gas CHP could reduce grid emissions for a longer period of time in states like California and New York compared to ICF's findings. In the future, renewable natural gas (RNG) could be incorporated into the natural gas supply thereby further reducing carbon emissions from CHP.

In addition to environmental benefits, CHP systems can be used in microgrids to provide resilient 24/7 power to critical loads during grid outages. New York and California – two states with 100 percent clean energy mandates – have both experienced recent extended power outages from natural disasters. These unplanned long duration outages have increased interest in accelerating adoption of resilient microgrids for critical facilities, many of which are incorporating natural gas CHP for baseload power and heat while integrating PV and other renewable technologies.

The results of the study show that CHP reduces carbon emissions compared to separate heat and grid power. As policymakers consider how to reduce carbon emissions, CHP should be considered as an economic alternative that provides carbon benefits immediately and well into the future, even as the electric grid becomes cleaner.

1. Introduction

As states and utilities implement policies to evolve the energy sector towards cleaner, renewable energy, there has been a growing sentiment that the future electric grid will be carbon-free, leading to wide-spread electrification of energy loads. There will be several challenges, however, in shifting to higher percentages of renewable generation and electrification, and it will take a considerable amount of time to achieve 100 percent clean or renewable energy. States and utilities recognize these challenges, with many aiming for 80 percent emission reductions by 2050 (80x50 plans). Market modeling from both EIA and ICF[4] suggests that even with decarbonization policies in place in states like California and New York, many regions of the country will continue to incorporate fossil fuel generation through 2050, particularly on the margin to serve incremental loads.

Across the U.S., the electric grid currently uses a mix of fossil fuel generators – peaking oil/gas plants, combined cycle power plants fueled by natural gas, and coal-fired power plants – to serve marginal electricity loads. The grid is evolving, and transitioning to more renewable resources and higher efficiency gas-fueled power plants on the margin. While this evolution is reducing grid carbon emissions, combined heat and power (CHP) systems installed at customer sites, fueled by natural gas, can continue to reduce carbon emissions compared to the grid. Renewable biogas fuel can be used to achieve net zero emissions, and the gas industry is developing plans for Renewable Natural Gas options[5]. Therefore, CHP systems – which also offer economic and resiliency benefits – can play a strong role in decarbonization plans, serving as a bridge towards a renewable and decentralized energy future.

In this study, ICF examines the extent to which CHP has the potential to reduce emissions compared to separate heat and utility-purchased power. The evaluation compares the current and future status of marginal grid emissions – the carbon emissions that would be displaced by new CHP generation – across the continental U.S. to the net emissions produced by CHP systems to the marginal grid emissions through 2050.

This report covers the following topics:

- **Impact of Distributed Energy on Electric Grid Emissions -** how distributed energy resources impact grid emissions
- **Reduced Carbon Emissions from CHP-** when considering recovered thermal energy and avoided transmission and distribution (T&D) losses, CHP reduces emissions compared to the grid
- **Marginal Grid Emissions Estimates through 2050 -** Projections to estimate marginal grid emissions from 2020 through 2050
- **Methodology for CHP Emissions Analysis -** how CHP emissions are compared to marginal grid emissions over time
- **Results of 2020-2050 CHP Emissions Analysis -** estimated emission reductions for CHP over time for each eGRID region
- **Conclusions -** the extent to which CHP can reduce grid emissions and be incorporated into decarbonization planning

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[4] U.S. Department of Energy, Energy Information Administration, Annual Energy Outlook, and ICF, Integrated Planning Model®

[5] American Gas Foundation, *Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment*, prepared by ICF, December 2019, https://gasfoundation.org/wp-content/uploads/2019/12/AGF-2019-RNG-Study-Full-Report-FINAL-12-18-19.pdf

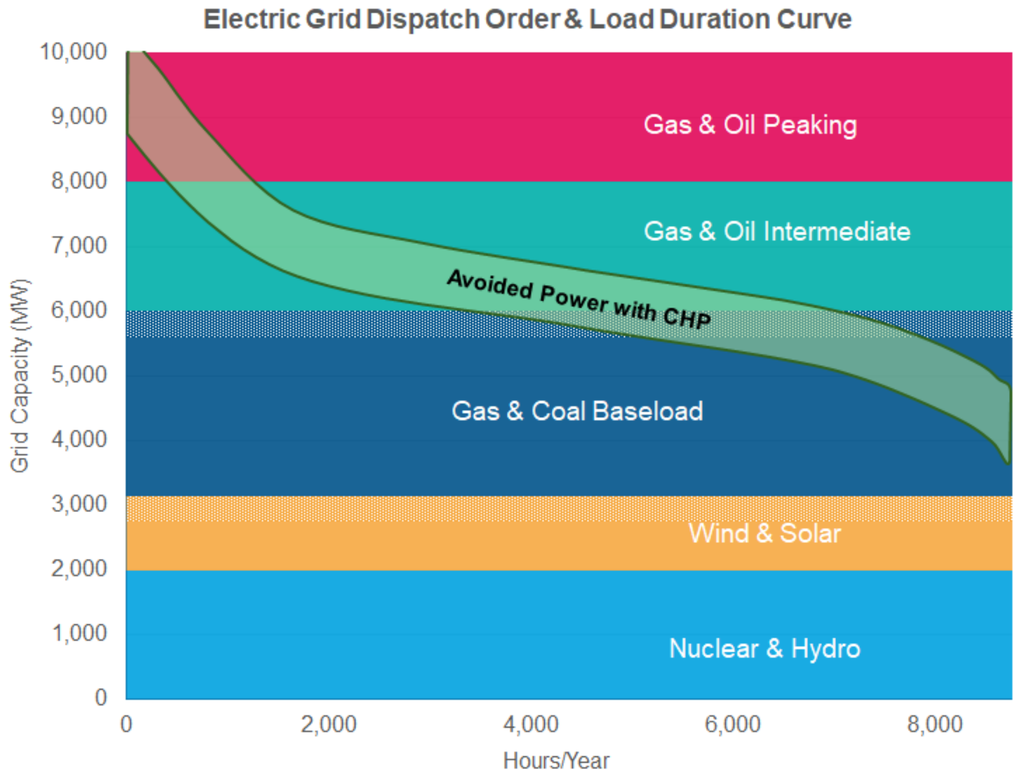
2. Impact of Distributed Energy on Grid Emissions

Average and marginal emission factors are two approaches for estimating grid emissions. Average emission factors that consider all generating resources are one way to represent grid emissions. However, when estimating the emissions impact of distributed energy resources (DERs), marginal grid emissions need to be considered.

Power generation in the United States generally follows a "dispatch order" in which resources are deployed to meet increasing customer loads. This can be thought of as a stack of resources to meet required loads at any point in time. Nuclear, hydroelectric, and renewable resources are generally used as available -- at the bottom of the stack due to their low variable cost and their lack of ability to actually respond to changes in demand in the case of renewables – whereas fossil fuel resources with higher variable costs such as fuel are used to meet additional loads. First, coal and combined cycle gas plants to meet baseload customer requirements, and then intermediate and peaking gas/oil plants are dispatched to meet peak loads. The last resource to be deployed at any given point in time – the one at the top of the stack – is considered the marginal resource.

For a DER such as CHP, the avoided grid emissions will correspond to the emission characteristics of the grid resource at the top of the stack. During daytime hours, these are the intermediate and peaking grid resources, while at night when electricity demand is low, some baseload resources – including coal plants – may be at the top of the stack. For a CHP system that operates 24/7, marginal emissions currently consist of a mix of fossil fuel resources in most locations. Figure 1 shows an example load duration curve for a hypothetical vertically integrated utility with a 10 GW peak and a mix of generation resources. In this example, if 1 GW of CHP that operates 24/7 were to come online, the power from CHP would not displace any renewable or zero-emission resources – only fossil fuel resources would be displaced.

Figure 1. Avoided Power with CHP for an Example Utility



Currently, the average fossil fuel emissions from the grid provides a reasonable representation of the marginal grid emissions displaced by a behind-the-meter CHP system operating 24 hours a day. As described in the methodology for the [EPA CHP Emissions Calculator](https://www.epa.gov/chp/chp-energy-and-emissions-savings-calculator)[6], the eGRID[7] *Average Fossil Fuel* emissions factors can be used to estimate displaced grid emissions from 24/7 CHP systems, while the eGRID *Non-Baseload* emissions factors can be used to estimate grid emissions displaced by CHP systems that operate during daytime hours. These systems would primarily be displacing intermediate and peaking resources.

While these factors can be used as proxies for current displaced grid emissions, the mix of marginal grid resources is expected to change over time as more renewables are implemented, and fossil fuel generation shifts to efficient combined cycle power plants.

3. Reduced Carbon Emissions from CHP

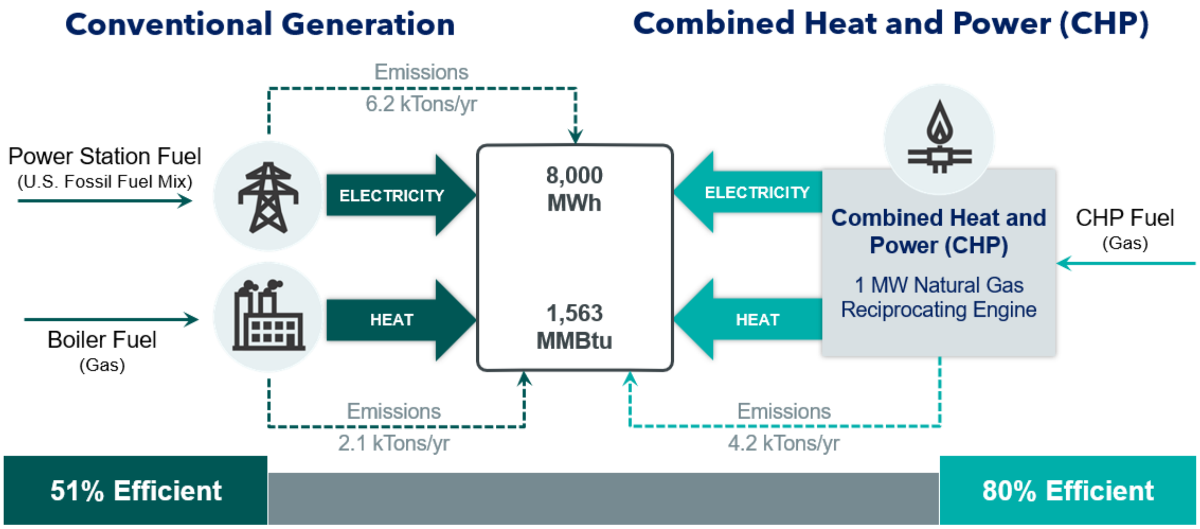
On-site CHP systems are an efficient way to generate power and heat with combustible fuels. When heat from CHP is recovered and utilized, it most commonly displaces steam or hot water from a boiler, which is typically fueled by natural gas. As a result, emissions from the on-site boiler are reduced, lowering the net emissions impact of CHP when compared to separate heat from an onsite boiler and

[6] U.S. Environmental Protection Agency, CHP Partnership, CHP Energy and Emissions Savings Calculator, https://www.epa.gov/chp/chp-energy-and-emissions-savings-calculator

[7] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

power generated from the grid. Additionally, by generating power on-site, there are no losses associated with electricity flowing through the transmission and distribution systems.[8] Figure 2 illustrates the energy and emission savings that can be achieved with CHP compared to separate heat and grid power.

Figure 2. Energy and Emission Savings Associated with CHP[1]



[1]Calculated from eGRID2018 U.S. Average emissions factors: https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

To illustrate the emission benefits of CHP, consider a 1 MW CHP system fueled by natural gas in two different applications: 24/7 operation at a hospital, and daytime operation at a large office building. The methods used to calculate net CO_2 emissions from CHP and grid CO_2 emissions avoided with CHP, as well as results from both applications, are show below.

1. 24/7 Operation at a Hospital

Avoided Boiler Emissions (tons CO_2):

$$\left[Boiler\ Emission\ Rate: \mathbf{116.9}\ \left(\frac{lb}{MMBtu}\right)\right] \times \left[\frac{CHP\ Thermal\ Output: \mathbf{4.45}\ \left(\frac{MMBtu}{hr}\right)}{Boiler\ Efficiency: \mathbf{80\%}}\right] \times [CHP\ Full\ Load\ Hours: \mathbf{8,000}]$$
$$\times [Thermal\ Utilization: \mathbf{80\%}] \times \left[\frac{0.0005\ tons}{lb}\right] = \mathbf{2,081}\ \boldsymbol{tons\ CO_2}$$

Gross CHP Emissions (tons CO_2):

$$\left[CHP\ Gross\ Emission\ Rate: \mathbf{1,062}\ \left(\frac{lb}{MWh}\right)\right] \times [CHP\ Operation: \mathbf{8,000\ MWh}] \times \left[\frac{0.0005\ tons}{lb}\right] = \mathbf{4,248}\ \boldsymbol{tons\ CO_2}$$

Net CHP Emissions (tons CO_2):

$$[Gross\ CHP\ Emissions: \mathbf{4,248\ tons}\ \boldsymbol{CO_2}] - [Avoided\ Boiler\ Emissions: \mathbf{2,081}\ \boldsymbol{tons\ CO_2}] = \mathbf{2,167}\ \boldsymbol{tons\ CO_2}$$

Utility Grid Emissions (tons CO_2):

[8] Transmission and distribution losses occur while supplying electricity to consumers and are typically between 4-5% according to EPA's Emissions & Generation Resource Integrated Database (eGRID) Grid Gross Loss (GLL) values: https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid-questions-and-answers#egrid5a

$$\left[\frac{\left[eGRID\ Fossil\ Emission\ Rate: \mathbf{1,481}\ \left(\frac{lb}{MWh}\right)\right] \times [CHP\ Operation: \mathbf{8,000\ MWh}]}{1-[eGRID\ Grid\ Gross\ Loss\ (GGL): \mathbf{4.87}\%]}\right] \times \left[\frac{0.0005\ tons}{lb}\right] = \mathbf{6,225}\ \boldsymbol{tons\ CO_2}$$

Total Annual Emissions Savings from CHP (tons CO_2):

$$[Utility\ Grid\ Emissions: \mathbf{6,225}\ \boldsymbol{tons\ CO_2}] - [Net\ CHP\ Emissions: \mathbf{2,167\ tons}\ \boldsymbol{CO_2}] = \mathbf{4,058}\ \boldsymbol{tons\ CO_2}$$

Table 1. Annual Emissions Saved from a 1 MW CHP Operating at a Hospital

eGRID2018 U.S. Average Fossil Fuel Emission Rate	Net CO_2 Emissions from CHP (includes avoided boiler emissions)	Utility Grid CO_2 Emissions Avoided with CHP	Total Annual CO_2 Savings from CHP
1,481 lb/MWh CO_2	2,167 tons CO_2	6,225 tons CO_2	4,058 tons CO_2

2. Daytime Operation at a Large Office Building

Avoided Boiler Emissions (tons CO_2):

$$\left[Boiler\ Emission\ Rate: \mathbf{116.9}\ \left(\frac{lb}{MMBtu}\right)\right] \times \left[\frac{CHP\ Thermal\ Output: \mathbf{4.45}\ \left(\frac{MMBtu}{hr}\right)}{Boiler\ Efficiency: \mathbf{80}\%}\right] \times [CHP\ Full\ Load\ Hours: \mathbf{5,000}]$$
$$\times [Thermal\ Utilization: \mathbf{80}\%] \times \left[\frac{0.0005\ tons}{lb}\right] = \mathbf{1,301}\ \boldsymbol{tons\ CO_2}$$

Gross CHP Emissions (tons CO_2):

$$\left[CHP\ Gross\ Emission\ Rate: \mathbf{1,348}\ \left(\frac{lb}{MWh}\right)\right] \times [CHP\ Operation: \mathbf{5,000\ MWh}] \times \left[\frac{0.0005\ tons}{lb}\right] = \mathbf{2,655}\ \boldsymbol{tons\ CO_2}$$

Net CHP Emissions (tons CO_2):

$$[Gross\ CHP\ Emissions: \mathbf{2,655\ tons}\ \boldsymbol{CO_2}] - [Avoided\ Boiler\ Emissions: \mathbf{1,301}\ \boldsymbol{tons\ CO_2}] \times = \mathbf{1,354}\ \boldsymbol{tons\ CO_2}$$

Utility Grid Emissions (tons CO_2):

$$\left[\frac{\left[eGRID\ Fossil\ Emission\ Rate: \mathbf{1,432}\ \left(\frac{lb}{MWh}\right)\right] \times [CHP\ Operation: \mathbf{5,000\ MWh}]}{1-[eGRID\ Grid\ Gross\ Loss\ (GGL): \mathbf{4.87}\%]}\right] \times \left[\frac{0.0005\ tons}{lb}\right] = \mathbf{3,764}\ \boldsymbol{tons\ CO_2}$$

Total Annual Emissions Savings from CHP (tons CO_2):

$$[Utility\ Grid\ Emissions: \mathbf{6,225}\ \boldsymbol{tons\ CO_2}] - [Net\ CHP\ Emissions: \mathbf{2,166\ tons}\ \boldsymbol{CO_2}] = \mathbf{2,410}\ \boldsymbol{tons\ CO_2}$$

Table 2. Annual Emissions Saved from a 1 MW CHP Operating at a Large Office Building

eGRID2018 U.S. Average Non-Baseload Emission Rate	Net CO_2 Emissions from CHP (includes avoided boiler emissions)	Utility Grid CO_2 Emissions Avoided with CHP	Total Annual CO_2 Savings from CHP
1,432 lb/MWh CO_2	1,354 tons CO_2	3,764 tons CO_2	2,410 tons CO_2

In both of these examples, total annual CO_2 emissions are significantly reduced when compared to eGRID U.S average fossil emission rates. While savings will vary by region and over time as grid emission factors change, CHP systems can provide significant CO_2 emission savings when compared to the grid as long as fossil fuels are used on the margin.

While a CHP system operating on natural gas can reduce emissions compared to the current grid mix, the potential for emission reductions in the future is uncertain, and will depend on several factors, including the rate of renewable generation additions to the grid mix, and whether the CHP system runs on natural gas, renewable biogas, or a blend. Renewable gas can potentially be added over time to achieve continued emissions savings when CHP systems no longer provide savings compared to the grid.

To evaluate the potential for natural gas CHP systems to reduce grid emissions over time, ICF developed estimates for marginal grid emission factors by eGRID subregion through 2050 for this study, and compared to the net CHP emissions for a 1 MW system and a smaller 100 kW system.

4. Marginal Grid Emissions Estimates through 2050

In 2019, fossil fuels (encompassing coal, natural gas, petroleum, and other gases) accounted for 63% of overall US electricity generation.[9] In US electricity markets, the generators that operate "on the margin" are those that have available capacity that can be used to generate the next incremental MWh to meet varying electric demand at the lowest marginal cost. As described earlier, these generators are also referred to being at the "top of the stack".

The generators that are on the margin are usually not operating at full capacity, and thus their production can be ramped up or down to satisfy changing demand. Renewable generators are typically not operating on the margin as they do not have the ability to respond to changes in load, as their dispatch is driven by weather patterns such as wind speeds and solar irradiation. In addition, nuclear facilities with zero carbon emissions do not have the ability to quickly respond to changes in load given their operational parameters and the time it takes to power them down and back up. As a result, most marginal generators in the U.S. currently operate on fossil fuels.

When considering only fossil fuel generation, coal-fired facilities represented 43% of the total, while natural gas-fired facilities contributed 55%. The remaining 2% of fossil generation were a mix of petroleum liquids and coke as well as other gaseous fuels.

The 2018 average emission rate for coal based on information provided by EIA is 2,208 lbs/MWh, whereas the average gas emission rate is 869 lbs/MWh. The natural-gas fired rate is a combination of combined cycle facilities, which provide most of the gas-fired baseload generation and generally feature emission rates in the range of 750 – 1,000 lbs/MWh, and gas or oil peaking units such as simple cycle gas turbines with emission rates in the range of 1,000-1,500 lbs/MWh. Emission rates for gas and oil peaking facilities vary more broadly depending on the fuel used (gas versus oil) and the efficiency of the facility.

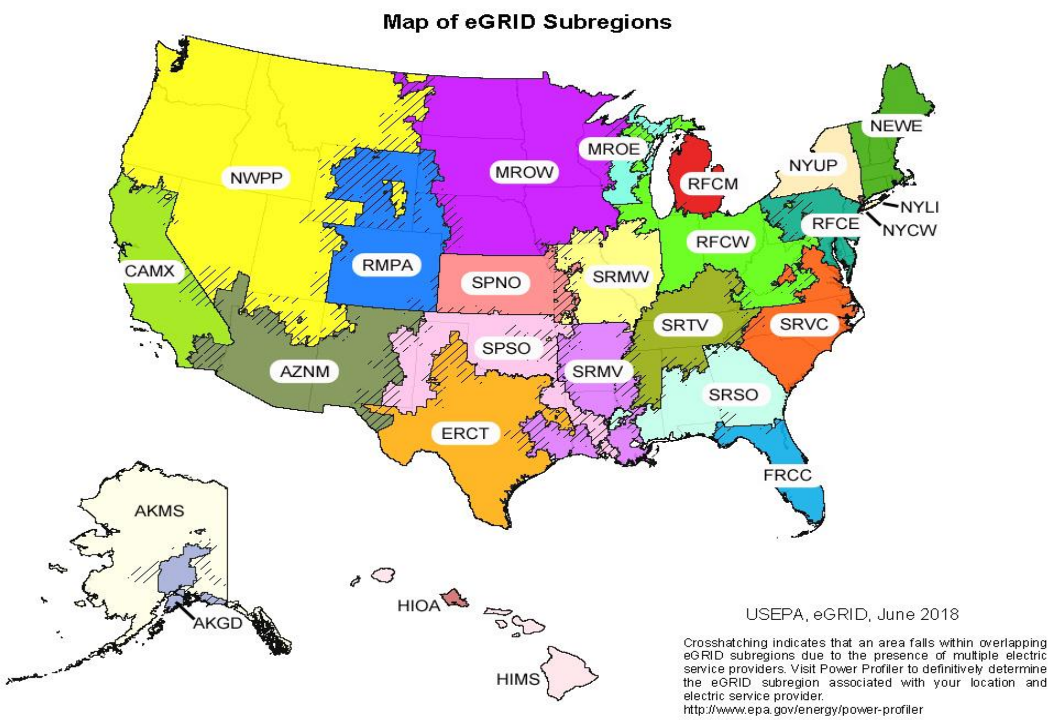
As a result of the US generation mix and the emission rates of the various technologies and fuels, the average eGRID reported fossil fuel emission rate in the United States – which can be used to represent displaced emissions for 24/7 CHP systems as described above – was 1,481 lbs/MWh CO_2. The average non-baseload emission rate – which can be used to represent displaced emissions from daytime CHP operation (when grid demand is high and intermediate/peaking resources are being deployed) – was reported at 1,432 lbs/MWh.

