NYSERDA Smart Grid Evaluation Case Study: Orange & Rockland Grid Modernization Investments

Final Report

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Notice

NYSERDA Smart Grid Program Case Study: An evaluation of grid modernization investments at Orange & Rockland[1]

Key Results

- $3 million awarded ($1M in 2015, $2M in 2016) to Orange & Rockland by NYSERDA for grid modernization upgrades.
- $8.7 million invested by Orange & Rockland ($3.4M in 2015, $5.3M in 2016) in the grid modernization upgrades.
  - $2.90 committed by Orange & Rockland for every $1 of NYSERDA funding.
- Reliability benefits of the grid modernization upgrades valued to be at least $14.5 million for three storm events in 2020-2021. As the frequency and severity of storms increases due to climate change, the upgrades made during the project are likely to provide additional reliability benefits.
- Economic benefits of $1.4 million from deferring $5 million capital expenditure of building a new substation by 8 years.
- 5,274 metric tons of CO_{2e} emissions avoided from deferring substation construction.
- $1.3 million of environmental benefits from avoided CO_{2e} from deferred substation construction.
- $3.0 million in health benefits from avoided $PM_{2.5\ eq.}$ and the reduction in adverse health events from air pollution, from deferred substation construction.
- Total benefit of NYSERDA's and Orange & Rockland's funding is approximately $20 million.
  - $3.87 in benefits for every $1 of NYSERDA funding (valued in $2024).
- NYSERDA's funding helped inform Orange & Rockland's decision to plan significant follow-on smart grid investments and enabled equipment suppliers to further develop technologies and expand their businesses.

1. Introduction

NYSERDA's Smart Grid program promotes modernization of New York State's electric grid by funding research and technology development projects that can be implemented at the utility scale. Through these projects, the program aims to:

- Increase grid efficiency by reducing losses and improving system management,
- Reduce costs and improve technologies associated with integrating renewable energy sources, and
- Improve the ability of the grid to predict, withstand, and recover from power outages.

Examples of smart grid technologies include remote sensing devices for monitoring grid conditions in real-time, tools enabling two-way communication between a utility's operations center and various points on the grid, and automated controls for optimizing grid performance. These technologies and devices are relatively new on the market and are evolving quickly.

[1] NYSERDA contracted with IEc (the Evaluation Contractor) to evaluate the impacts of NYSERDA's investments in grid modernization at Orange & Rockland and to present the results in this case study.

Orange & Rockland is one of seven electric utilities in New York State. Its service territory covers over 300,000 households across six counties in New York and New Jersey (Figure 1). NYSERDA's Smart Grid program began supporting Orange & Rockland's grid modernization efforts in 2007, when the utility responded to a competitive solicitation for distribution automation proposals. NYSERDA selected Orange & Rockland's proposal and awarded $1 million to the utility to conduct a smart grid pilot project (Contract ID 10474). The pilot upgraded two 13.2 kV electric circuits in West Nyack with advanced sensors, field devices, online decision-making software, and improved communications. In 2010, Orange & Rockland successfully applied for NYSERDA funding to expand its distribution automation work (Contract ID 28823). NYSERDA awarded $2 million under Contract ID 28823 for upgrades to the southeastern portion of Orange & Rockland's territory in Rockland County. The work was carried out over three years from 2014-2016 and included upgrades to fourteen 13.2 kV electric circuits sensors. One of the main drivers for the project was to improve grid reliability for customers, especially during major storm events.[2]

Figure 1: Orange & Rockland Utility Map

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[2] NYSERDA has supported Orange & Rockland's grid modernization work through multiple awards including Contract ID 78942 (DER Interconnection Assessment Application), Contract ID 78943 (Micatu Voltage Sensors), Contract ID 149165 (Smart Inverters), Contract ID 152025 (Feeder of the Future). However, this case study focuses on the two projects described in the main body of this report: Contract ID 10474 and Contract ID 28823. With respect to the other projects listed in this footnote: Micatu Voltage Sensors were included in a previous NYSERDA case study (https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Publications/PPSER/Program-Evaluation/NYSERDA-GridModernization-Micatu-EvaluationCaseStudyReport-July2020.pdf); the other projects were not mature enough to be evaluated when the current case study was initiated.

Orange & Rockland installed Supervisory Control and Data Acquisition (SCADA) operable reclosers, Siemens Motor Operated Air Break switches (MOABs), capacitors, and G&W Electric voltage sensors. The deployment of these grid technologies provides Orange & Rockland information about real-time power flows, which allows the utility to manage their system using a model-centric approach. A model-centric approach uses a computer model and real-time power flow information to make informed grid management decisions. There are numerous benefits from investing in smart grid technologies and using a model-centric approach. Some of the main benefits described in this case study are:

- Improvements in grid reliability (preventing, or recovering more quickly from, power outages).
- Avoided and/or deferred capital upgrades or expansions because of improved grid efficiency, resulting in reduced greenhouse gas and air pollution emissions.
- Improved safety from reduced number of truck rolls.