[9] U.S. Department of Energy, Energy Information Administration, Frequently Asked Questions, https://www.eia.gov/tools/faqs/faq.php?id=427&t=3, 2019 data, accessed June 2020.

4.1 EPA eGRID Emissions Factors

The eGRID subregions are assigned by the US Environmental Protection Agency (EPA), and the eGRID region assignments incorporate both NERC regions and electricity balancing authorities.[10] Plants are assigned using a five-step process, based on the NERC region, balancing authority, and transmission, distribution and utility territory of each plant. A map showing the current eGRID regions in the US is shown in Figure 3.

Figure 3. Map of eGRID Subregions



As discussed in ICF's 2019 white paper, the difference between average grid all-source emission factors and average fossil or non-baseload grid emission factors is key to understanding CHP's impact on emissions. Using all-source average emissions rates would underestimate the potential for emission savings from CHP as the all-source rate includes generation from non-emitting resources such as solar, hydro, wind and nuclear that would not be displaced by CHP systems, and that are therefore static regardless of the CHP system's installation. The average fossil and non-baseload emission factors, on the other hand, are representative of units on the margin and reflect the emissions of units that would most likely be displaced by CHP systems, and which can therefore be compared to CHP emission rates to estimate savings.

4.2 Projected Changes to Electricity Grid

The US electricity sector is undergoing a shift in its composition both overall and within the fossil fuel sector itself. Non-emitting sources such as hydro, nuclear, wind, and solar have increased their share of

[10] https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid-questions-and-answers#egrid1

the generation mix from 32% to 40% between 2010 and 2019.[11] At the same time, the share of fossil in the generation mix has fallen from over 70% to 63%.

Within the fossil generation sector, the roles of coal and natural gas have flipped over the last decade. A 64:34%[12] split for coal and gas generation respectively in 2010 has shifted to a 61:37% share, favoring gas over coal.

Looking forward, as states are passing policies to increase the deployment of renewable energy resources, the share of renewables in the grid will continue to grow. States like New Mexico, California, and Washington are committed to 100% carbon free electricity before 2050. The state of New York recently passed the Climate Leadership and Community Protection Act (CLCPA), which has targets of 100% free electricity by 2040 and economy-wide net-zero carbon by 2050. Additionally, the Virginia Clean Economy Act requires 100% carbon-free renewable energy by 2050.

These policies are taking different shape and are often defined as targets for a certain percentage of energy sales to be met from renewable or non-emitting sources, such as renewable portfolio or clean energy standards. Additionally, states are passing mandates for specific resources to facilitate the achievement of these targets. For example, states on the Eastern Seaboard such as New York, Virginia, Maryland, and New Jersey have started large-scale offshore wind procurements. Mandates that require 100 clean energy supply by a certain date, such as California or New York, are considered in the analysis by assuming a marginal and average emissions rates of zero in the affected contiguous US regions by the time the policies are assumed to be realized.

As these resources enter operation, they will enter the dispatch order at the bottom given their low variable costs and their lack of flexibility in responding to changes in load. As the dispatch stack changes, the fossil contribution to the system will change overall as the fossil baseload contribution shrinks.

4.3 Marginal Grid Emissions Projection Methodology

The starting point for the emission savings potential estimates in this analysis are the 2018 eGRID *Average Fossil Fuel* emissions factors for the savings estimations of 24/7 CHP systems and the 2018 eGRID *Non-Baseload* emissions factors for the savings estimates of CHP systems that operate during daytime hours. This methodology is consistent with the EPA CHP Emissions Calculator and further described in ICF's 2019 white paper.

As discussed earlier, the grid mix is evolving in response to changing fuel prices, technology costs, and state policies, among other drivers, so it is unlikely that the emission rates today will be representative of emission rates in 2050. ICF therefore used a combination of eGRID data and modeling to develop a set of 2050 emission rates for this study.

To reflect the potential changes in emission rates through 2050, ICF used the Integrated Planning Model (IPM®), relying on public sources such as system operators, EIA, and EPA for assumptions such as electric load, natural gas prices, and technology costs, to develop projections of emission rates in 2050 on a regional basis. The projected changes in the generation mix and resulting emission rates are a function of the underlying assumptions and requirements imposed by existing state policies specific to renewable

[11] U.S. Department of Energy, Energy Information Administration,U.S. utility-scale electricity generation by source, amount, and share of total in 2019, https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

[12] The remaining percentage is contributed by petroleum coke and liquids as well as other gases.

and clean energy penetration, such as renewable portfolio standards (RPSs) and clean energy standards (CESs). For every eGRID region, the modeled reductions in the marginal emission rates through to 2050 is applied to the 2018 eGRID rate to arrive at 2050 rates for use in the evaluations of the CHP savings. The average fossil fuel emission rate is used to estimate savings for 24/7 CHP systems and the non-baseload emission rate to project savings for daytime CHP systems.

4.4 Emission Factors by eGRID Region

The emission rates developed by ICF for the Energy Solutions Center are shown in Table 3.

Table 3. 2018 eGRID Emission Factors and 2050 Forecasted Factors by eGRID Subregion

eGRID Subregions		24/7 Baseload Operation (Fossil Fuel Emission Rate)		Daytime Operation (Non-baseload Emission Rate)	
eGRID Code	**eGRID Name**	**2018 eGRID**	**2050 Forecast**	**2018 eGRID**	**2050 Forecast**
AZNM	WECC Southwest	1,501	537	1,435	523
CAMX	WECC California	954	0	930	0
ERCT	ERCOT All	1,301	1,007	1,261	906
FRCC	FRCC All	1,093	966	1,124	951
MROE	MRO East	1,936	1,528	1,634	1,274
MROW	MRO West	2,058	1,315	1,764	1,186
NEWE	NPCC New England	905	806	931	822
NWPP	WECC Northwest	1,701	703	1,575	709
NYCW	NPCC NYC/Westchester	943	0	1,068	0
NYLI	NPCC Long Island	1,136	0	1,320	0
NYUP	NPCC Upstate NY	894	0	931	0
RFCE	RFC East	1,249	1,121	1,243	1,152
RFCM	RFC Michigan	1,660	1,084	1,749	1,188
RFCW	RFC West	1,761	1,108	1,828	1,222
RMPA	WECC Rockies	1,813	1,240	1,543	1,114
SPNO	SPP North	1,979	1,265	1,946	1,194
SPSO	SPP South	1,598	1,281	1,603	1,208
SRMV	SERC Mississippi Valley	1,138	1,019	1,138	1,002
SRMW	SERC Midwest	2,084	1,357	1,907	1,225
SRSO	SERC South	1,391	873	1,414	898
SRTV	SERC Tennessee Valley	1,657	1,009	1,644	1,025
SRVC	SERC Virginia/Carolina	1,337	430	1,423	434
U.S.	U.S. Average	1,481	935	1,432	906

Across the U.S., CHP systems fueled by natural gas can reduce emissions compared to the current mix of marginal generators. However, the potential for emission reductions become smaller over time, and in some states like New York and California, CHP could in the future generate more carbon emissions compared to the grid. The path to zero emissions remains uncertain in terms of how and when it will be achieved, even in states with legislated mandates. Some simplifying assumptions were made to assess the potential for CHP emission reductions over the study period of 2020 to 2050.

5. Methodology for CHP Emissions Analysis

ICF assumed a linear change from the 2018 eGRID emission factors to the estimated 2050 emission factors to estimate the change in marginal grid emissions over time for each eGRID subregion. In the case of California, New York, and other states with legislated 100 percent clean energy mandates, emissions were set to zero in the target year (2045 for California, 2040 for New York, and 2050 for New Mexico, Virginia, and Washington).

Next, we compared the net emissions produced by representative CHP systems – as calculated in Section 3 – to the displaced grid emissions estimates over time. For the analysis, ICF selected two CHP systems to represent small (100-200 kW) and medium-sized (1-2 MW) commercial applications. A reciprocating engine was used in both cases. The performance parameters for the CHP systems, obtained from 2016 DOE CHP Fact Sheets, are shown in Figure 4. Gross CO_2 emissions are calculated by determining the avoided boiler emissions when CHP heat is recovered and utilized.

Figure 4. CHP Performance Parameters for Analysis

System Type	100 kW Recip. Engine	1 MW Recip. Engine
Capacity, kW	100	1,141
Heat Rate, Btu/kWh (HHV)	11,527	9,074
Thermal Recovery Output (MMBtu/hr)	0.613	4.452
Electrical Efficiency, % (HHV)	29.6%	37.6%
Total Efficiency, % (HHV)	82.8%	80.6%
NOx, lbs/MWh - Controls	0.15	0.15
CO_2, lbs/MWh (gross)	1,348	1,062
CO_2, lbs/MWh (net)	452	491
CO, lbs/MWh	0.22	0.22
Heat Recovery, H_2O/Steam	H_2O	H_2O
Economic Life (years)	15	15

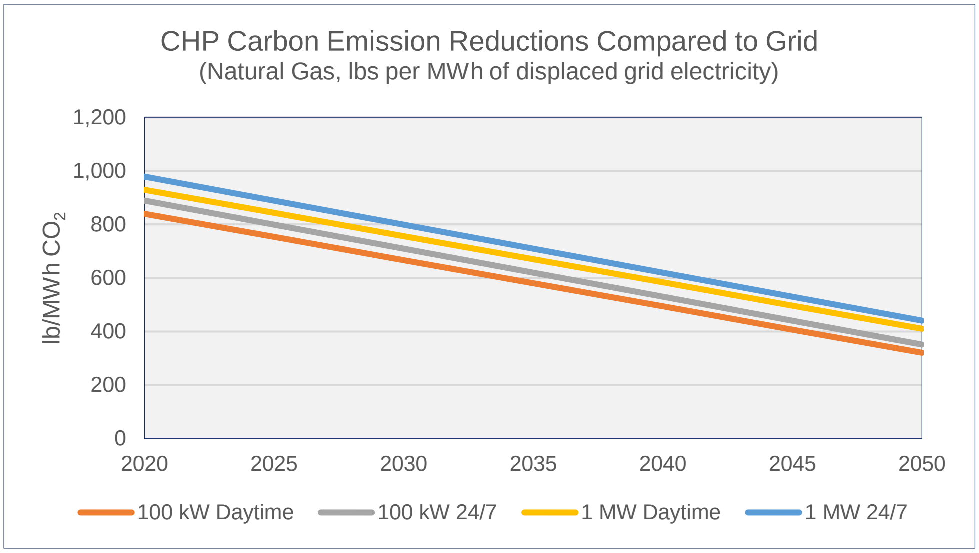
For each CHP system, two use cases were considered: 1) 24/7 operation, and 2) daytime operation. The results are presented in Section 6, first using national average emission factors, and then for each eGRID subregion in the continental U.S. Additionally, an analysis was carried out to estimate the emissions impact of CHP through 2050 in Ontario, Canada, with results found in Appendix A.

6. Results of 2020-2050 CHP Emissions Analysis

According to ICF's analysis, in most U.S. markets, CHP systems fueled by natural gas will continue to reduce carbon emissions through 2050 and beyond. Marginal generators in most regions are expected to remain reliant on fossil fuels, although there will be a shift towards efficient combined cycle gas power plants and away from coal, oil, and less efficient simple cycle gas generators.

Across the United States, CHP can be widely used to reduce carbon emissions over the next 30 years. The results of the analysis using estimated average U.S. grid emission factors are shown in Figure 5.

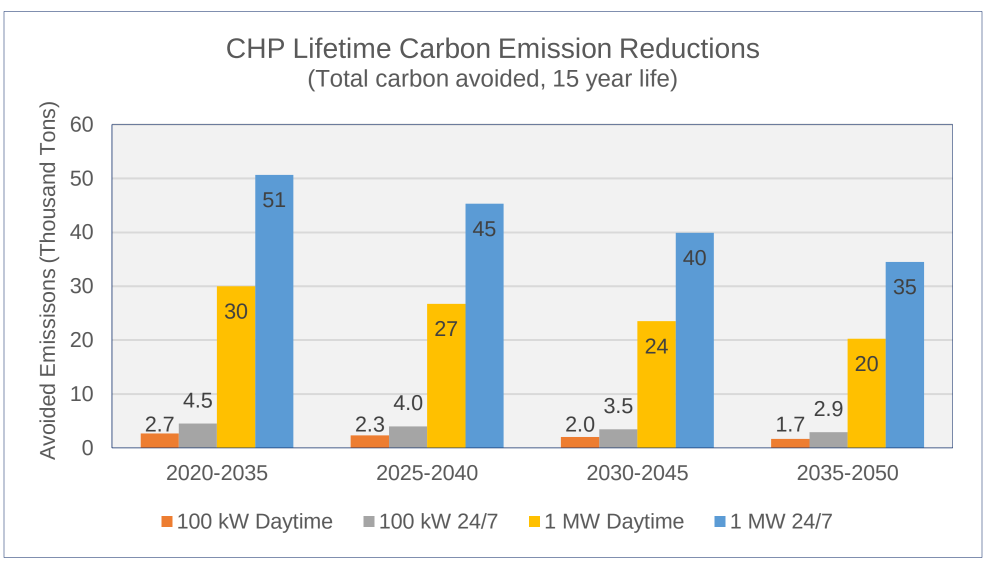
Figure 5. CHP Carbon Emission Reductions (lb/MWh) Compared to Average U.S. Marginal Grid Emissions



The estimated rate of carbon reduction for CHP in 2020 – on average across the U.S. – ranges from approximately 800 to 1,000 pounds for each MWh of displaced grid electricity. As we move to 2050, the rate of carbon reduction decreases, but even in 2050, CHP is estimated to reduce carbon emissions by approximately 300 to 450 pounds for each MWh of displaced electricity. Note that this analysis does not account for any RNG that may be introduced to the gas supply over the study period.

Figure 6 shows the average expected lifetime carbon emission reductions for a CHP engine with a 15-year life, installed in 2020, 2025, 2030, or 2035. Reductions are measured in tons (2,000 lbs).

Figure 6. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average U.S. Marginal Grid Emissions



The average CHP system in the United States that is retired before 2050 will reduce grid emissions by a substantial amount. A 1 MW system installed in 2020 will avoid close to 30 thousand tons of emissions by the end of its 15-year lifetime if it only operates during the daytime (~5,000 hours/year). The same system that operates 24/7 could avoid over 50 thousand tons of emissions. This is the equivalent to the current carbon emissions produced in powering 5,300 homes for one year, or in driving 9,930 passenger vehicles for one year, on average.[13] Smaller 100 kW systems will avoid 2,660 tons of carbon emissions if they are used only during the daytime and 4,530 tons of emissions if they operate 24/7.

For a 1 MW CHP system installed in 2035 and retired in 2050, over 20 thousand tons of carbon emissions can be avoided by operating during daytime hours. Operating 24/7, this system will avoid close to 35 thousand tons of emissions, equivalent to the current emissions produced in powering 3,610 homes for one year, or in driving 6,770 passenger vehicles for one year.[14] A 100kW system with the same lifespan will offset 1,690 tons of carbon emissions by 2050 operating in the daytime. By operating 24/7, it will offset 2,920 tons of emissions.

In the following sections, the current and future status of marginal generation, and estimated carbon emission reduction potential for CHP, is shown for each eGRID subregion in the Continental U.S.

6.1 WECC Southwest (AZNM)

The WECC Southwest eGRID region encompasses most of the states of Arizona and New Mexico in its geographic scope. Both states have climate goals, and large-scale changes due to these goals are expected in the region between 2020 and 2050. The overall electricity generation mix in AZNM in 2018 was made up of 41% gas, 27% coal and 19% nuclear power, with renewables making up less than 5% of the generation share. When looking at fossil fuels specifically, the overall regional fossil fuel generation mix was about 39% coal and 61% gas, and the non-baseload mix was about 1/3 coal and 2/3 gas. This is reflected in the 2018 non-baseload and fossil fuel average emissions rates, which are 1435 lbs/MWh and 1501 lbs/MWh, respectively.[15]

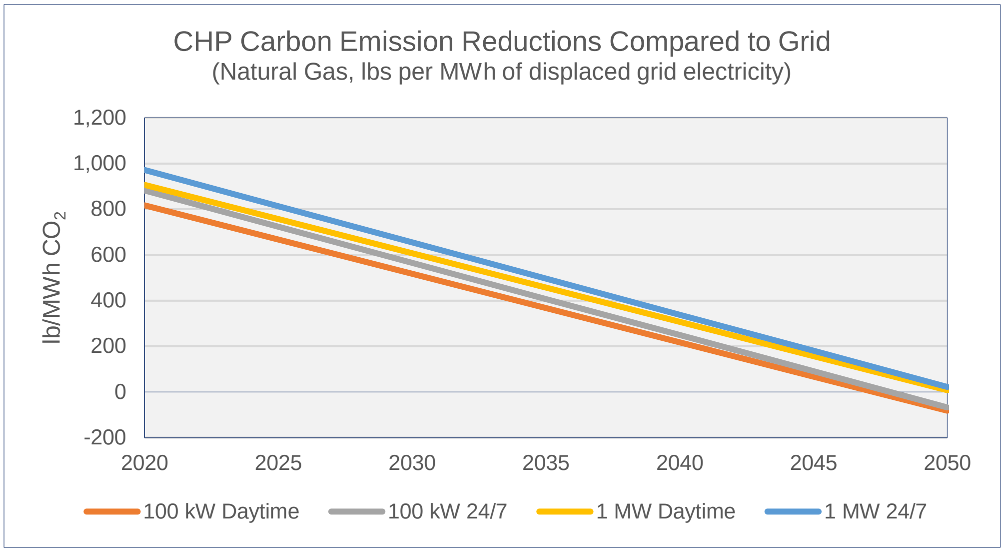
New Mexico implemented the Renewable Energy Act which inherits the previous RPS and establishes a goal of 20% of sales to be met by in-state renewable sources in 2020, increasing to a 100% RPS by 2045 for investor-owned utilities. Rural electric cooperatives will need to reach 100% renewable by 2050. Additionally, New Mexico has other policies that are advantageous for renewable expansion, such as net metering and financial incentives.[16]

The regional grid will consist of a mix of New Mexico and Arizona resources. The non-baseload emissions rate for 2050 is estimated as 523 lbs/MWh, while the emissions rate for 24/7 operation is estimated to be 537 lbs/MWh, indicating that natural gas generators are expected to be used for marginal electricity generation in parts of the region through 2050 as more renewables are incorporated.

Figure 7 shows the estimated carbon reductions for CHP compared to the grid in the AZNM eGRID subregion.

[13] U.S. Environmental Protection Agency, Greenhouse Gas Equivalencies Calculator, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator, March 2020.
[14] Ibid.
[15] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid
[16] U.S. Department of Energy, Energy Information Administration, State Profile, May 2020.

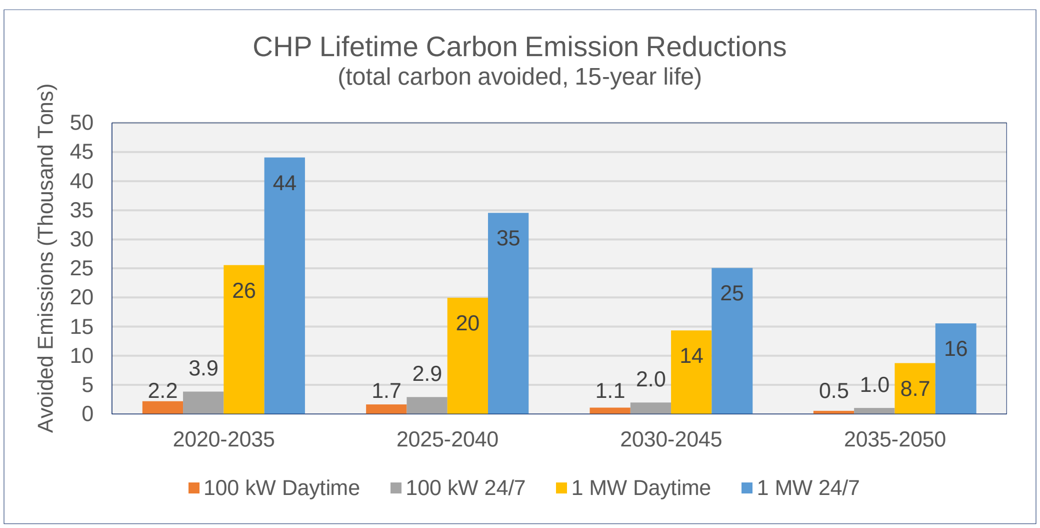
Figure 7. CHP Carbon Emission Reductions (lb/MWh) Compared to Average AZMN Marginal Grid Emissions



The estimated rate of carbon reduction for CHP in 2020 in AZNM ranges from 800 to 1,000 pounds for each MWh of displaced grid electricity. As we move to 2050 and New Mexico approaches a zero-carbon grid, the rate of carbon reduction for the region decreases, with smaller CHP systems adding emissions to the grid while larger systems avoid less than 50 pounds per MWh of displaced electricity.

Figure 8 shows the expected lifetime carbon emission reductions for a natural gas CHP engine with a 15-year life, installed in the AZMN subregion in 2020, 2025, 2030, or 2035.

Figure 8. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average AZMN Marginal Grid Emissions



CHP systems in the AZMN region that are retired before 2050 can reduce grid emissions by a substantial amount, especially in the near term. A 1 MW system installed in 2020 will avoid over 25 thousand tons of emissions by the end of its 15-year lifetime operating only during the daytime (~5,000 hours/year), while a system that operates 24/7 will avoid 44 thousand tons of emissions. This is the equivalent to the current emissions produced in powering 4,610 homes for one year, or in driving 8,630 passenger vehicles for one year, on average. Smaller 100 kW systems will avoid 2,220 tons of carbon emissions operating only during the daytime, while the same system operating nonstop will avoid 3,870 tons.

For a 1 MW CHP system installed in the AZMN region 2035 and retired in 2050, close to 9 thousand tons of carbon emissions can be avoided by operating during daytime hours. This system will avoid nearly 16 thousand tons of emissions operating nonstop, equivalent to the current emissions produced in powering 1,628 homes for one year, or in driving 3,049 passenger vehicles for one year, on average. A 100 kW system with the same lifespan will offset 540 tons of emissions by 2050 operating in the daytime. By operating 24/7, it will offset 1,020 tons of carbon emissions.

6.2 WECC California (CAMX)

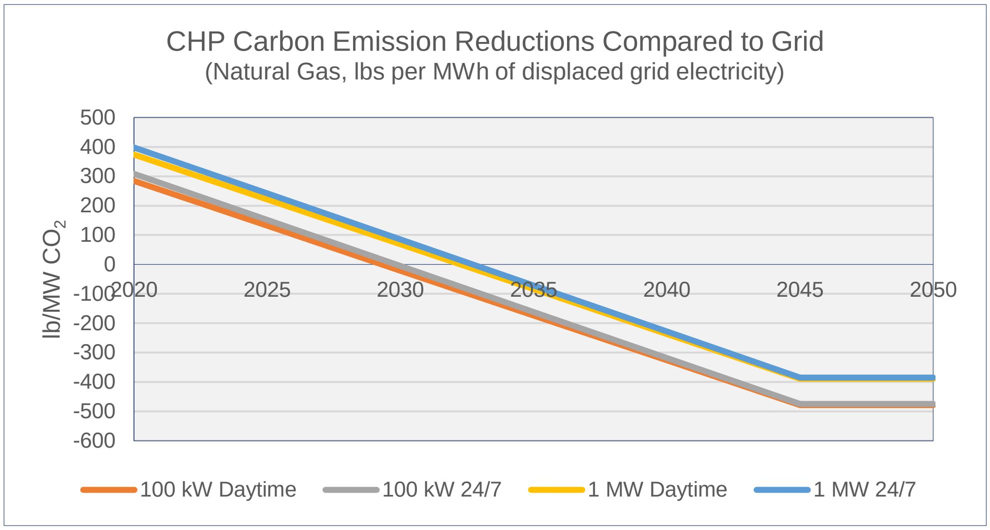
The WECC California eGRID region encompasses most of California, except for a small portion of Northern California that falls into WECC Northwest. California is the most populated state in the US and has the largest economy. California has made significant strides towards reducing its energy consumption per capita and its GHG emissions. The state has also slowed energy demand with its investments in energy efficiency technologies and has an energy efficiency resource standard to lower demand and ramp up efficiency gains. It has enacted EE policies such as a mandate in 2019 that requires all new homes to have rooftop solar, and the California Solar Initiative, which encourages people to install rooftop solar with rebates and buyback programs.

California leads the country in solar, biomass and geothermal generation, and its Renewable Portfolio Standard requires 100% renewable resources by 2045. California's Senate Bill 100 require the state to reach 100% zero carbon electricity by 2045, including renewable offsets for any remaining fossil generation.[17] As a result, the emissions rate for California was set to zero in 2045 and 2050 to account for the 100% target.

Figure 9 shows the expected carbon emission reductions for natural gas CHP systems in the CAMX eGRID subregion. We assume that the grid becomes 100% renewable in 2045, with emission factors declining to zero in a straight line from 2018 eGRID levels. Given the timing of the target in 2045, the timeframe for CHP systems to generate net emission reductions is more limited than in other regions of the country. CHP system fueled by fuels that may qualify as compliant with the definition of zero carbon may however still provide system benefits through their dispatchability and efficiency.

[17] California Senate Bill No. 100, California Renewables Portfolio Standard Program: Emissions of Greenhouse Gases, Chapter 312, https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100

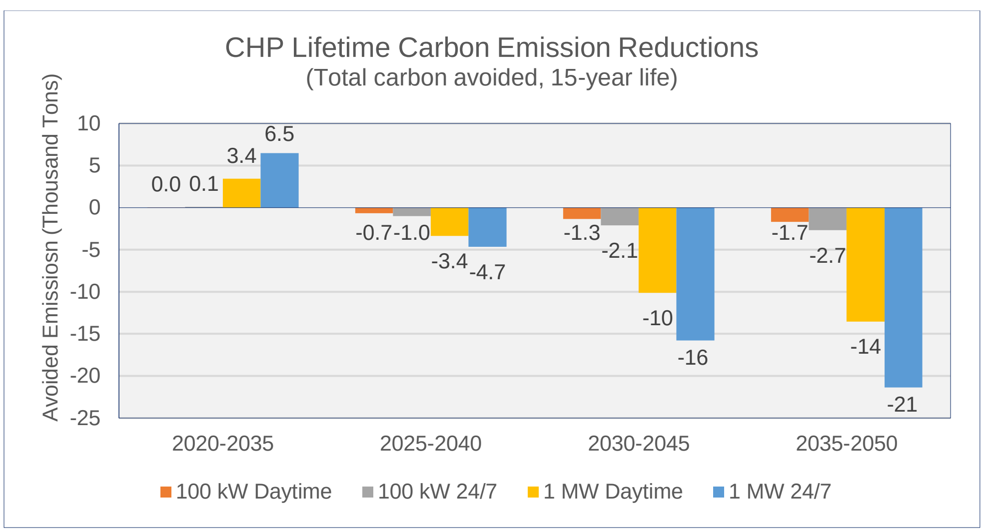
Figure 9. CHP Carbon Emission Reductions (lb/MWh) Compared to Average CAMX Marginal Grid Emissions



The estimated rate of carbon reduction for CHP in 2020 in the CAMX region ranges from just under 300 to 400 pounds for each MWh of displaced grid electricity. According to the modeling, smaller CHP systems become net carbon emitters in 2030, while 1 MW systems continue to reduce emissions until 2033. It is at this point that CHP systems would need to begin incorporating RNG to remain carbon neutral.

Figure 10 shows the expected lifetime carbon emission reductions for a natural gas CHP engine with a 15-year life, installed in California in 2020, 2025, 2030, or 2035.

Figure 10. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average CAMX Marginal Grid Emissions



The analysis suggested that over their lifetimes, only CHP systems installed before 2025 can run on natural gas without adding emissions to the California grid. A 100 kW system installed in 2020 will avoid 60 tons of emissions operating in the daytime. The same system operating 24/7 will avoid 110 tons of emissions. 1 MW systems will avoid 3,420 tons operating in the daytime and 6,480 tons operating nonstop. This is equivalent to the emissions produced to power 680 homes for a year or the average amount produced by driving 1,270 passenger vehicles in a year.

In later years, there may still be room for CHP systems to reduce emissions compared to the grid in California depending on how quickly marginal grid resources are converted to clean power, and how easily RNG can be supplied.

6.3 ERCOT (ERCT)

The Electric Reliability Council of Texas Independent System Operator (ERCOT) services 90% of Texas's electric market. ERCOT is a summer peaking system, and in the summer of 2019, Texas experienced an extreme heating event that caused a spike in air conditioning usage throughout the state. The peak demand in 2019 was 74,666 MW, an all-time high for the system.[18] Since most of ERCOT's peak hour demand gap is met by emissive combustion turbine plants, CHP would be a valuable source for ERCOT to reduce its GHG emissions.

In 2018, the 2018 fuel mix in ERCOT was 23% coal, 49% gas, 17% wind and 10% nuclear, with less than 1% of generation coming from solar power. eGRID data for 2018 demonstrates that the non-baseload generation in the ERCOT region was made up of 70% natural gas combined cycle and combustion turbine generators and 28% coal. Similar to the non-baseload mix, the overall fossil fuel mix is split about 2/3 gas and 1/3 coal. The similarity in the non-baseload and overall fossil emission rates translates to the ERCOT emission factors, which are reported at 1,261 lbs/MWh for the non-baseload 1,301 lbs/MWh for the fossil fuel average emissions factor.[19]

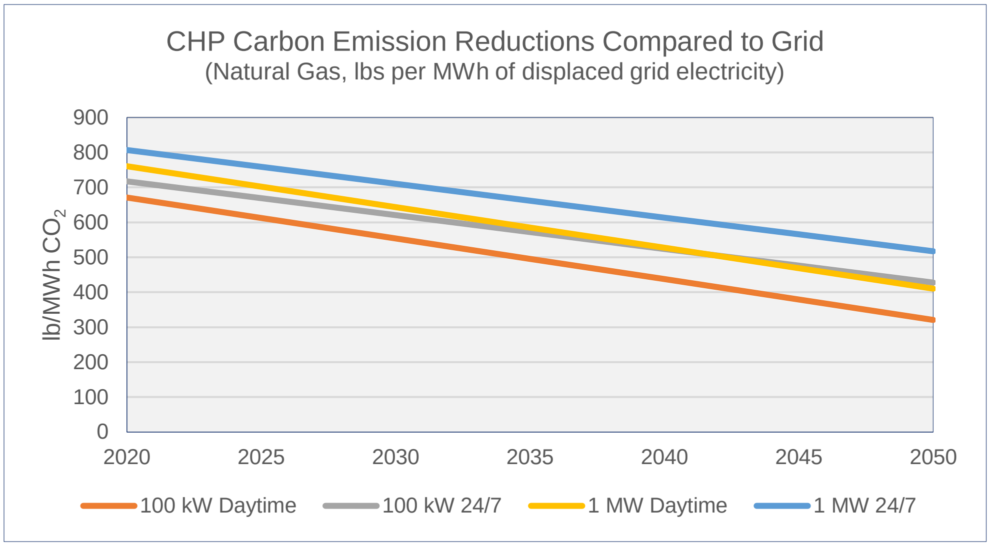
For 2050, the average non-baseload emissions factor is 906 lbs/MWh, while the emissions factor for 24/7 operation is estimated as 1,007 lbs/MWh. These rates imply that the generation mix in 2050 is overall about 30% cleaner compared to 2018, and that there will be natural gas generation providing marginal generation.

Figure 11 shows the estimated carbon emission reductions for natural gas CHP in the ERCOT region.

[18] ERCOT Summer 2019 Update, Public Utility Commission of Texas, November 5, 2019

[19] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

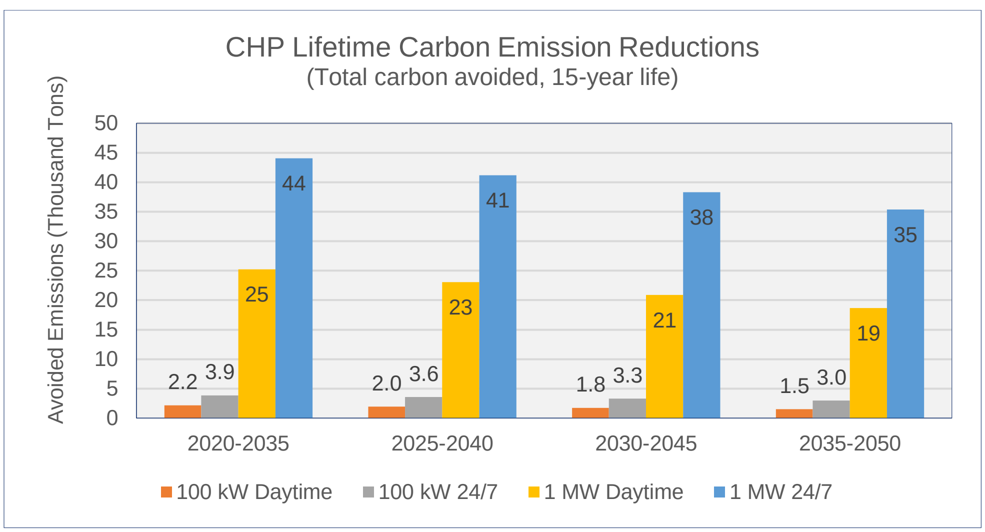
Figure 11. CHP Carbon Emission Reductions (lb/MWh) Compared to Average ERCT Marginal Grid Emissions



The estimated rate of carbon reduction for CHP in 2020 in the ERCT region ranges from 650 - 800 lbs. per MWh of grid electricity displaced. Even with projected decreases in grid emissions, CHP can still produce substantial emissions reductions in ERCOT by 2050. The rate of carbon reduction by 2050 ranges from 300 to 500 lbs. per MWh of displaced electricity.

Figure 12 shows the expected lifetime carbon emission reductions for a natural gas CHP engine with a 15-year life, installed in 2020, 2025, 2030, or 2035.

Figure 12. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average ERCT Marginal Grid Emissions



CHP systems retired in Texas before 2050 will reduce grid emissions over their lifespan. 100 kW systems installed in 2020 will avoid 2,190 tons of emissions operating only in the daytime, and 3,870 tons of emissions operating 24 hours a day. A 1 MW system will avoid over 25 thousand tons of emissions if it operates only during the day. 1 MW systems operating 24/7 will offset over 44 thousand tons, equivalent to the emissions produced by 8,640 cars over one year or by powering 4,610 homes for a year.

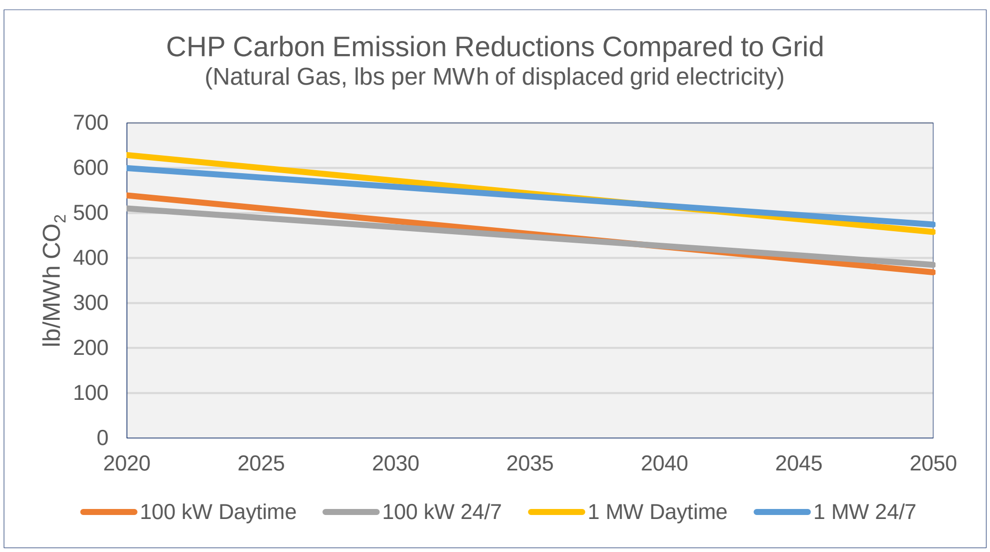
For a 100 kW system beginning operation in Texas in 2035, 1,530 tons of emissions can be avoided by operating during the daytime. Operating the same system 24/7 will avoid 3,000 tons of emissions. A 1 MW system installed in 2035 can avoid close to 19 thousand tons of emissions operating during the daytime, and over 36 thousand tons operating 24 hours a day. That amount is equivalent to the emissions produced to power 3,700 homes for a year, or emitted by 6,930 cars driving for a year, based on current averages.

6.4 FRCC All (FRCC)

Florida is the second largest producer of electricity in the US after California, and demand is predominately met by natural gas. Coal generation has halved in the last decade and in 2018, the overall generation mix was ~12% coal, 70% gas and 13% nuclear, with less than 10% of generation from renewable energy sources. The 2018 non-baseload mix was 22% coal and 77% gas, which closely reflected the fossil average portions for 2018. In 2018 the eGRID fossil fuel average emissions factor was 1093 lbs/MWh, and the non-baseload average emissions factor was 1124 lbs/MWh. In 2050, the projected equivalent emissions factors are 966 and 951 lbs/MWh, respectively. This implies that although the region will be slightly cleaner in 2050, there will be predominantly fossil generation providing marginal generation, with overall lower emissions compared to 2018.[20]

Figure 13 shows the estimated carbon emission reductions for natural gas CHP through 2050 in Florida.

Figure 13. CHP Carbon Emission Reductions (lb/MWh) Compared to Average FRCC Marginal Grid Emissions



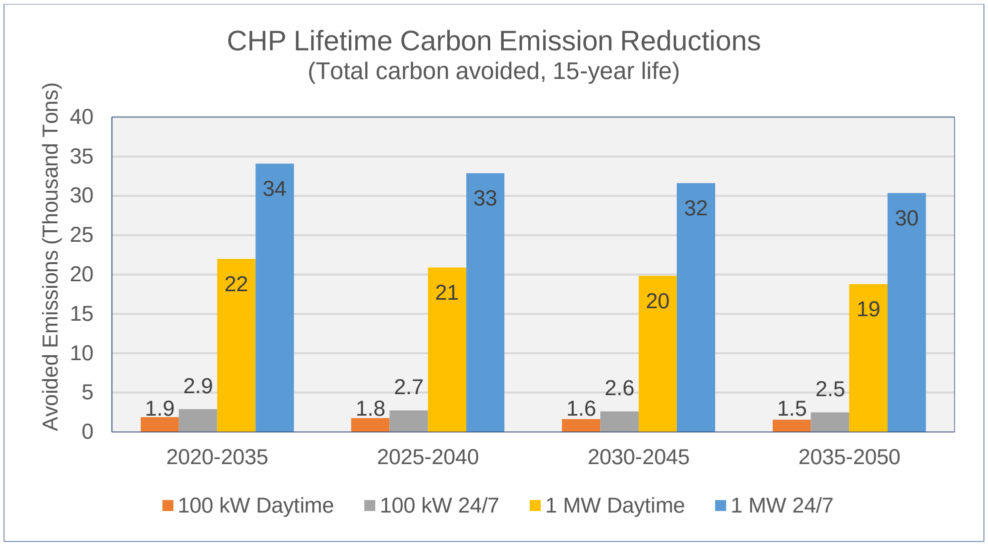
The estimated rate of carbon reduction for CHP in 2020 in the FRCC region ranges from 500 to 600 pounds for each MWh of displaced grid electricity, with smaller systems being on the lower end of that

[20] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

scale. As we move to 2050, the rate of carbon reduction decreases to between 400 and 500 pounds per MWh of displaced grid electricity.

Figure 14 shows the expected lifetime carbon emission reductions for a natural gas CHP engine with a 15-year life, installed in Florida in 2020, 2025, 2030, or 2035.

Figure 14. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average FRCC Marginal Grid Emissions



CHP systems in the FRCC region can reliably reduce emissions between 2020 and 2050. A 1 MW system installed in 2020 will avoid over 25 thousand tons of emissions by the end of its lifetime only during the daytime. By operating 24/7, this system can avoid 34 thousand tons of emissions during its lifetime, equivalent to the current emissions produced in powering 3,570 homes for one year, or emitted by 6,680 passenger vehicles in one year, on average. A smaller 100 kW system can avoid 1,860 tons of emissions operating in daytime hours, and 2,870 tons of emissions operating 24 hours a day.

For a 1 MW system installed in 2035 and retired in 2050, close to 19 thousand tons of carbon emissions can be avoided by operating during daytime hours. By operating 24/7, this system can avoid over 30 thousand tons of emissions, the same amount emitted by 5,950 cars during a year or produced to power 3,180 homes for a year, on average. A 100 kW system installed in 2035 could avoid 1,540 tons of carbon emission operating during the daytime or 2,500 tons of emissions operating 24 hours a day.

6.5 MRO East (MROE)

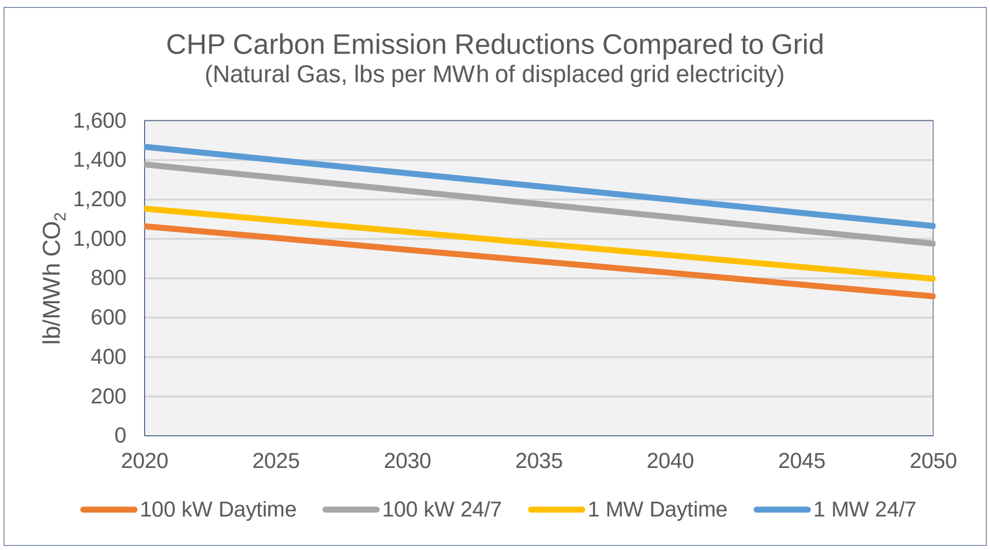
The MRO East region encompasses most of the Upper Peninsula of Michigan and east Wisconsin. In Wisconsin, natural gas has expanded rapidly in the past decade and coal usage has declined. In 2018 the overall electricity generation mix, which is 64% coal, 23% natural gas, 4% biomass, 5% hydroelectric generation and 3% wind power. The non-baseload mix is 55% coal, 38% gas and ~1% oil. Thus, MROE generation is primarily coal and natural gas, and the 2018 fossil fuel specific generation mix was about ¼ coal and ¾ natural gas, with a small amount of oil.[21]

In 2019, the governor of Wisconsin signed an executive order with the goal of net-zero electricity in the state by 2050. Michigan also has renewable energy standards that require an increasing amount of electricity sales to be from renewable sources. The RPS allows a wide variety of sources solar power, biomass, wind, geothermal energy, municipal solid waste, landfill gas, existing hydroelectricity, and tidal, wave, and river currents. The mandate currently requires 12.5% of sales to come from these sources and is set to increase to 15% in 2021.[22]

The CAPs in place in both states will necessitate a transition to a cleaner fuel mix. In 2018, the eGRID fossil fuel average emissions factor was 1,936 lbs/MWh and the non-baseload emissions factor was 1,634 lbs/MWh. By 2050, the analysis showed these factors declining to 1,528 lbs/MWh and 1,274 lbs/MWh, respectively. Based on these changes, the region's electricity mix is expected to shift significantly during the time horizon under study. The region has potential for solar power expansion and more solar projects are planned during this time horizon.

Figure 15 shows the estimated emission reductions for natural gas CHP compared to the grid in the MRO East subregion.

Figure 15. CHP Carbon Emission Reductions (lb/MWh) Compared to Average MROE Marginal Grid Emissions



MRO East's estimated rate of carbon reduction for CHP in 2020 is one of the highest amongst all regions, ranging from 1,000 to 1500 pounds for each MWh of displaced grid electricity, with 24/7 systems reducing more emissions than daytime only systems. As we move to 2050, the rate of carbon reduction decreases to between 700 and 1000 pounds per MWh of displaced grid electricity.

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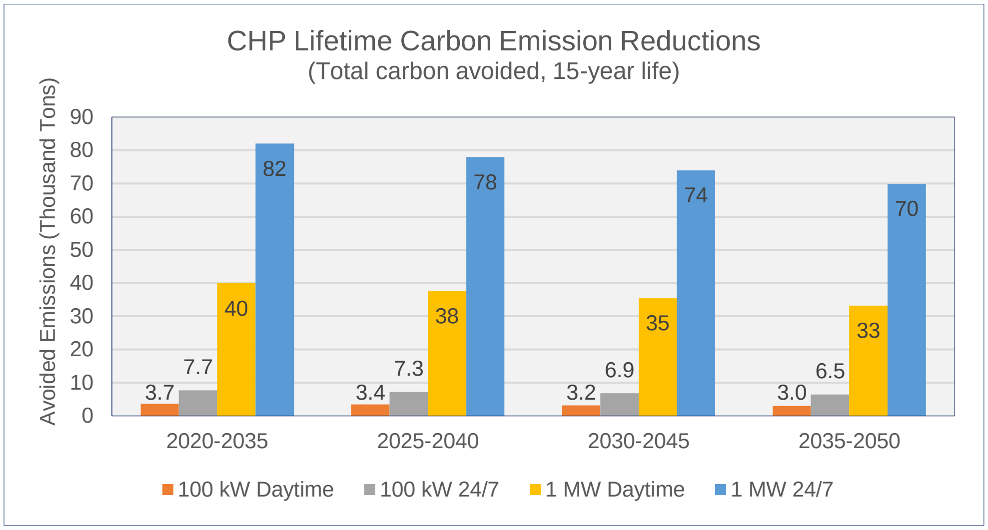
[21] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

[22] U.S. Department of Energy, Energy Information Administration, State Profile, May 2020.

Figure 16 shows the expected lifetime carbon emission reductions for a natural gas CHP engine with a 15-year life, installed in 2020, 2025, 2030, or 2035.

Figure 16. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average MORE Marginal Grid Emissions



A 1 MW CHP system installed in 2020 in the MRO East region will avoid close to 40 thousand tons of emissions by the end of its lifetime when only operating during the daytime. By operating 24/7, this system can avoid nearly 82 thousand tons of emissions during its lifetime, equivalent to the current emissions produced in powering 8,580 homes or emitted collectively by 16,060 passenger vehicles in one year, on average. A smaller 100 kW system can avoid 3,650 tons of emissions operating in the daytime, and 7,660 tons of emissions operating 24 hours a day.

A 1 MW system installed in 2035 and retired in 2050 in the MRO East region can avoid 33 thousand tons of carbon emissions by operating during daytime hours. By operating 24/7, this system could avoid nearly 70 thousand tons of emissions, the same amount emitted by 13,700 cars during a year or produce to power 7,316 homes for a year. A 100 kW system installed in 2035 could avoid 2,990 tons of carbon emissions operating in the daytime or 6,460 tons of emissions operating 24 hours a day.

6.6 MRO West (MROW)

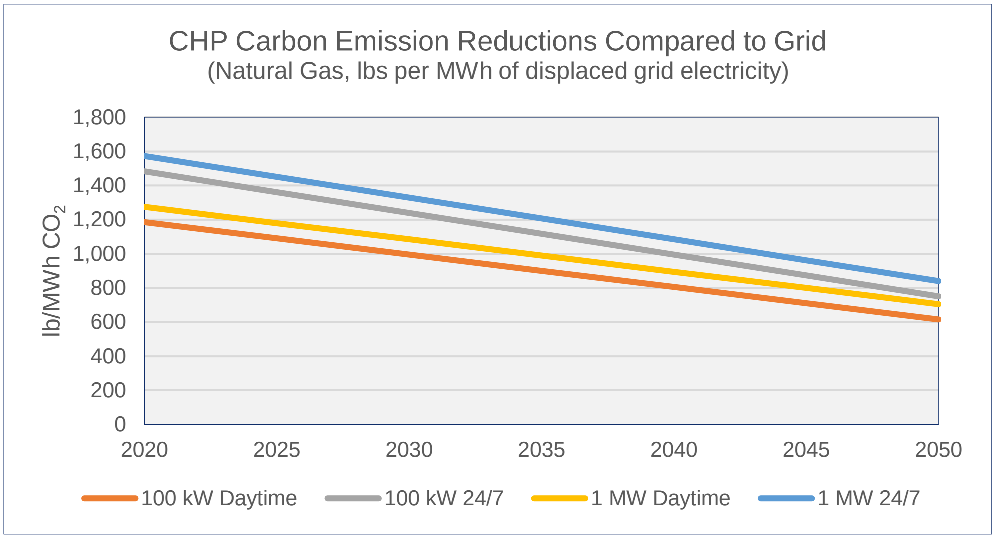
The MRO West eGRID region encompasses the mid-northwest part of the contiguous US, and includes eastern portions of Montana, North Dakota, South Dakota, most of Nebraska, Iowa, Minnesota, western portions of Wisconsin, and a northwest sliver of Illinois. These states have varying CAPs and overall energy generation mixes, but it is reasonable to group them together based on their similar geography, and because of the NERC and utility boundaries that make up the region. Coal accounted for more generation than any other fuel type in 2018 at ~52% of overall generation, followed by wind generation at 21%, nuclear at 10% and natural gas at 8%. The fossil fuel specific mix for 2018 was 86% coal and 14% natural gas, and non-baseload fuels were at 66% coal and 30% gas.[23]

[23] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

The MROW region also has a lot of wind expansion potential, especially in Iowa. Its fossil fuel average emissions rate is expected to fall from 2,058 lbs/MWh in 2018 to 1,315 lbs/MWh in 2050, and its non-baseload average emissions rate is expected to drop from 1,764 lbs/MWh in 2018 to 1,186 lbs/MWh in 2050. The 2050 rates imply that most coal power will shift to natural gas within the time horizon.

Figure 17 shows the estimated carbon emission reductions for CHP in the MROW region through 2050.

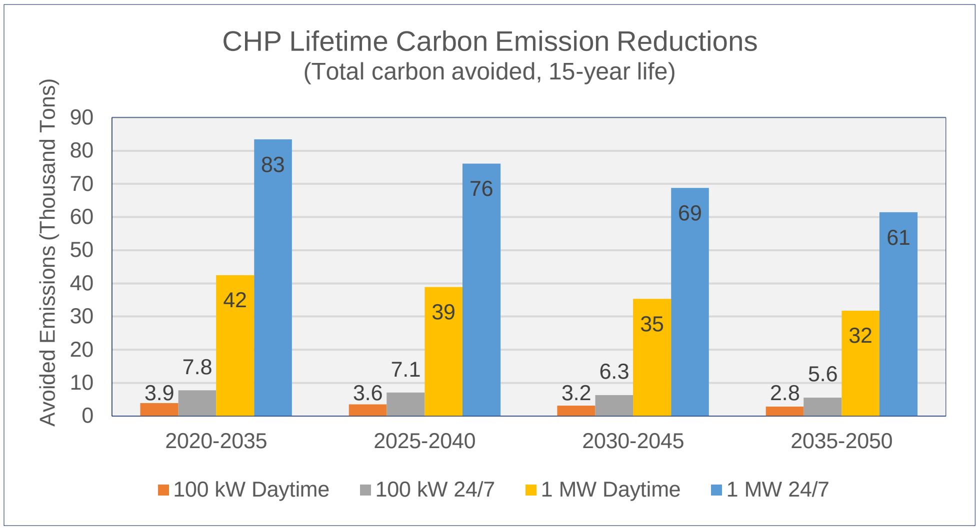
Figure 17. CHP Carbon Emission Reductions (lb/MWh) Compared to Average MROW Marginal Grid Emissions



MROW estimated rate of carbon reduction for CHP in 2020 similarly high like MROE, ranging from 1,200 to 1600 pounds for each MWh of displaced grid electricity, with 24/7 systems reducing more emissions than daytime only systems as well, due to coal being used during the night. As we move to 2050, the rate of carbon reduction decreases to between 600 and 900 pounds per MWh of displaced grid electricity.

Figure 18 shows the expected lifetime carbon emission reductions for a natural gas CHP engine with a 15-year life, installed in 2020, 2025, 2030, or 2035.

Figure 18. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average MROW Marginal Grid Emissions



Across system lifetime, a 1 MW system installed in 2020 will avoid over 42 thousand tons of emissions in total operating only during the daytime. By operating 24/7, this system can avoid over 83 thousand tons of emissions during its lifetime, equivalent to the current emissions produced in powering 8,730 homes for one year or emitted by 16,340 passenger vehicles in one year, on average. A smaller 100 kW system can avoid 3,912 tons of carbon emissions operating in the daytime, and 7,800 tons of emissions operating 24 hours a day.

A 1 MW system installed in 2035 that operates in the daytime avoid close to 32 thousand tons of carbon emissions by its 2050 retirement. By operating 24/7, this system can avoid over 61 thousand tons of emissions, the same amount produced by 12,040 cars or emitted to power 6,430 homes for a year, on average. A 100 kW system can avoid 2,830 tons of emission operating in the daytime or 5,610 tons of emissions operating 24 hours a day.

6.7 NPCC New England (NEWE)

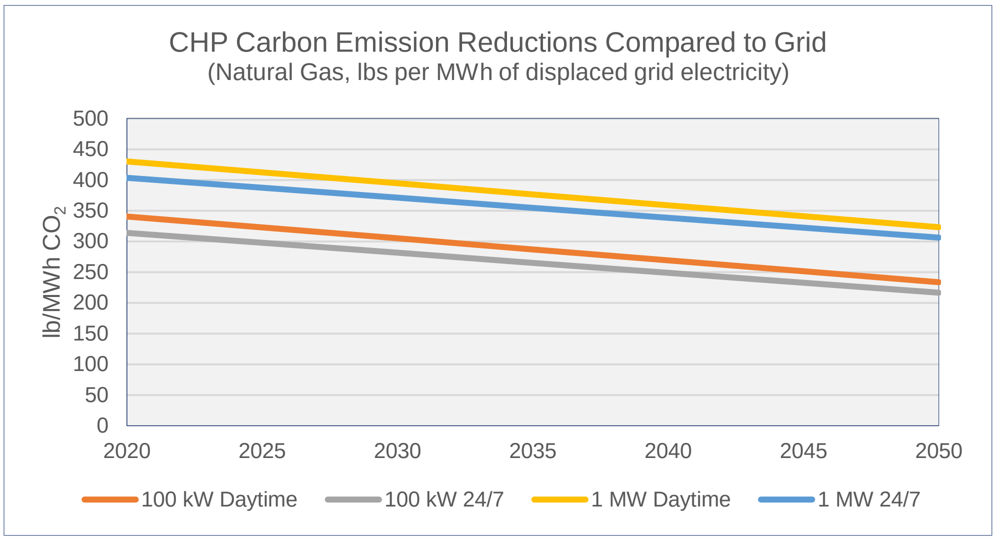
The NPCC New England region is made up of the states commonly referred to by the EIA as the New England region. These states are Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island. All the states, along with Delaware and New York, are members of the Regional Greenhouse Gas Initiative (RGGI) which is a cap and trade effort among its member states to reduce GHG emissions. Additionally, many of the states have other climate efforts in place to aid development of renewable projects. For instance, Maine has an RPS that requires 10% of electricity sales through 2022 to be from renewables installed after 2005 and offers rebates to some renewables. New Hampshire has an RPS that requires 25.2% of electricity sold to come from renewable sources after 2025. Vermont has programs for small-scale projects, such as a feed-in tariff for small renewable generation and a Clean Energy Development Fund to aid small projects. Massachusetts has an RPS, an Alternative Energy Portfolio Standard, and a Clean Energy Standard, which includes hydroelectric power and nuclear power and has the goal of 80% of clean energy sales by 2050. Rhode Island has a Renewable Energy Standard requiring 38% of in-state sales to come from renewable sources by 2035, and Connecticut also has an RPS that is increasing by about 10% every five years.

The non-baseload generation mix was ~88% natural gas in 2018, with coal and oil making up the remainder of non-baseload generation. The fossil fuel-specific mix is also predominately natural gas. In 2018 the overall generation was ~49% natural gas, 30% nuclear, 6% hydroelectric power, 7% biomass, and 3% wind, with the small remainder made up by coal and natural gas mostly met by natural gas and nuclear power.[24]

The CAP in this region, including the RPS's and RGGI program in the member states, will drive a cleaner electric grid. This is also suggested by the changes to emissions factors in the region: between 2018 and 2050, the emissions factor for 24/7 CHP is projected by ICF to drop from 905 lbs/MWh to 806 lbs/MWh and the emissions factor for daytime operation is projected to drop from 931 lbs/MWh to 822 lbs/MWh. The 2050 rates imply that there will still be some efficient or renewable natural gas running on the margin in this region.

Figure 19 shows the estimated carbon emission reductions over time for natural gas CHP systems in New England.

Figure 19. CHP Carbon Emission Reductions (lb/MWh) Compared to Average NEWE Marginal Grid Emissions

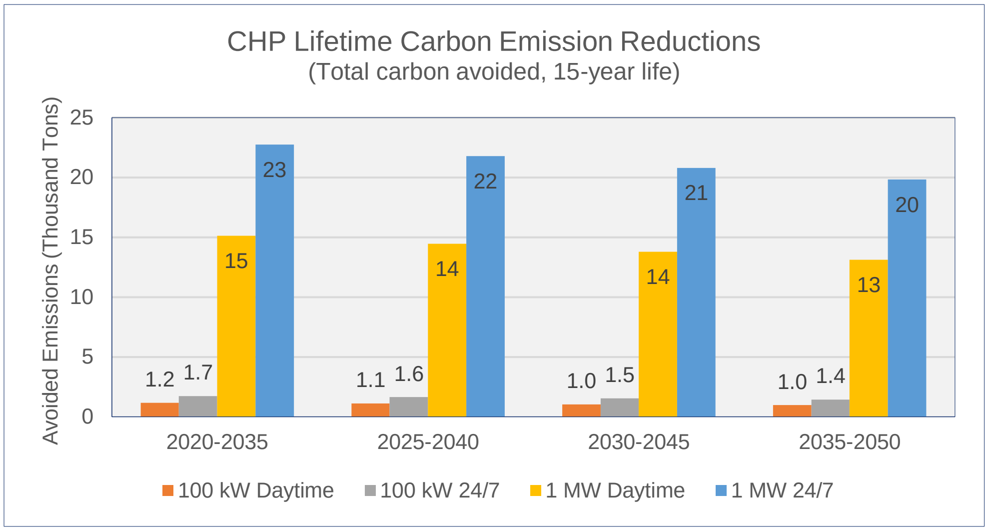


In New England, the estimated rate of carbon reduction for CHP in 2020 ranges from 300 to 450 pounds per MWh of displaced grid electricity, with 1 MW systems having higher reductions. In 2050, the estimated rate of carbon emissions reductions ranges from 200 to 350 pounds for each MWh of displaced grid electricity.

Figure 20 shows the expected lifetime carbon emission reductions for a natural gas CHP engine with a 15-year life, installed in New England in 2020, 2025, 2030, or 2035.

[24] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

Figure 20. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average NEWE Marginal Grid Emissions



CHP systems in New England retired before 2050 have the potential to reduce grid emissions significantly over their lifespan. 100 kW systems installed in 2020 will avoid 1,860 tons of emissions operating only in the daytime, and 2,870 tons of emissions operating 24 hours a day. A 1 MW system will avoid close to 22 thousand tons of emissions if it operates only during the day. 1 MW systems operating 24/7 will offset 34 thousand tons, equivalent to the average emissions currently produced by 6,680 cars over one year or by powering 3,570 homes for a year.

For a 100 kW system beginning operation in 2035, 1,540 tons of emissions can be avoided by operating it during the daytime. Operating the same system 24/7 will avoid 2,500 tons of emissions. A 1 MW system installed in 2035 can avoid close to 19 thousand tons of emissions operating during the daytime, and over 30 thousand tons operating 24 hours a day. That amount is equivalent to the average emissions produced to power 3,180 homes for a year or produced by 5,950 cars driving for a year.

6.8 WECC Northwest (NWPP)

The WECC Northwest eGRID region includes several states in the northwestern contiguous U.S., including Washington, Oregon, Idaho, most of Montana, most of Wyoming, Utah, Nevada, a small section of Northern California, and small sections of northern Arizona and northern New Mexico. Hydropower generates more electricity than any other energy type in this region, and the overall electricity generation mix for 2018 was 48% hydroelectric, 21% coal, 16% natural gas, and less than 10% for nuclear, wind and solar. For 2018, the overall fossil fuel proportion between natural gas and coal is 42% and 57%, respectively, and the non-baseload fuel proportion is roughly equal (50% natural gas, 50% coal). Coal has been on the decline in many of the region's states in the past decade, and the EIA reports that it is expected to continue declining.[25]

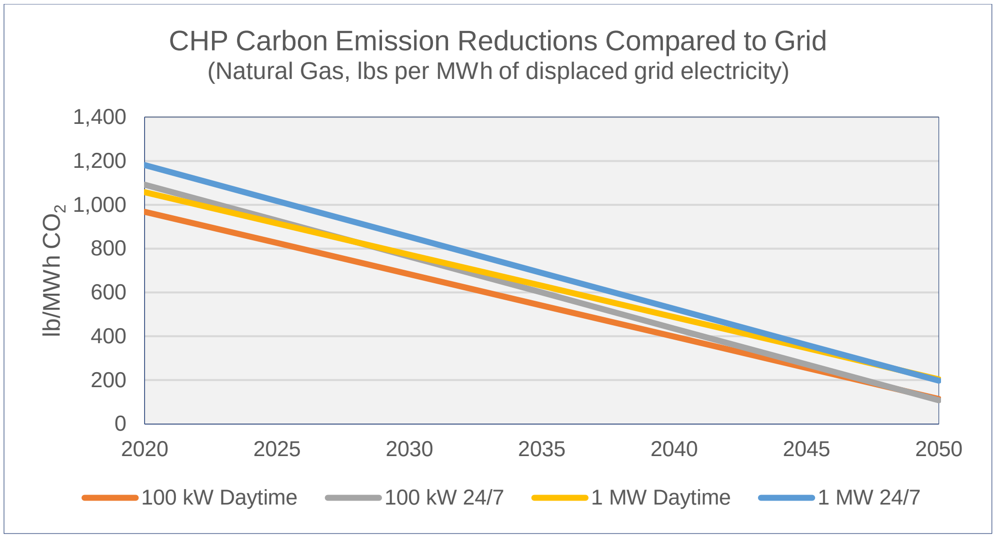
In 2050, changes are expected on the region's electric system, and a cleaner grid could have gaps filled by efficient natural gas. The 2018 emissions factors were 1,701 lbs/MWh for fossil fuel average and 703

[25] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

lbs/MWh for non-baseload average. In 2050, these factors become to 1,575 lbs/MWh and 709 lbs/MWh, respectively.

Figure 21 shows the estimated carbon emission reductions over time for natural gas CHP in the NWPP eGRID subregion.

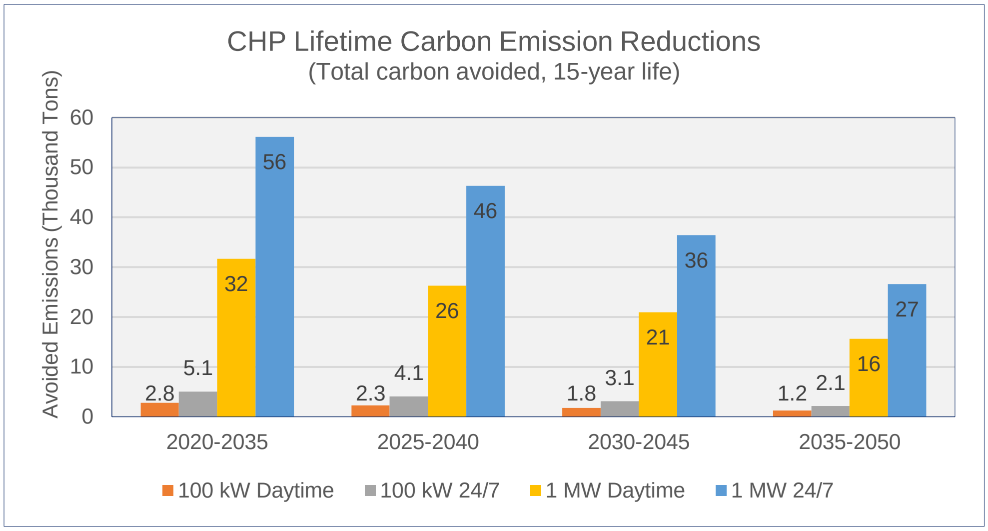
Figure 21. CHP Carbon Emission Reductions (lb/MWh) Compared to Average NWPP Marginal Grid Emissions



The estimated rate of carbon reduction for CHP in 2020 in NWPP ranges from 1000 to 1200 pounds for each MWh of displaced grid electricity. Moving to 2050, the rate of carbon reduction decreases steeply to between 100 and 200 pounds per MWh of displaced grid electricity, with smaller systems contributing less to grid reductions per MWh.

Figure 22 shows the expected lifetime carbon emission reductions for a natural gas CHP engine with a 15-year life, installed in the Northwest in 2020, 2025, 2030, or 2035.

Figure 22. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average NWPP Marginal Grid Emissions



In line with the steep rate of emissions decrease, lifetime carbon emissions decrease steeply the later a system is installed. A 1 MW system installed in 2020 will avoid close to 32 thousand tons of emissions by the end of its lifetime only during the daytime. By operating 24/7, this system can avoid over 56 thousand tons of emissions during its lifetime, equivalent to the current emissions produced in powering 5,870 homes for one year, or emitted collectively by 11,000 passenger vehicles in one year. The same system installed in 2035 will avoid about half of these amounts.

A smaller 100 kW system installed in 2020 can avoid 2,830 tons of emissions operating in the daytime, and 5,070 tons of emissions operating 24 hours a day. The same sized system installed in 2035 and retiring by 2050 will avoid 1,230 tons of emissions operating in the daytime and 2,130 tons of emissions when operating 24 hours a day.

6.9 New York State (NYCW, NYLI, NYUP)

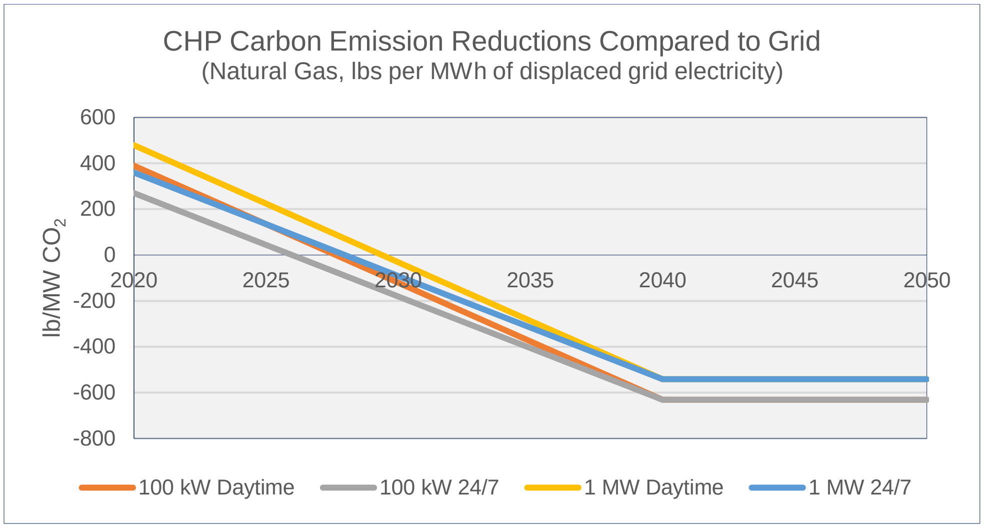
Currently, the marginal generation in New York is primarily made up of natural gas combined cycle generators, as well as some nuclear power in NYLI and NYUP, and some hydroelectric power in upstate New York. The eGRID marginal (non-baseload) emissions rate for New York City in 2018 is 1068 lb/MWh, and ICF assumes that the state-wide average fossil fuel and non-baseload emission rates will both reduce to 0 lb/MWh by 2040 in order to meet the state's legislated climate targets. New York's CAP, CLCPA, is one of the most aggressive in the world, with a target of a net-zero electricity grid by 2040 and net-zero emissions throughout all sectors by 2050. New York's climate goals will necessitate a shift towards more solar and wind power generation by 2050.

New York is split up into three eGRID subregions, representing New York City and Westchester (NYCW), Long Island (NYLI), and Upstate New York (NYUP). In all regions, natural gas CHP is modeled to become a net carbon emitter between 2025 and 2030. At this point, increasing amounts of RNG would need to be incorporated in order for CHP to maintain carbon neutrality.

6.9.1 NPCC NYC/Westchester (NYCW)

Figure 23 shows the estimated carbon emissions reductions over time for natural gas CHP systems in the New York City area.

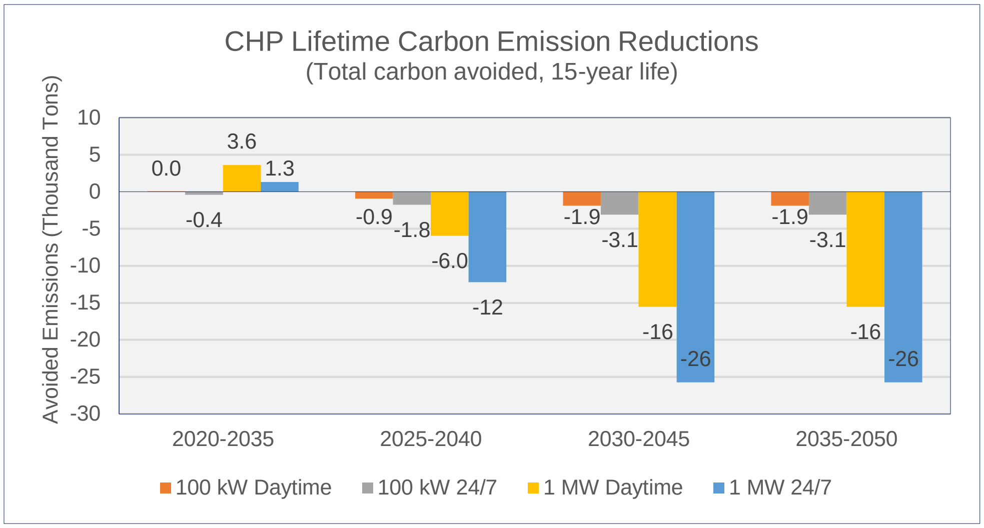
Figure 23. CHP Carbon Emission Reductions (lb/MWh) Compared to Average NYCW Marginal Grid Emissions



The estimated rate of carbon reduction for CHP in 2020 in NYCW region ranges from 250 to 500 pounds for each MWh of displaced grid electricity. All CHP systems begin adding emissions to the grid between 2025 and 2030, with 100 kW systems adding emissions sooner than their 1 MW counterparts. By 2040, when the grid will be decarbonized, CHP will add between 550 and 650 lbs. of carbon per MWh of displaced grid electricity when using natural gas.

Figure 24 shows the expected lifetime carbon emission reductions for a CHP engine with a 15-year life in New York City, installed in 2020, 2025, 2030, or 2035.

Figure 24. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average NYCW Marginal Grid Emissions

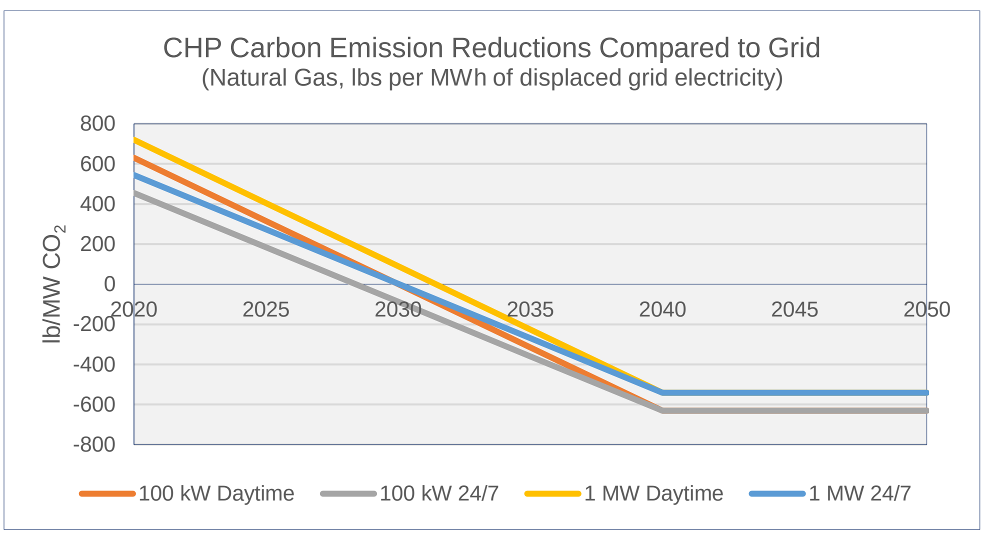


In 2020, 100 kW systems that operate 24/7 are already expected to add to grid emissions over their lifetime, while systems that operate during the daytime will avoid 25 tons of emissions by their retirement in 2035. A 1 MW system operating during the daytime will offset 3,600 tons of emissions, while a system operating 24/7 will only avoid 1,300 tons of emissions. By 2025, all CHP systems are expected to produce carbon emissions over a 15-year life when fueled by natural gas.

6.9.2 NPCC Long Island (NYLI)

Figure 25 shows the estimated emission reductions over time for natural gas CHP systems installed in Long Island.

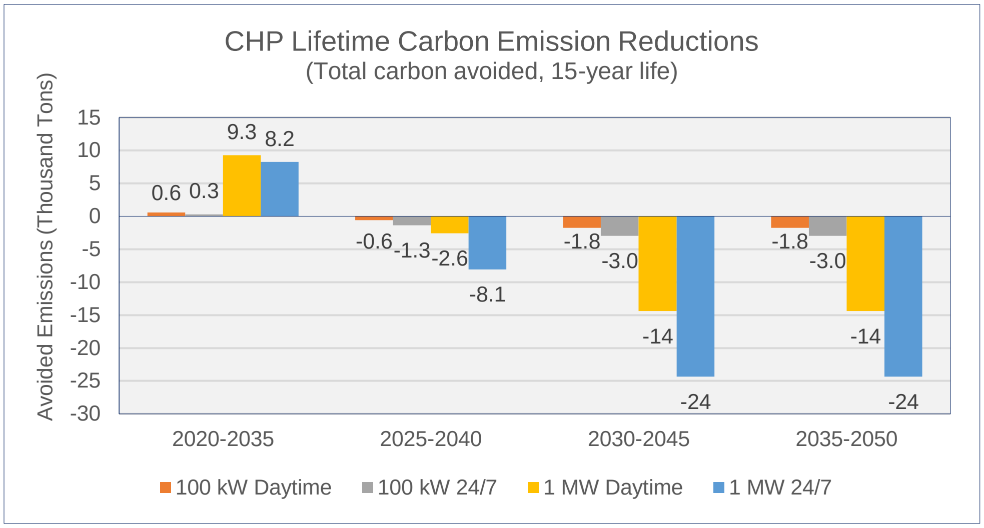
Figure 25. CHP Carbon Emission Reductions (lb/MWh) Compared to Average NYLI Marginal Grid Emissions



The estimated rate of carbon reduction for CHP in 2020 in NYLI region ranges from 450 to 650 pounds for each MWh of displaced grid electricity. By 2030, 100 MW systems fueled by natural gas begin adding emissions to the grid, while 1 MW systems begin adding emissions soon afterward.

Figure 26 shows the expected lifetime carbon emission reductions for a natural gas CHP engine with a 15-year life, installed in Long Island in 2020, 2025, 2030, or 2035.

Figure 26. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average NYLI Marginal Grid Emissions

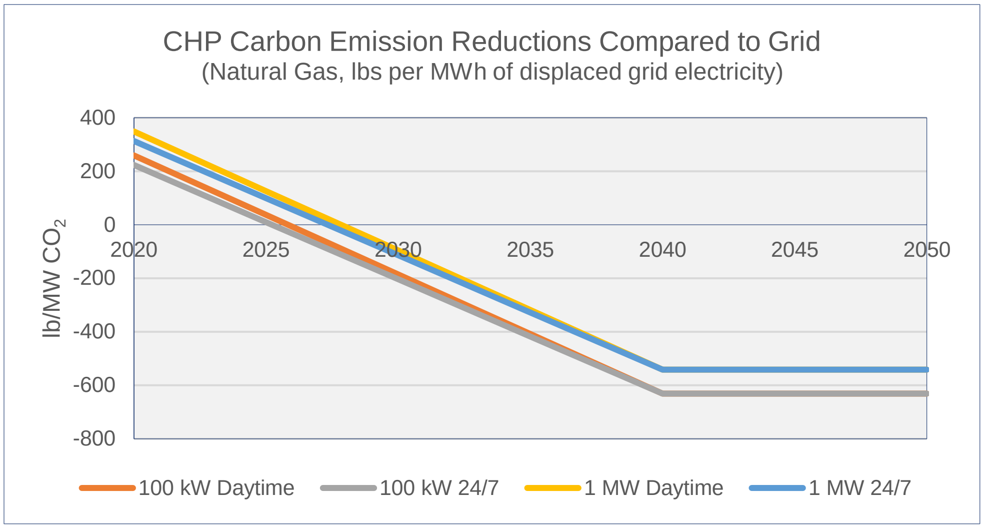


A 1 MW system operating during the daytime will avoid over 9 thousand tons of emissions if installed in 2020, while a system operating 24/7 will avoid over 8 thousand tons of emissions. Systems installed after 2025 add emissions if natural gas is used as a fuel.

6.9.3 NPCC Upstate NY (NYUP)

Figure 27 shows estimated carbon emission reductions over time for natural gas CHP in Upstate New York.

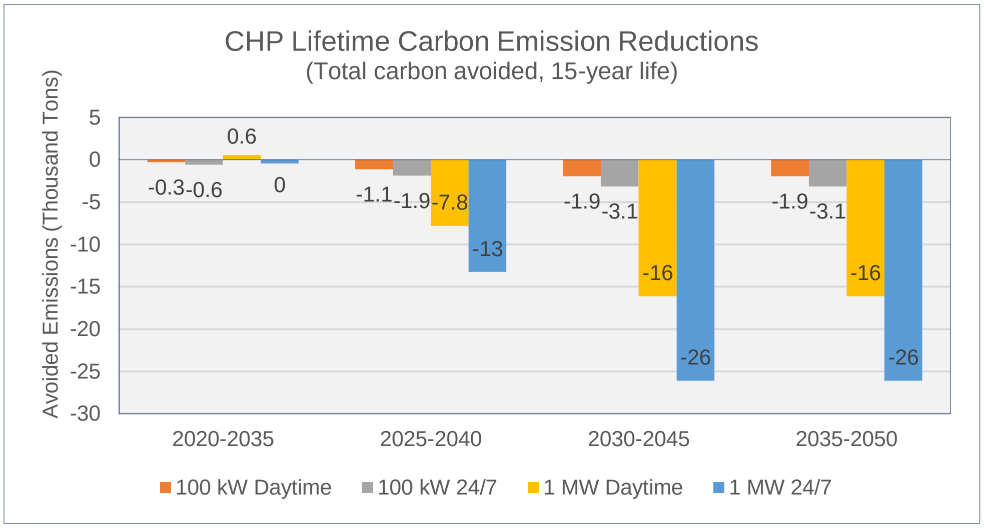
Figure 27. CHP Carbon Emission Reductions (lb/MWh) Compared to Average NYUP Marginal Grid Emissions



The estimated rate of carbon reduction for CHP in 2020 in NYUP region ranges from 200 to 350 pounds for each MWh of displaced grid electricity. By 2030, all CHP systems begin adding emissions to the grid, with 100 kW adding emissions shortly after 2025.

Figure 28 shows the expected lifetime carbon emission reductions for a natural gas CHP engine with a 15-year life, installed in 2020, 2025, 2030, or 2035.

Figure 28. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average NYUP Marginal Grid Emissions



In 2020, according to our modeling the only system that avoids emissions in NYUP over its lifespan is a 1 MW system operating during the daytime. Other CHP systems fueled by natural gas in Upstate New York are expected to result in a net increase in carbon emissions.

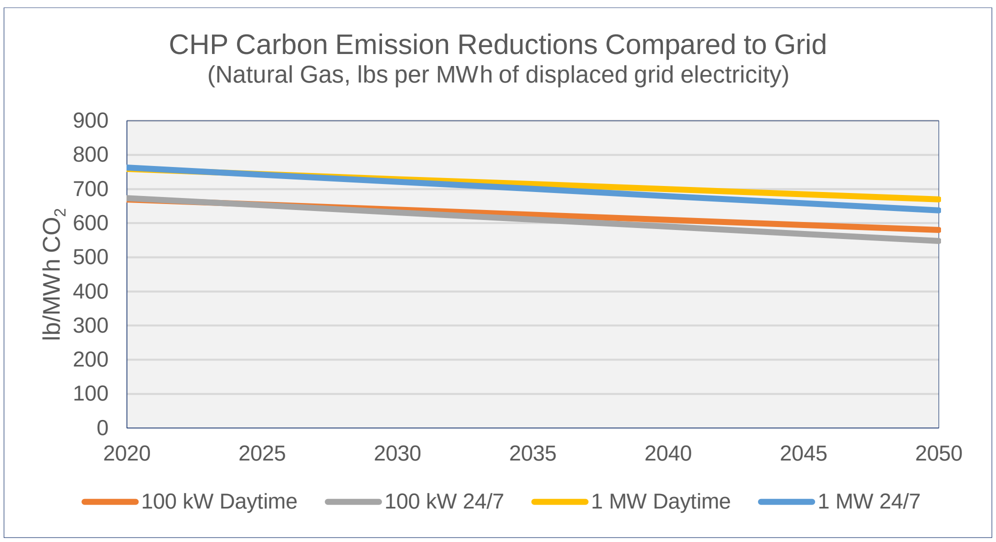
6.10 RFC East (RFCE)

The RFC East eGRID region includes most of Pennsylvania, New Jersey, Delaware, and most of Maryland. Some of these states, such as Maryland, have CAPs that will reduce emissions significantly during the time horizon under study and incentives to promote solar and wind expansion. This region's electricity demand is mostly satisfied by natural gas and nuclear power. Specifically, the 2018 overall electricity generation mix reported by eGRID is 40% natural gas, 39% nuclear power, 16% coal, and the remainder filled by oil and renewable generation. The 2018 fossil fuel specific mix is made up of 28% coal, 71% gas and 1% oil. Similarly, the 2018 non-baseload mix is 65% gas, 28% coal and 5% oil, which implies that oil is used to fill gaps at peak times.[26]

In 2018, the fossil fuel average emissions factor is 1,249 lbs/MWh and the non-baseload average emissions rate is 1,243 lbs/MWh. The factors do not change substantially through 2050, with a projected 1,121 lbs/MWh and 1,152 lbs/MWh, respectively.

Figure 29 shows estimated carbon reductions for natural gas CHP installed in the RFC East region through 2050.

Figure 29. CHP Carbon Emission Reductions (lb/MWh) Compared to Average RFCE Marginal Grid Emissions

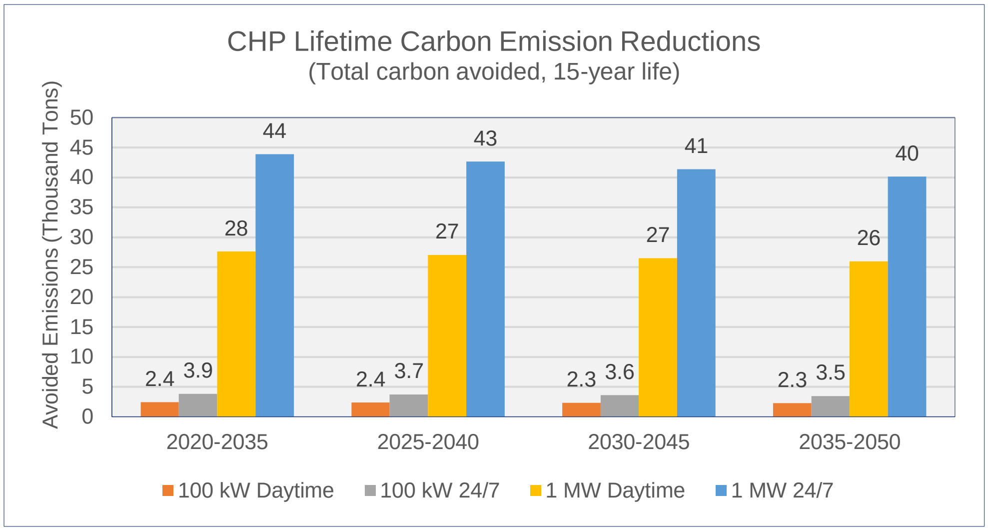


The estimated rate of carbon reduction for CHP in 2020 ranges from 650 to 750 pounds per MWh of displaced grid electricity, with 1 MW systems having higher reductions. In 2050, the estimated rate of carbon emissions reductions ranges from 550 to 650 pounds for each MWh of displaced grid electricity.

Figure 30 shows the expected lifetime carbon emission reductions for a natural gas CHP engine with a 15-year life, installed in 2020, 2025, 2030, or 2035.

[26] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

Figure 30. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average RFCE Marginal Grid Emissions



Natural gas CHP systems retired before 2050 will reduce grid emissions over their lifespan. 100 kW systems installed in 2020 will avoid 2,430 tons of emissions operating only in the daytime, and 3,850 tons of emissions operating 24 hours a day. A 1 MW system will avoid close to 28 thousand tons of emissions if it operates only during the day. 1 MW systems operating 24/7 will offset nearly 44 thousand tons, equivalent to the emissions produced by 8,600 cars over one year or by powering 4,590 homes for a year.

For a 100 kW system beginning operation in 2035, 2,260 tons of emissions can be avoided by operating it during the daytime. Operating the same system 24/7 will avoid 3,480 tons of emissions. A 1 MW system installed in 2035 can avoid close to 26 thousand tons of emissions operating during the daytime, and 40 thousand tons operating 24 hours a day. That amount is equivalent to the carbon emissions produced to power 4,199 homes for one year, or produced by 7,863 cars driving for one year.

6.11 RFC Michigan (RFCM)

This region includes Michigan's Lower Peninsula which is the most populated area of the state and the part of the state that includes most of its generation capacity. Coal accounts for the largest proportion of electricity generation in Michigan, but its use has declined in the past five years from 53% in 2013 to 37% in 2018. Michigan has three nuclear power plants that account for about a fourth of the state's generation. The overall eGRID reported generation in RFCM for 2018 was 43% coal, 32% gas, 13% nuclear, and less than 10% from renewable power. The fossil fuel proportion was roughly 55% coal and 41% natural gas in 2018, and the 2018 non-baseload generation reflected this ratio as well.[27] Michigan has renewable energy standards that require an increasing amount of electricity sales to be from renewable sources, which includes a wide variety of sources such as solar power, biomass, wind,

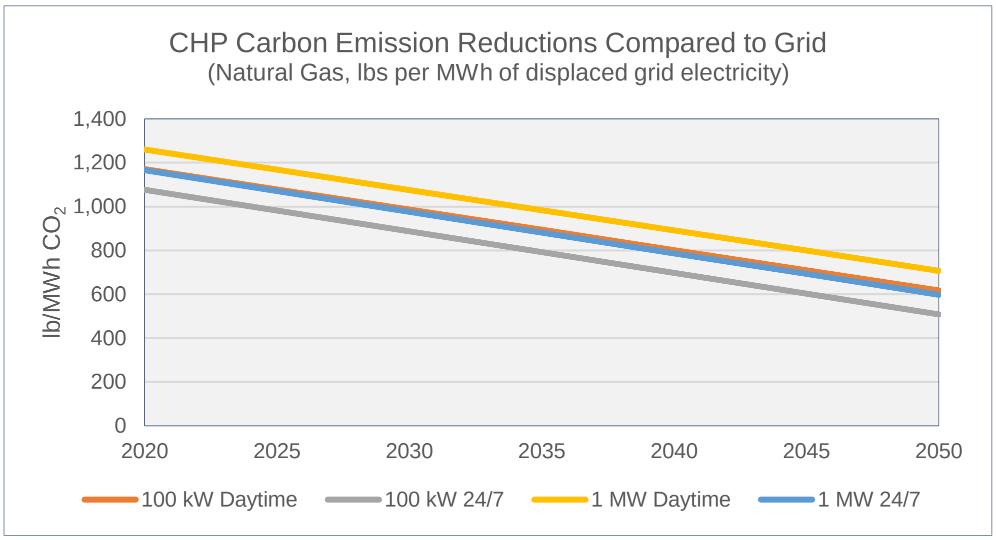
[27] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

geothermal energy, municipal solid waste, landfill gas, existing hydroelectricity, and tidal, wave, and river currents. The target is currently set at 12.5% of sales and is set to increase to 15% in 2021.[28]

In 2018, the eGRID fossil fuel average emissions factor was 1,660 lbs/MWh in this region, and the non-baseload average emissions factor was 1,749 lbs/MWh in 2018. In 2050, these factors are expected to decrease to 1,084 lbs/MWh and 1,188 lbs/MWh respectively, implying that the grid will transition to cleaner fuel sources but may still have some efficient natural gas installed.

Figure 31 shows estimated carbon emission reductions for natural gas CHP systems over time in the RFCM region.

Figure 31. CHP Carbon Emission Reductions (lb/MWh) Compared to Average RFCM Marginal Grid Emissions

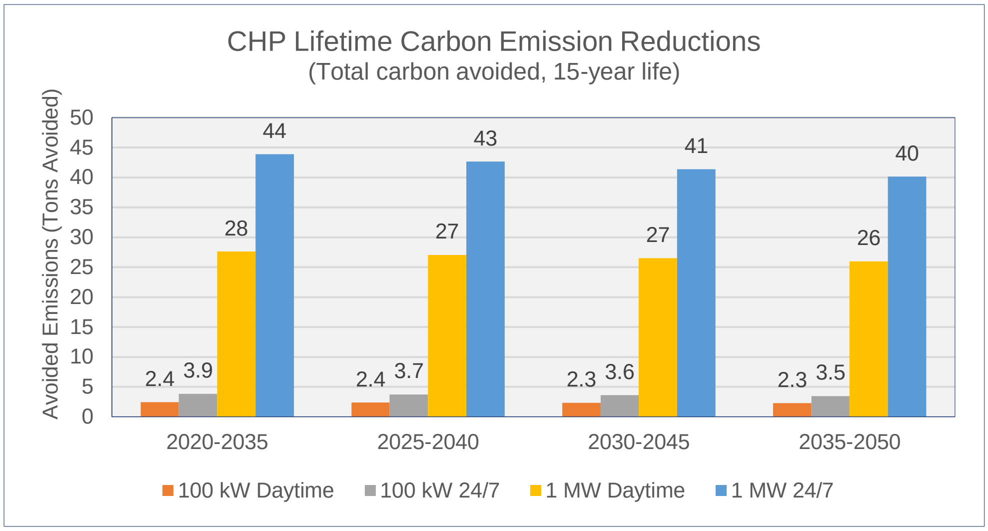


The estimated rate of carbon reduction for CHP in 2020 in RFC Michigan ranges from 1,100 to 1,250 pounds for each MWh of displaced grid electricity. As we move to 2050, the rate of carbon reduction decreases to between 500 and 700 pounds per MWh of displaced grid electricity.

Figure 32 shows the expected lifetime carbon emission reductions for a natural gas CHP engine with a 15-year life, installed in 2020, 2025, 2030, or 2035.

[28] U.S. Department of Energy, Energy Information Administration, State Profile, May 2020.

Figure 32. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average RFCM Marginal Grid Emissions



CHP systems in the RFCM region can reliably reduce grid emissions between 2020 and 2050. A 1 MW system installed in 2020 will avoid close to 28 thousand tons of emissions by the end of its lifetime only during the daytime. By operating 24/7, this system can avoid nearly 44 thousand tons of emissions during its lifetime, equivalent to the current emissions produced in powering 4,590 homes for one year or emitted collectively by 8,600 passenger vehicles in one year, on average. A smaller 100 kW system can avoid 2,430 tons of emissions operating in the daytime, and 3,850 tons of emissions operating 24 hours a day.

For a 1 MW system installed in 2035 and retired in 2050, 25,950 tons of carbon emissions can be avoided by operating during daytime hours. By operating 24/7, this system can avoid 40,130 tons of emissions, the same amount emitted by 7,863 cars during a year or produced to power 4,199 homes for a year. A 100 kW system can avoid 2,260 tons of emission operating in the daytime or 3,480 tons of emissions operating 24 hours a day.

6.12 RFC West (RFCW)

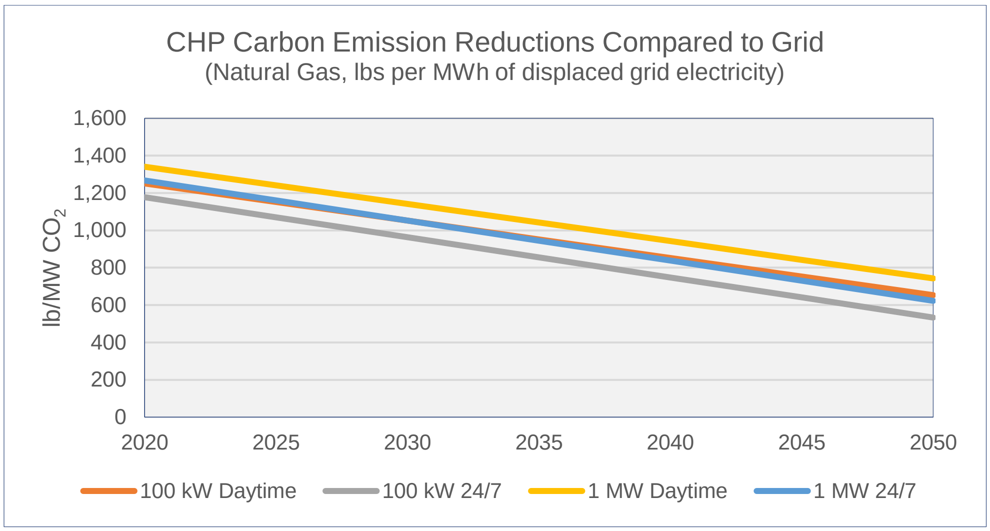
The RFC West eGRID region includes Indiana, Ohio, small parts of Wisconsin and Illinois, West Virginia, some of Virginia and small parts of Kentucky. The region's overall electricity generation mix mostly comes from coal, as West Virginia, Indiana and Ohio all use coal to satisfy a large portion of their electricity demand. Specifically, the overall electricity generation mix for 2018 was 44% coal, 21% gas, and 28% nuclear power. The fossil fuel specific generation mix in 2018 was about 2/3 coal and 1/3 gas, and the non-baseload fossil fuel mix also reflected this ratio.[29] The grid is expected to change in the time horizon under study, and some states have CAPs in place. In Ohio, there is a modest RPS and an Energy Efficiency Portfolio Standard to reduce peak demand. West Virginia, which is predominately powered by coal, had an RPS but repealed it in 2015.

[29] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

Between 2018 and 2050, there will be changes to this region's electricity system as evidenced by changes in the emissions factors between these years. The emissions factor for 24/7 CHP systems is expected to decline from 1,761 lbs/MWh in 2018 to 1,108 lbs/MWh in 2050, and the non-baseload average emissions factor is expected to decrease from 1,828 lbs/MWh in 2018 to 1,222 lbs/MWh in 2050. The 2050 rates imply that some coal will be replaced by efficient gas or clean electricity generation sources in the region, and that the electricity grid will become cleaner.

Figure 33 shows expected emissions reductions for CHP systems in the RFC West region through 2050.

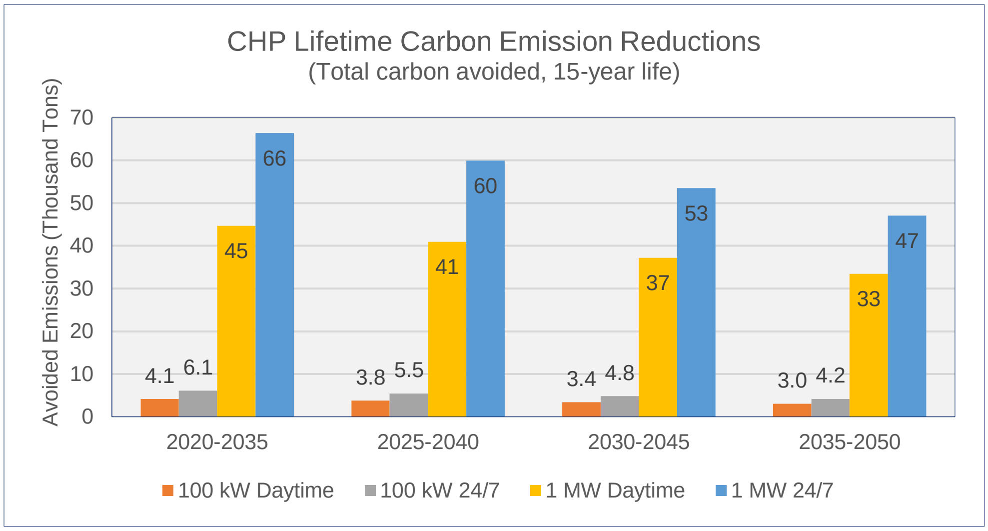
Figure 33. CHP Carbon Emission Reductions (lb/MWh) Compared to Average RFCW Marginal Grid Emissions



In RFCW, the estimated rate of carbon reduction for CHP in 2020 ranges from 1,200 to 1,350 pounds for each MWh of displaced grid electricity, with 24/7 systems reducing more emissions than daytime only systems. As we move to 2050, the rate of carbon reduction decreases to between 550 and 750 pounds per MWh of displaced grid electricity.

Figure 34 shows the expected lifetime carbon emission reductions for a natural gas CHP engine with a 15-year life, installed in 2020, 2025, 2030, or 2035.

Figure 34. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average RFCW Marginal Grid Emissions



Across system lifetime, a 1 MW system installed in 2020 will avoid close to 45 thousand tons of emissions in total operating only during the daytime. By operating 24/7, this system can avoid 66 thousand tons of emissions during its lifetime, equivalent to the current emissions produced in powering 6,940 homes or emitted by 13,000 passenger vehicles in one year, on average. A smaller 100 kW system can avoid 4,130 tons of emissions operating in the daytime, and 6,100 tons of emissions operating 24 hours a day.

A 1 MW system installed in 2035 that operates in the daytime avoid over 33 thousand tons of carbon emissions by its 2050 retirement. By operating 24/7, this system can avoid 47 thousand tons of emissions, the same amount produced by 9,220 cars during a year or to power 4,920 homes for a year. A 100 kW system can avoid 3,010 tons of emission operating in the daytime or 4,170 tons of emissions operating 24 hours a day.

6.13 WECC Rockies (RMPA)

The WECC Rockies eGRID region includes all of Colorado as well as small portions of Nebraska, Wyoming, South Dakota, New Mexico, and a sliver of west Kansas. Coal currently makes up most of the electricity mix in this region, and together coal and natural gas composed over 70% of overall generation in 2018, with 12.5% hydropower and 15% wind power as well. The non-baseload generation for 2018 in this region was 43% coal and 57% natural gas.[30]

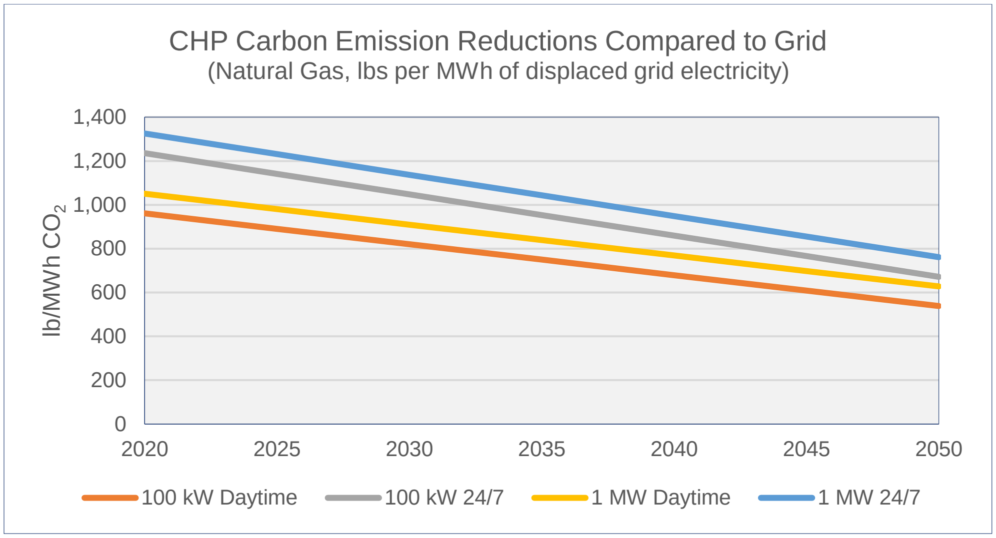
By 2050, CAPs and other technological and economic pressures within this region will drive retirement of coal and will lead to other changes to the electricity mix, such as increased proportion of gas in relation to coal power. This is evident when analyzing the changes in emissions factors between 2018 and 2050: in 2018, the fossil fuel average emissions factor was 1,813 lbs/MWh, and by 2050 the equivalent emissions factor for 24/7 CHP applications drops to 1,240 lbs/MWh. The non-baseload

[30] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

average emissions factor was 1,543 lbs/MWh in 2018 and is expected to drop to 1,114 lbs/MWh by 2050. If these projections hold, natural gas will likely still run on the margin to fill gaps.

Figure 35 shows estimated carbon reductions for CHP in the RMPA eGRID subregion through 2050.

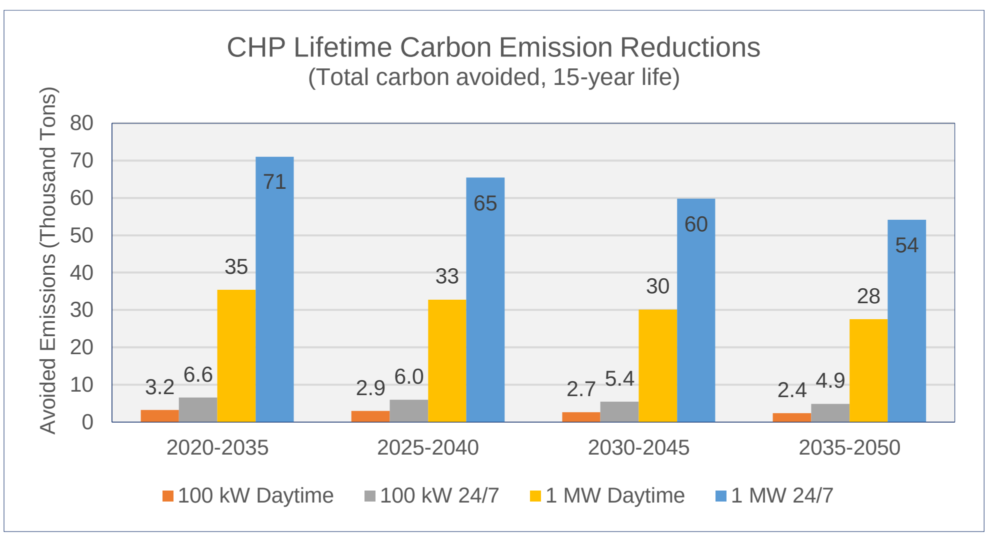
Figure 35. CHP Carbon Emission Reductions (lb/MWh) Compared to Average RMPA Marginal Grid Emissions



The estimated rate of carbon reduction for CHP in 2020 ranges from 950 to 1250 pounds per MWh of displaced grid energy, with 24/7 systems having higher reductions than daytime systems. In 2050, the estimated rate of carbon emissions reductions ranges from 550 to 800 pounds for each MWh of displaced grid electricity.

Figure 36 shows the expected lifetime carbon emission reductions for natural gas CHP engines with a 15-year life, installed in the RMPA region in 2020, 2025, 2030, or 2035.

Figure 36. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average RMPA Marginal Grid Emissions



CHP systems retired before 2050 will reduce grid emissions in the RMPA region over their lifespan. 100 kW systems installed in 2020 will avoid 3,210 tons of emissions operating only in the daytime, and 6,583 tons of emissions operating nonstop. A 1 MW system will avoid over 35 thousand tons of emissions if it operates only during the day. 1 MW systems operating 24/7 will offset 71 thousand tons, equivalent to the emissions produced by 13,923 cars over one year or by powering 7,435 homes for a year.

For a 100 kW system beginning operation in 2035, 2,420 tons of emissions can be avoided by operating during daytime hours. Operating the same system 24/7 will avoid 4,880 tons of emissions. A 1 MW system installed in 2035 can avoid close to 28 thousand tons of emissions operating during the daytime, and 54 thousand tons operating nonstop. That amount is equivalent to the emissions produced to power 5,670 homes for one year, or emitted by 10,610 cars driving for one year.

6.14 SPP North (SPNO)

The SPP North eGRID region encompasses Kansas and about half of Missouri, including the urban parts (St. Louis and Kansas City) which are mostly served by investor owned utilities.

Kansas has a lot of wind resources; according to EIA, wind was responsible for about 41% of state's net generation in 2019, when wind surpassed coal for the first time ever. Kansas has one nuclear plant that provided 18% of total generation in 2019. The state also has an RPS 20% of power demand capacity from renewables every year after 2020: it works based on generating capacity rather than generation or retail sales. Missouri is mostly powered by coal, which accounts for 8 out of 10 power plants in the state. Coal is declining, however, and Missouri has lots of planned wind, lots of exports, and a renewable portfolio standard with a cost cap that prevent cost of electricity from rising more than 1% and that requires 15% renewable generation by 2021.[31]

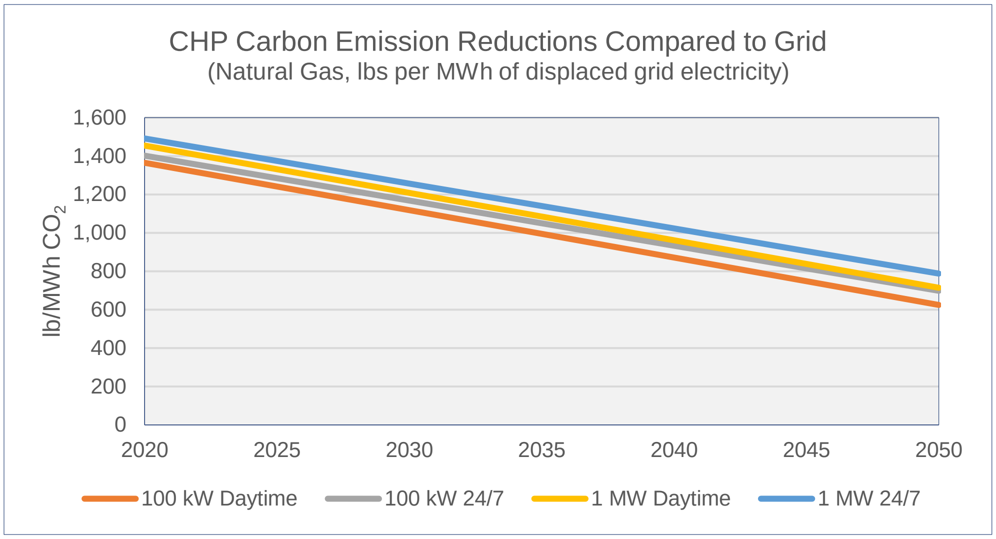
Aggregating the regions together, the overall regional electricity generation mix for 2018 was 47% coal, 12% natural gas, 13% nuclear power, and 28% wind power. The fossil fuel specific generation mix was 80% coal and 20% natural gas, and the non-baseload mix was ~77% coal and 23% natural gas.[32] The emissions in SPNO are expected to decrease along the time horizon to meet CAPs and planned wind installation targets. In 2018, the fossil fuel average emissions rate was 1,979 lbs/MWh, and by 2050, the equivalent emissions factor is expected to decrease to 1,265 lbs/MWh. The 2018 non-baseload average emissions rate was 1,946 lbs/MWh and by 2050 this rate is expected to decrease to 1,194 lbs/MWh.

Figure 37 shows the estimated carbon emission reductions for natural gas CHP in the SPNO eGRID subregion through 2050.

[31] U.S. Department of Energy, Energy Information Administration, State Profile, May 2020.

[32] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

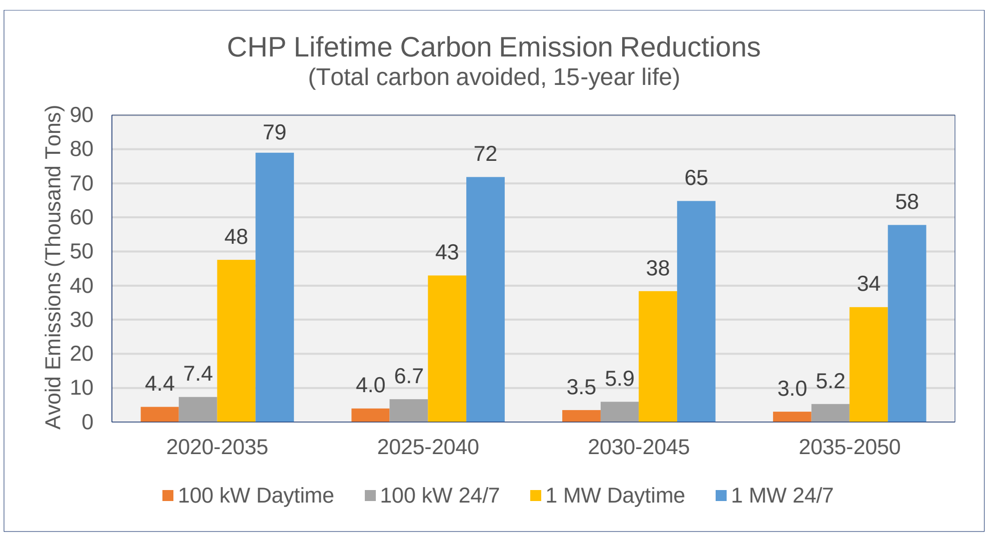
Figure 7. CHP Carbon Emission Reductions (lb/MWh) Compared to Average SPNO Marginal Grid Emissions



SPNO, like the MRO region, is a region where CHP can offset some of the largest amounts of grid emissions in the country. The estimated rate of carbon emission reductions in 2020 ranges from 1,350 to 1,500 pounds for each MWh of displaced grid electricity. As we move to 2050, the rate of carbon reduction decreases to between 600 and 800 pounds per MWh of displaced grid electricity.

Figure 38 shows the expected lifetime carbon emission reductions for a natural gas CHP engine with a 15-year life, installed in 2020, 2025, 2030, or 2035.

Figure 38. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average SPNO Marginal Grid Emissions



Across system lifetime, 1 MW system installed in 2020 will avoid nearly 48 thousand tons of emissions in total operating only during the daytime. By operating 24/7, this system can avoid close to 79 thousand tons of emissions during its lifetime, equivalent to the current emissions produced in powering 8,260 homes or emitted by 15,470 passenger vehicles in one year, on average. A smaller 100 kW system can avoid 4,420 tons of emissions operating in the daytime, and 7,360 tons of emissions operating 24 hours a day.

A 1 MW system installed in 2035 that operates in the daytime avoid nearly 34 thousand tons of carbon emissions by its 2050 retirement. By operating 24/7, this system can avoid 58 thousand tons of emissions, the same amount produced by 11,330 cars or emitted to power 6,050 homes in a year. A 100 kW system can avoid 3,040 tons of emission operating in the daytime or 5,250 tons of emissions operating 24 hours a day.

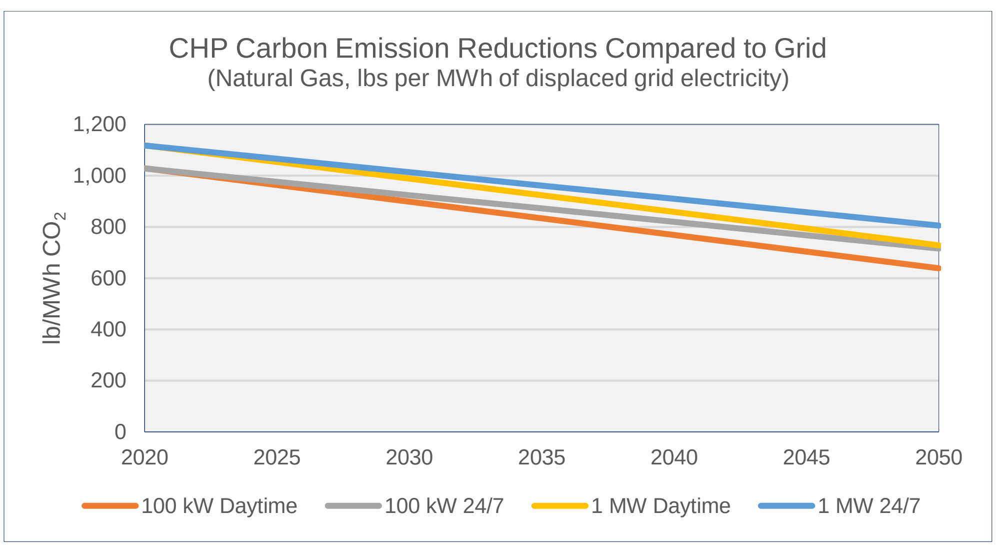
6.15 SPP South (SPSO)

The SPP South eGRID region includes most of Texas Panhandle including the High Plains and Llano Estacado, east New Mexico, most of Oklahoma, west Arkansas, and northwest Louisiana. The region is very windy, and according to the EIA wind will soon generate more electricity proportionally than other energy types. There are also many natural gas generators installed in this region. The overall electricity mix for SPSO in 2018 was 31% coal, 40% natural gas and 22% wind, with less than 10% from other electricity sources. The fossil fuel average makeup in this region for 2018 was 42% coal and 55% natural gas, and similarly the 2018 non-baseload fossil fuel proportions were 45% coal and 55% natural gas.[33]

Geographical factors such as high wind and solar availability are likely to drive more economic wind and solar expansion during the study's time horizon. The fossil fuel average and non-baseload average emissions factors in 2018 were 1,598 lbs/MWh and 1,603 lbs/MWh, respectively. By 2050, the fossil fuel average and non-baseload average emissions rates are expected to decline to 1,281 lbs/MWh and 1,208 lbs/MWh, respectively.

Figure 39 shows the estimated carbon emission reductions for natural gas CHP in the SPSO eGRID subregion through 2050.

Figure 39. CHP Carbon Emission Reductions (lb/MWh) Compared to Average SPSO Marginal Grid Emissions

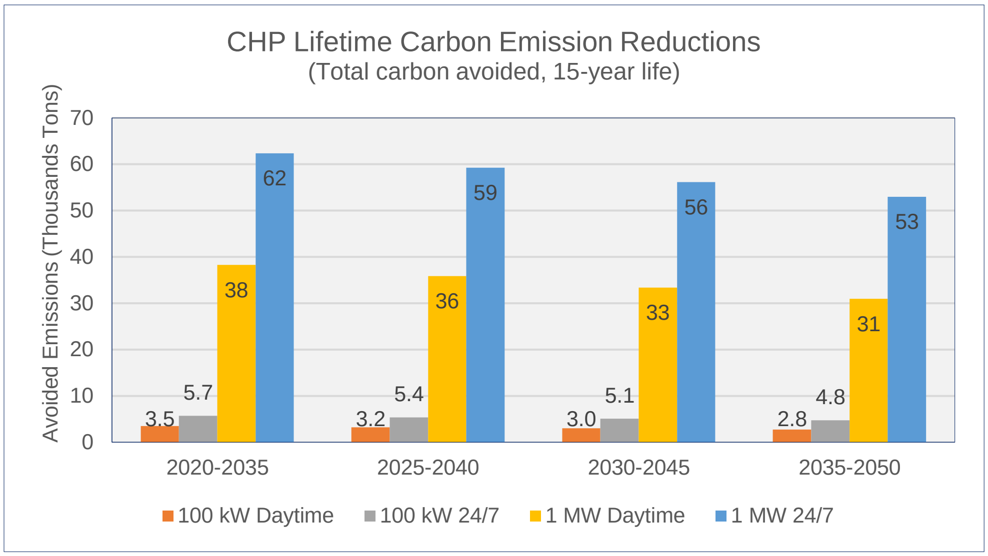


[33] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

In SPSO, the estimated rate of carbon emission reductions in 2020 ranges from 1,000 to 1,100 pounds for each MWh of displaced grid electricity. As we move to 2050, the rate of carbon reduction decreases to between 600 and 800 pounds per MWh of displaced grid electricity.

Figure 40 shows the expected lifetime carbon emission reductions for a natural gas CHP engine with a 15-year life, installed in 2020, 2025, 2030, or 2035.

Figure 40. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average SPSO Marginal Grid Emissions



Across system lifetime, 1 MW system installed in 2020 will avoid over38 thousand tons of emissions in total operating only during the daytime. By operating 24/7, this system can avoid over 62 thousand tons of emissions during its lifetime, equivalent to the current emissions produced in powering 6,530 homes or emitted by 12,220 passenger vehicles in one year, on average. A smaller 100 kW system can avoid 3,490 tons of emissions operating in the daytime, and 5,700 tons of emissions operating 24 hours a day.

A 1 MW system installed in 2035 that operates in the daytime avoid nearly 31 thousand tons of carbon emissions by its 2050 retirement. By operating nonstop, this system can avoid 53 thousand tons of emissions, the same amount produced by 10,380 cars or emitted to power 5,550 homes in a year. A 100 kW system can avoid 2,760 tons of emission operating in the daytime or 4,760 tons of emissions operating 24 hours a day.

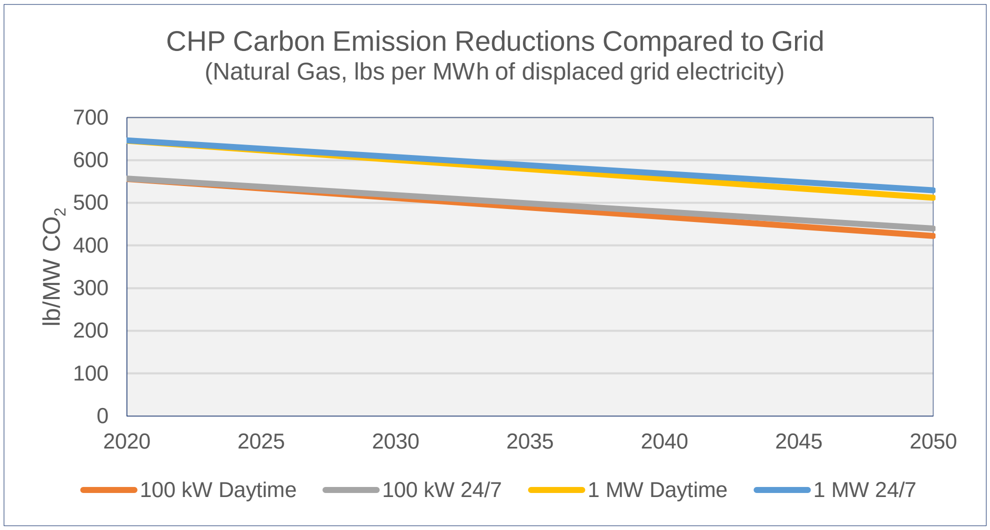
6.16 SERC Mississippi Valley (SRMV)

The Mississippi Valley region of the US includes some of Mississippi, east Arkansas, most of Louisiana, chunk of mid-eastern Texas near the southern Louisiana border. About 57% of overall generation in this region came from natural gas in 2018, and the remainder of overall generation was made up by 17% coal, 21% nuclear power, and less than 10% of electricity from other sources. The 2018 fossil fuel specific average is 22% coal and 74% natural gas. The 2018 non-baseload fossil mix is 17.2% coal, 73% natural gas, and 6% oil.[34]

The fossil fuel average and non-baseload average emissions factors in 2018 were equal, at 1,138 lbs/MWh. By 2050, the equivalent average emissions rates are expected to decline to 1,019 lbs/MWh and 1,002 lbs/MWh, respectively.

Figure 41 shows the estimated carbon emission reductions for natural gas CHP in the SRMV eGRID subregion.

Figure 41. CHP Carbon Emission Reductions (lb/MWh) Compared to Average SRMV Marginal Grid Emissions

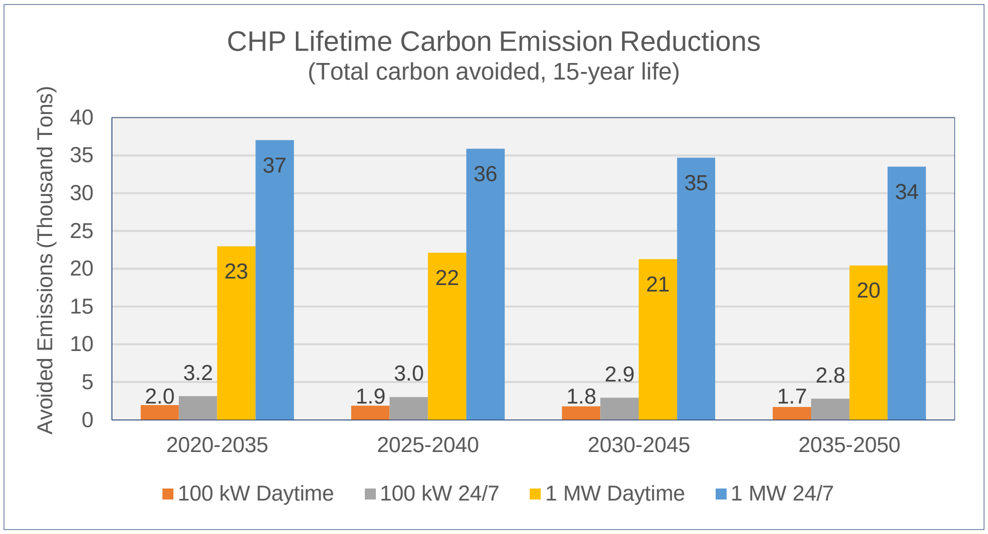


The estimated rate of carbon reduction for CHP in 2020 in SRMV ranges from 550 to 650 pounds for each MWh of displaced grid electricity, with smaller systems being on the lower end of that scale. As we move to 2050, the rate of carbon reduction decreases to between 400 and 550 pounds per MWh of displaced grid electricity.

Figure 42 shows the expected lifetime carbon emission reductions for a CHP engine with a 15-year life, installed in 2020, 2025, 2030, or 2035.

[34] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

Figure 42. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average RMV Marginal Grid Emissions



CHP systems in the SRMV region can reliably reduce grid emissions between 2020 and 2050. A 1 MW system installed in 2020 will avoid 23 thousand tons of emissions by the end of its lifetime when operating during the daytime. By operating 24/7, this system can avoid 37 thousand tons of emissions during its lifetime, equivalent to the current emissions produced in powering 3,880 homes or emitted by 7,260 passenger vehicles in one year, on average. A smaller 100 kW system can avoid 1,960 tons of emissions operating in the daytime, and 3,170 tons of emissions operating 24 hours a day.

For a 1 MW system installed in 2035 and retired in 2050, over 20 thousand tons of carbon emissions can be avoided by operating during daytime hours. By operating 24/7, this system can avoid 33,523 tons of emissions, the same amount produced by 6,570 cars during a year or emitted to power 3,510 homes for a year. A 100-kW system can avoid 1,540 tons of emission operating in the daytime or 2,497 tons of emissions operating 24 hours a day.

6.17 SERC Midwest (SRMW)

The SERC Midwest region includes most of Illinois and eastern Missouri, which is the less populated part of Missouri where electricity demand is mostly satisfied by electric rural cooperatives. The regional overall electricity generation mix for 2018 was 70% coal, 9.4% natural gas, 15% nuclear power, 4% wind and less than 10% from other sources. The 2018 fossil fuel specific ratio reflected the strong bias towards coal over natural gas in the region and was 88% coal and 12% natural gas. Similarly, the non-baseload fossil fuel mix for 2018 was 78% coal and 21.4% natural gas.[35]

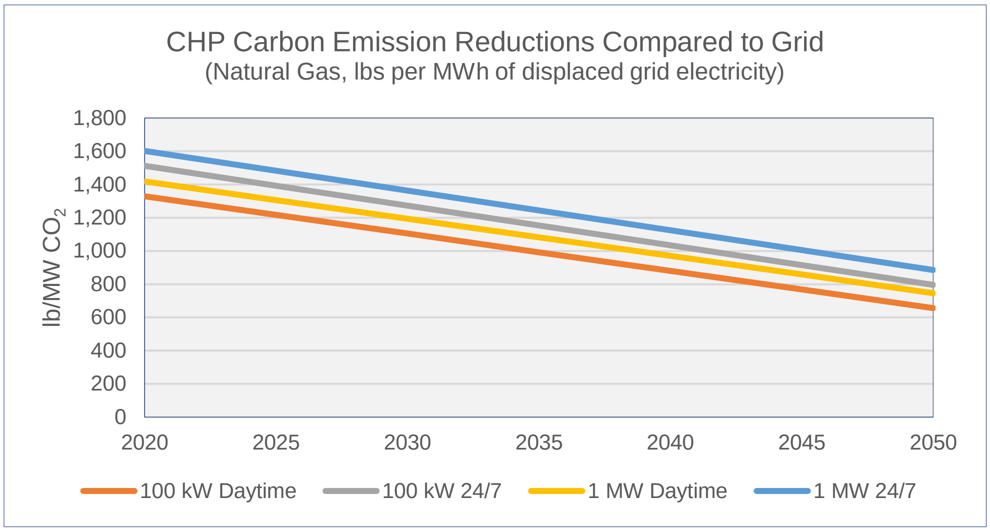
Illinois has six nuclear plants, and an RPS with a goal of 25% of retail sales from renewable sources by 2025. The state also has implemented an energy efficiency portfolio standard with the goal of reducing peak demand. Missouri mostly uses coal plants, but that could by 2050 because of favorable economic and geographical factors for wind, and the states' CAPs. The fossil fuel average and non-baseload average emissions factors in 2018 were 2,084 lbs/MWh and 1,907 lbs/MWh, respectively. By 2050, the

[35] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

fossil fuel average and non-baseload average emissions rates are expected to decline to 1,387 lbs/MWh and 1,225 lbs/MWh, respectively. The lower emissions factors in 2050 are suggestive of an electricity mix that is less dependent on coal, with an increasing proportion of natural gas on the margin.

Figure 43 shows the estimated emission reductions for natural gas CHP over time in the SRMW eGRID subregion.

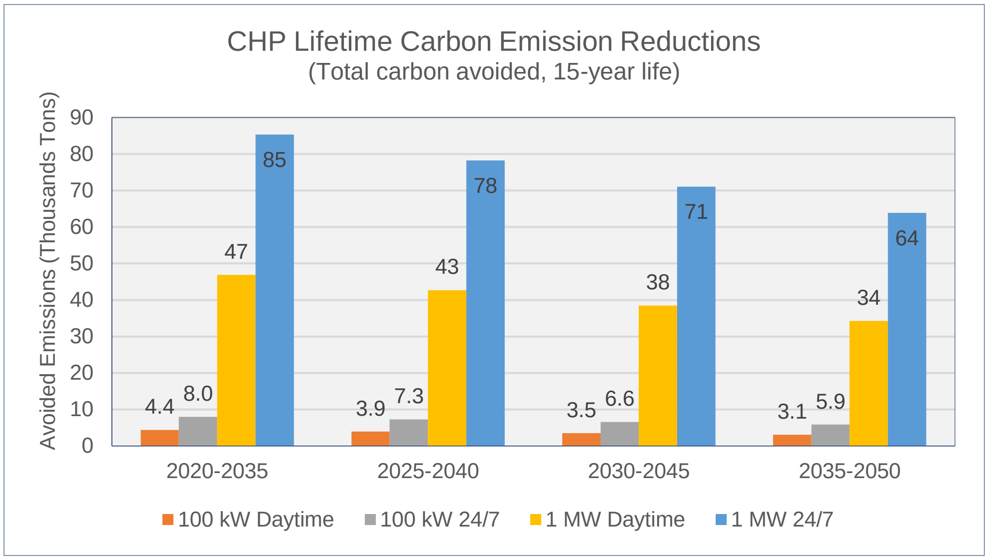
Figure 43. CHP Carbon Emission Reductions (lb/MWh) Compared to Average SRMW Marginal Grid Emissions



SRMW's estimated rate of carbon reduction for CHP in 2020 is one of the highest amongst all regions, ranging from 1,300 to 1,600 pounds for each MWh of displaced grid electricity, with 24/7 systems reducing more emissions than daytime only systems. As we move to 2050, the rate of carbon reduction decreases to between 650 and 900 pounds per MWh of displaced grid electricity.

Figure 44 shows the expected lifetime carbon emission reductions for a CHP engine with a 15-year life, installed in 2020, 2025, 2030, or 2035.

Figure 44. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average SRMW Marginal Grid Emissions



A 1 MW CHP system installed in 2020 will avoid 46,886 tons of emissions by the end of its lifetime only during the daytime. By operating 24/7, this system can avoid 85 thousand tons of emissions during its lifetime, equivalent to the current emissions produced in powering 8,930 homes for one year or emitted by 16,730 passenger vehicles in one year, on average. A smaller 100 kW system can avoid 4,350 tons of emissions operating in the daytime, and 8,000 tons of emissions operating 24 hours a day.

A 1 MW system installed in 2035 and retired in 2050 can avoid 34 thousand tons of carbon emissions by operating during daytime hours. By operating 24/7, this system can avoid close to 64 thousand tons of emissions over its life, the same amount produced by 12,520 cars or emitted to power 6,680 homes for a year. A 100 kW system can avoid 3,090 tons of emission operating in the daytime or 5,850 tons of emissions operating 24 hours a day.

6.18 SERC South (SRS)

The states included in the SERC South eGRID region are most of Georgia, most of Alabama, southeast Mississippi, and the Florida panhandle. Although Georgia does not have a renewable portfolio standard, it allows net metering and has utilities that incentivize renewables. In Alabama, incentives for clean energy are also encouraged although there is no CAP. Alabama and Georgia primarily generate natural gas, but there is also a large nuclear plant in Alabama as well as hydroelectric power potential.

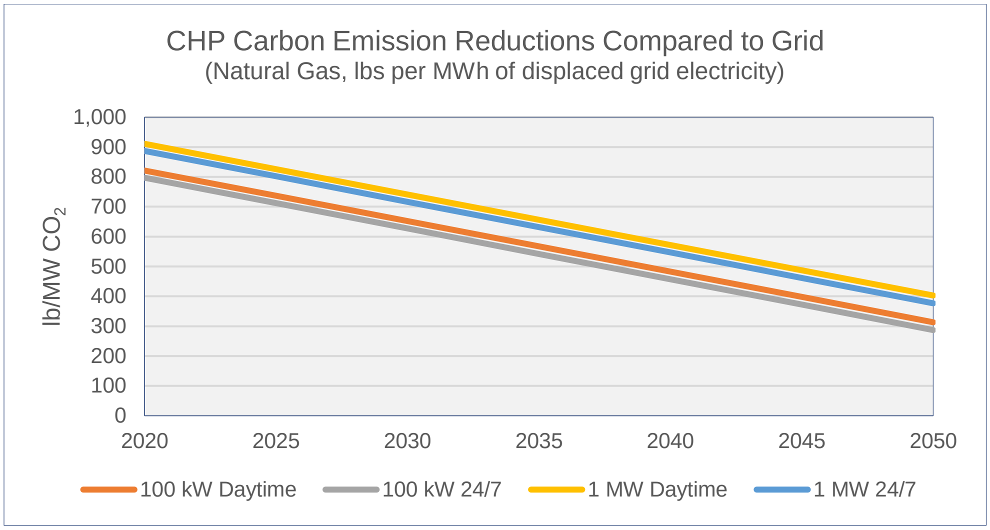
In 2018, the electricity mix in SRSO was composed of 26% coal, 47% gas, 19% nuclear, 3% hydroelectric power and ~4% biomass. The 2018 fossil fuel fuel mix was almost evenly split between coal and natural gas. In the time horizon under study, changes are expected in this region's electricity system as observed by changes to the emissions factor that occur between 2018 and 2050. The emissions factor change in this time horizon is significant. In 2018, the fossil fuel average emissions rate is 1,391 lbs/MWh and the non-baseload average emissions rate is 1,414 lbs/MWh.[36] In 2050, the equivalent rates fall to

[36] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

873 lbs/MWh and 898 lbs/MWh, respectively. The electricity grid will thus become almost 50% cleaner, with natural gas likely displacing some of the coal that currently runs on the margin.

Figure 45 shows the estimated carbon emission reductions for natural gas CHP over time in the SRS eGRID subregion.

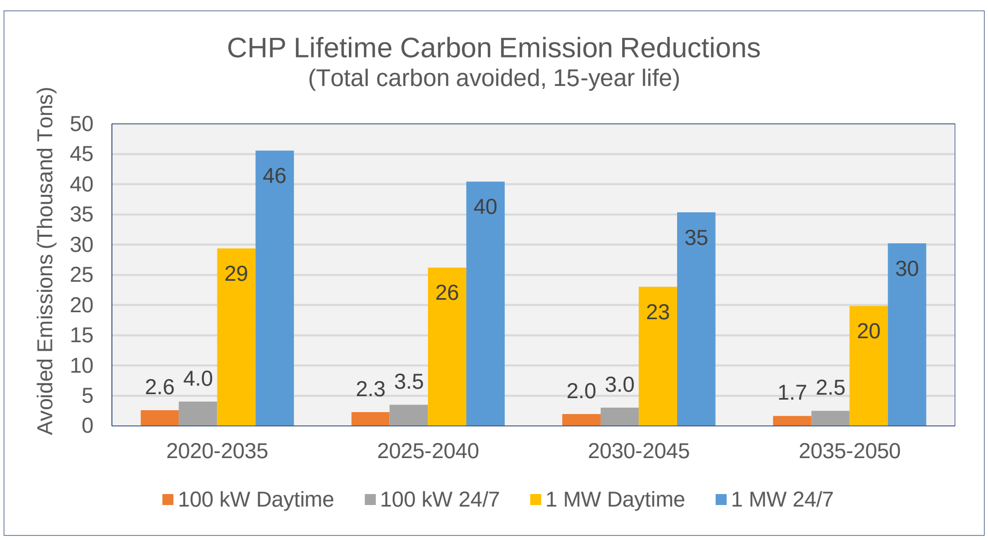
Figure 45. CHP Carbon Emission Reductions (lb/MWh) Compared to Average SRS Marginal Grid Emissions



The estimated rate of carbon reduction for CHP in 2020 in SRS ranges from 800 to 1,000 pounds for each MWh of displaced grid electricity. As we move to 2050, the rate of carbon reduction decreases, with smaller CHP systems adding emissions to the grid.

Figure 46 shows the expected lifetime carbon emission reductions for a natural gas CHP engine with a 15-year life, installed in 2020, 2025, 2030, or 2035.

Figure 46. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average SRS Marginal Grid Emissions



A 1 MW system installed in 2020 will avoid 29 thousand tons of emissions by the end of its 15-year lifetime operating only during the daytime, while a system that operates 24/7 will avoid nearly 46 thousand tons of emissions. This is the equivalent to the current emissions produced in powering 4,770 homes for one year, or in driving 8,930 passenger vehicles for one year, on average. Smaller 100 kW systems will avoid 2,600 tons of emissions operating only during the daytime, while the same system operating 24/7 will avoid 4,020 tons.

For a 1 MW system installed in 2035 and retired in 2050, close to 20 thousand tons of carbon emissions can be avoided by operating during daytime hours. This system will avoid 30 thousand tons of emissions operating 24/7, equivalent to the current emissions produced in powering 3,165 homes for one year, or in driving 5,927 passenger vehicles for one year, on average. A 100kW system with the same lifespan will offset 1,651 tons of emissions by 2050 operating in the daytime. By operating 24/7, it will offset 2,487 tons of emissions.

6.19 SERC Tennessee Valley (SRTV)

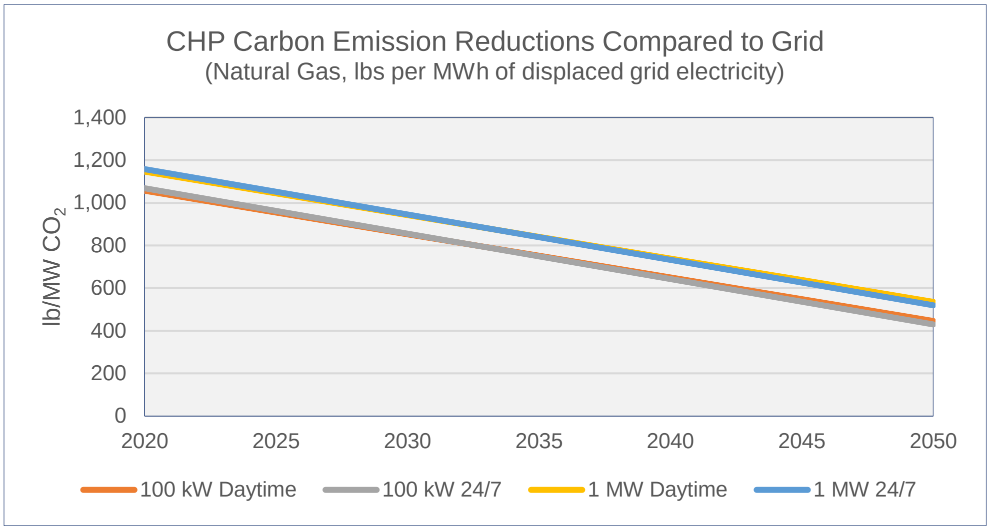
The Tennessee Valley Authority (TVA) is the largest public power owner in the US, and the states included in this eGRID region's scope are Tennessee, most of Kentucky, small northern parts of Mississippi, Alabama, Georgia, and a small portion of Virginia. It produces most of the electricity that is used by the state of Tennessee. The 2018 eGRID TVA generation mix is made up of 35.5% coal, 26.5% natural gas, 27.5% nuclear power, 9.5% hydroelectric power, and less than 10% from other sources. The fossil fuel specific ratio in 2018 was 57% coal and 43% gas, and the non-baseload generation mix was 61% coal and 37% natural gas. [37]

The region offers some incentives for clean energy growth, although there is not an official CAP in the region. Still, changes emissions rates between 2018 and 2050 imply that the electricity mix will become cleaner in this region. Specifically, the fossil fuel average emissions rate in 2018 was 1,657 lbs/MWh, and the non-baseload average emissions rate in 2018 was 1,644 lbs/MWh. In 2050, the fossil fuel average emissions rate and non-baseload average emissions rate are expected to drop to 1,009 lbs/MWh and 1,025 lbs/MWh, respectively.

Figure 47 shows the estimated carbon emission reductions for natural gas CHP over time in the SRTV eGRID subregion.

[37] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

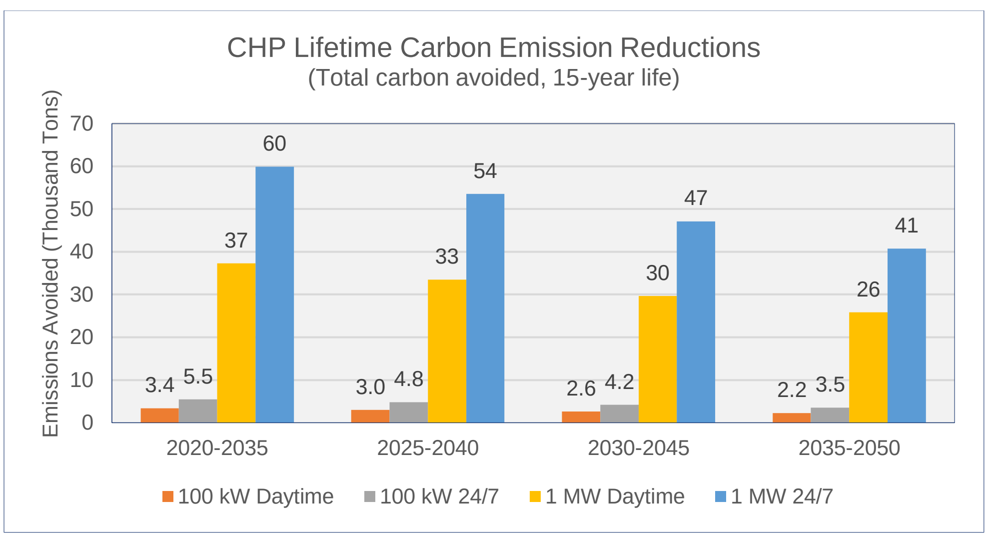
Figure 47. CHP Carbon Emission Reductions (lb/MWh) Compared to Average SRTV Marginal Grid Emissions



The estimated rate of carbon reduction for CHP in 2020 in the SRTV region ranges from 1,050 to 1,150 lbs. per MWh of grid electricity displaced, with larger systems contributing more reductions. Even with projected decreases in grid emissions, CHP can still produce substantial emissions reductions in SRTV by 2050. The rate of carbon reduction by 2050 ranges from 400 to 550 lbs. per MWh of displaced electricity.

Figure 48 shows the expected lifetime carbon emission reductions for a CHP engine with a 15-year life, installed in 2020, 2025, 2030, or 2035.

Figure 48. CHP Carbon Emission Reductions (Thousand Tons) Over System Life, Compared to Average SRTV Marginal Grid Emissions



CHP systems retired before 2050 will reduce grid emissions over their lifespan. 100 kW systems installed in 2020 will avoid 3,390 tons of emissions operating only in the daytime, and 5,450 tons of emissions operating 24 hours a day. A 1 MW system will avoid 37,266 tons of emissions if it operates only during the day. 1 MW systems operating 24/7 will offset 60 thousand tons, equivalent to the emissions produced by 11,740 cars or powering 6,270 homes for one year.

For a 100 kW system beginning operation in 2035, 2,250 tons of emissions can be avoided by operating during the daytime. Operating the same system nonstop will avoid 3,540 tons of emissions. A 1 MW system installed in 2035 can avoid close to 26 thousand tons of emissions operating during the daytime, and 41 thousand tons operating 24 hours a day. That amount is equivalent to the emissions produced to power 4,264 homes or produced by 7,985 cars driving for one year.

6.20 SERC Virginia/Carolina (SRVC)

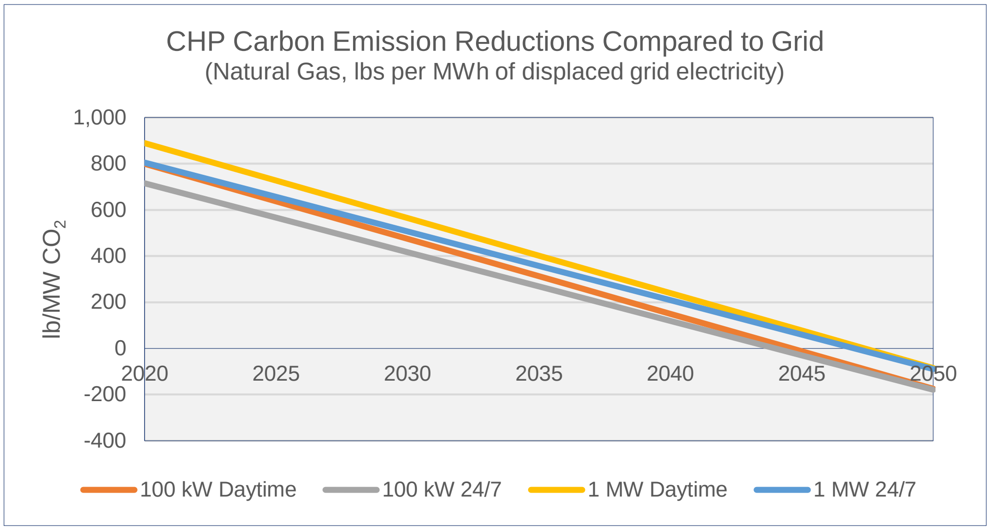
The SERC Virginia and Carolina eGRID region includes half of Virginia, South Carolina, and North Carolina. Virginia has an RPS goal of 15% of 2007 sales to come from renewable sources by 2025, and their current renewable share comes mostly from biomass. Over half of South Carolina's electricity is produced by nuclear power, and coal accounts for about a fifth of overall generation. In South Carolina Coal use is declining and natural gas is expanding. In North Carolina, there is no net zero target, but the state has put in place a Renewable Energy and Energy Efficiency Portfolio Standard (REPS) that requires an increasing portion of renewables as well as curbed demand growth.

The SRVC region's 2018 electricity mix was mostly satisfied by natural gas and nuclear power in 2018; specifically, generation from this year was composed of 19% coal, 34.6% natural gas, 38% nuclear power, and less than 10% from renewable generation sources. The 2018 fossil fuel specific ratio was 35% coal and 64% natural gas in this region, and the non-baseload mix was ~44% coal and 52% natural gas. The REPS and CAPs throughout the region are expected to drive renewable growth during the study's time horizon, and Virginia has an aggressive CAP in place. Specifically, the fossil fuel average emissions rate in 2018 was 1,337 lbs/MWh, and the non-baseload average emissions rate in 2018 was 1,423 lbs/MWh. In 2050, the equivalent emissions rates are expected to drop to 430 lbs/MWh and 434 lbs/MWh, respectively.[38]

Figure 49 shows the estimated carbon emission reductions for natural gas CHP in the SRVC eGRID subregion.

[38] Emissions & Generation Resource Integrated Database (eGRID), https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

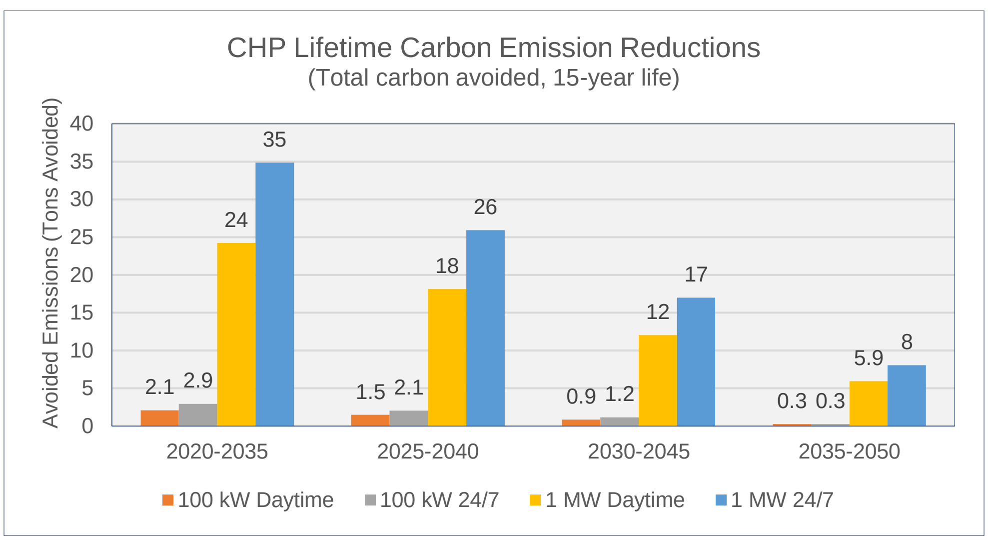
Figure 49. CHP Carbon Emission Reductions (lb/MWh) Compared to Average SRVC Marginal Grid Emissions



The estimated rate of carbon reduction for CHP in 2020 in SRVC ranges from 700 to 900 pounds for each MWh of displaced grid electricity. As we move to 2050, the rate of carbon reduction decreases, with smaller CHP systems adding emissions to the grid by 2045. 1 MW systems contribute to grid emissions by 2049.

Figure 50 shows the expected lifetime carbon emission reductions for a natural gas CHP engine with a 15-year life, installed in 2020, 2025, 2030, or 2035.

Figure 50. CHP Carbon Emission Reductions (Tons) Over System Life, Compared to Average SRVC Marginal Grid Emissions



CHP systems in the SRVC region that are retired before 2050 will reduce grid emissions, but the benefits become substantially smaller as time passes. A 1 MW system installed in 2020 will avoid 24 thousand tons of emissions by the end of its 15-year lifetime operating only during the daytime while a system that operates 24/7 will avoid 35 thousand tons of emissions. This is the equivalent to the current emissions produced in powering 3,650 homes for one year, or in driving 6,830 passenger vehicles for one year, on average. Smaller 100 kW systems will avoid 2,090 tons of emissions operating only during the daytime, while the same system operating nonstop will avoid 2,950 tons.

For a 1 MW system installed in 2035 and retired in 2050, 6 thousand tons of carbon emissions can be avoided by operating during daytime hours. This system would avoid 8 thousand tons of emissions operating 24/7, equivalent to the current emissions produced in powering 840 homes for one year, or the collective emissions released by 1,580 passenger vehicles for one year, on average. A 100kW system with the same lifespan will offset 260 tons of emissions by 2050 operating in the daytime or 270 tons operating 24 hours a day.

7. Conclusions

CHP systems, which operate at high efficiency and are most often fueled by natural gas have the potential to reduce carbon emissions from grid electricity across the entire country. In the electric grid of 2020, fossil fuel generators are deployed as marginal grid resources at the top of the dispatch stack to serve incremental customer loads. When CHP resources are installed, they reduce grid requirements for these marginal resources. CHP systems fueled by natural gas currently reduce carbon emissions across the continental U.S.

In the future, as coal plants are retired and utilities shift towards efficient combined cycle gas power plants and renewable generation, the gap between carbon emissions from CHP and the grid will be narrowed. When renewable or zero-carbon resources are used on the margin, CHP could become a net carbon emitter, requiring biogas or RNG to be incorporated into the CHP fuel supply to maintain a carbon emissions advantage. RNG is expected to be introduced to the gas supply in many U.S. regions over the study period, which could have an impact on the study's findings.

New York and California are expected to be the first states to reach 100% zero-carbon electricity, with legislated mandates for 2040 and 2045, respectively. According to our analysis, in New York CHP will become a net carbon emitter between 2025 and 2030, and in California CHP will produce net carbon emissions between 2030 and 2033. However, in all other regions CHP systems fueled by natural gas are expected to continue reducing carbon emissions.

The analysis showed that a CHP system installed in 2020 will reduce carbon emissions across the continental U.S. with the exception of Upstate New York. This is illustrated in Figure 51, which shows the total lifetime emission reductions for a 1 MW CHP system operating 24 hours a day.

Figure 51. Lifetime Carbon Emission Reductions for 1 MW 24/7 CHP System Fueled by Natural Gas, installed in 2020 and retired in 2035

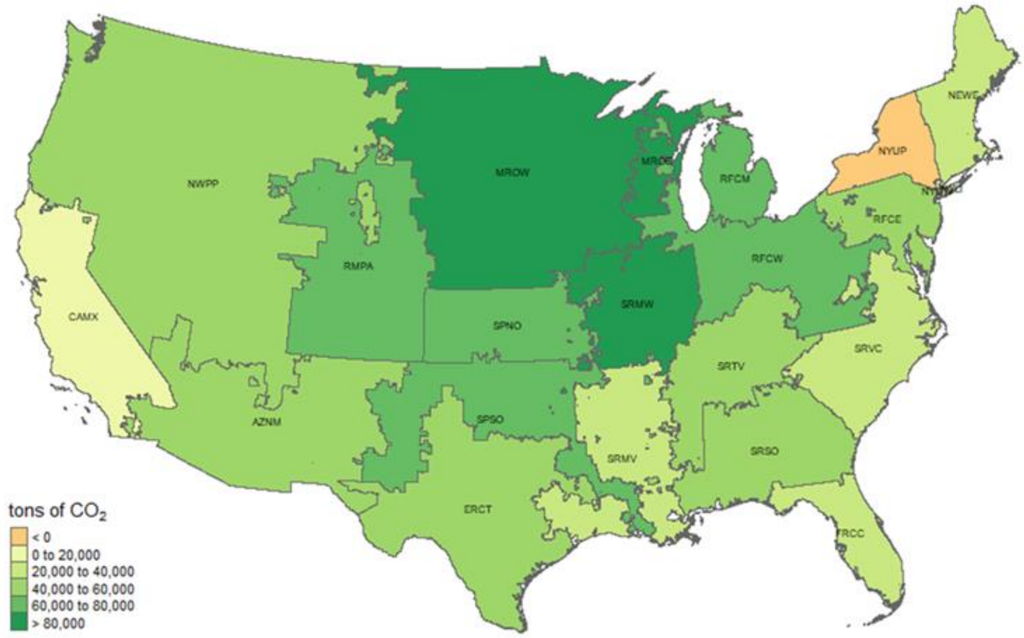
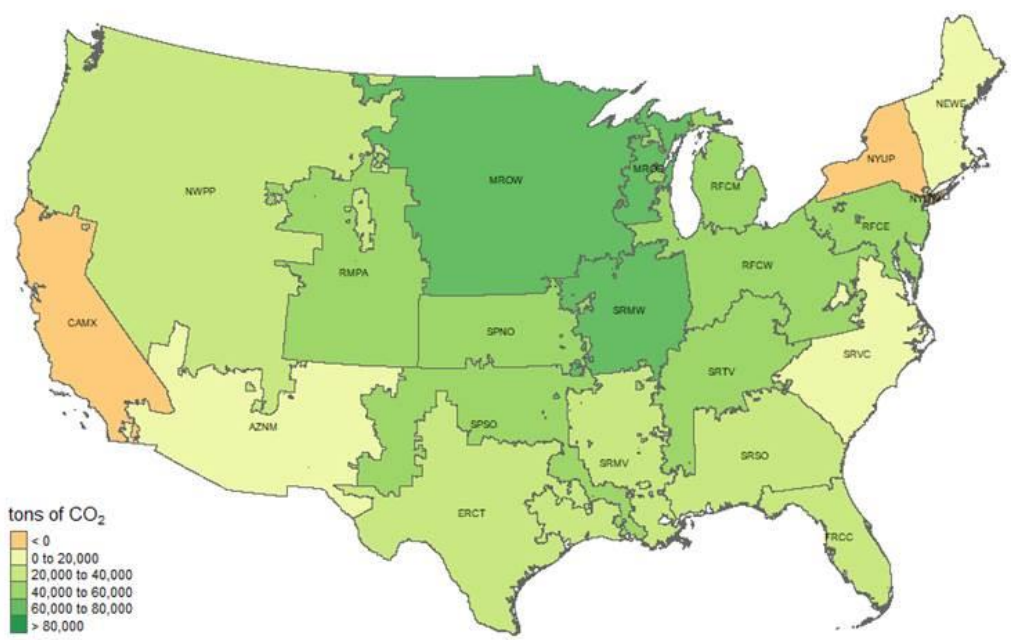


Figure 52 shows the lifetime carbon emissions for the same system installed in 2035, retired in 2050.

Figure 52. Lifetime Carbon Emission Reductions for 1 MW 24/7 CHP System Fueled by Natural Gas, installed in 2035 and retired in 2050



Even for natural gas CHP systems installed in 2035, lifetime emission reductions are expected across the country with the exception of New York and California.

With the potential for CHP to significantly reduce carbon emissions compared to separate heat and grid power, CHP can serve an important role in reducing carbon emissions. While many states have developed renewable targets, reaching zero carbon emissions will take decades to achieve. Additionally, as regional grids approach 100 percent clean energy, it is likely that fossil fuel resources will remain in use to serve marginal loads. If fossil generators operate on the margin, natural gas CHP could reduce grid emissions for a longer period of time in states like California and New York compared to the findings presented in this report. In the future, RNG could be incorporated into the natural gas supply thereby further reducing carbon emissions from CHP.

In addition to environmental benefits, CHP systems can be used in microgrids to provide resilient 24/7 power to critical loads during grid outages. New York and California – two states with 100 percent clean energy mandates – have both experienced recent extended power outages from natural disasters. These unplanned long duration outages have increased interest in accelerating adoption of resilient microgrids for critical facilities, many of which are incorporating natural gas CHP for baseload power and heat while integrating PV and other renewable technologies.

The results of this study show that CHP reduces carbon emissions compared to separate heat and power. As policymakers consider how to reduce carbon emissions, CHP should be considered as an economic alternative that provides carbon benefits immediately and well into the future, even as the electric grid becomes cleaner.