The smart grid upgrades, deployed from 2014-2016, significantly improved grid reliability in Orange & Rockland, significantly reducing the frequency and duration of electricity outages after 2016 when compared to past performance, and performance statewide. The grid upgrades also increased grid efficiency, allowing Orange & Rockland to defer the construction of a new substation by eight years. The deferred construction creates environmental benefits by delaying construction-related greenhouse gas and air pollution emissions, and economic benefits from deferred capital expenditures for the new substation. Since the initial work with NYSERDA, Orange & Rockland have continued to invest in grid improvements across their service territory and have planned additional grid modernization investments through 2044.

This case study quantifies the key benefits that resulted from Orange & Rockland and NYSERDA's investment in the Utility's grid modernization improvements, including improved grid reliability, economic cost savings, and avoided CO_2 air pollution emissions. Information for this case study was collected through review of NYSERDA's and Orange & Rockland's project materials, interviews with the NYSERDA Program Manager and contacts at Orange & Rockland Utilities, as well as supplementary research.

2. Reliability Benefits

Many smart grid technologies and tools – particularly those related to grid monitoring and automation – aim to improve grid reliability by preventing or responding to outages in real-time. Smart grid technologies can, for example, monitor grid conditions to identify potential problems and automatically reroute power around those areas to minimize the number of customers affected.

Grid reliability is typically measured using two main metrics. SAIFI, the System Average Interruption Frequency Index, measures the average number of disruptions per customer in a year. SAIFI is primarily influenced by system design, capital investment, maintenance, and weather.[3] CAIDI, the Customer Average Interruption Duration Index, measures the average length of disruption per disruption event. It is affected by the management and size of the utility

[3] 2022 Electric Reliability Performance Report, New York State, Department of Public Service, 2022.

and line crew workforce, as well as geography.[4] In New York State electricity disruption is most frequently caused by trees falling on power lines.[5] Other common causes are major storms, equipment failure, and accidents. See the information box for more information on CAIDI and SAIFI.

SAIFI and CAIDI values can be reported including and excluding major storms. When excluding major storms, values are more comparable across different New York regions, as the effects of extreme weather events are felt differently in different locations. However, the values including major storms provide important insights into the effects of grid automation on reliability during major storm events. This case study presents SAIFI and CAIDI values both ways: *excluding* major storms for comparisons across New York utilities, and *including* major storms to capture the effects of grid upgrades on power reliability during major storms. As noted above, improving grid reliability during major storms was a key driver for Orange & Rockland's grid modernization investments.

Like any performance metric, SAIFI and CAIDI are imperfect. Orange & Rockland have proposed outcome and implementation-based methods for measuring the grid reliability outcomes of the smart grid upgrades, including avoided outages and number of devices installed per year. Going forward, Orange & Rockland plan on publishing these additional metrics biannually, in addition to SAIFI and CAIDI metrics.

How is Grid Reliability Measured?

Reliability for electric utilities is typically measured using two indices:

- **CAIDI**, the Customer Average Interruption Duration Index, represents the average outage duration time in hours that any customer would expect to experience over the course of a year.
- **SAIFI**, the System Average Interruption Frequency Index, represents the average number of interruptions a customer would expect to experience in that year.

Electric utilities across the country commonly track and report CAIDI and SAIFI to state public utility commissions. These metrics allow utilities and regulators to monitor reliability performance and take corrective actions when necessary to improve performance. ***For both CAIDI and SAIFI, the lower the value, the better. A decrease in these values over time generally signifies improved reliability.***

Because reliability can be affected by weather and other elements beyond the control of the utility, CAIDI and SAIFI are reported in two ways: *including* or *excluding* the impacts of major storms.

O&R carried out the grid automation upgrades between 2014 and 2016. Therefore, to compare the performance of the grid before and after automation, the average performance for the years 2010-2014, before the grid automation upgrades, is compared with the 2017-2022 average

[4] 2022 Electric Reliability Performance Report, New York State, Department of Public Service, 2022.

[5] 2022 Electric Reliability Performance Report, New York State, Department of Public Service, 2022.

performance, average after the upgrades. Table 1 shows the averages before and after grid automation, alongside the percentage differences, for Orange & Rockland as well as statewide.

Table 1: Historic SAIFI and CAIDI Indexes as averages for the years before grid automation (2010-2014) and after grid automation (2017-2022), for Orange & Rockland and Statewide[6]

Major Storms	**Region**	**SAIFI** (frequency)			**CAIDI** (duration)		
		Before (2010 – 2014)	**After (2017 – 2022)**	**% difference before vs. after**	**Before (2010 – 2014)**	**After (2017 – 2022)**	**% difference before vs. after**
Excluded	**O&R**	1.02	1.03	**1%**	1.6	1.7	**2%**
	Statewide (excluding ConEd)[7]	0.91	1.03	**13%**	1.83	1.86	**2%**
Included	**O&R**	1.60	1.38	**-13%**	11.8	4.4	**-63%**
	Statewide (excluding ConEd)	1.36	1.43	**5%**	6.4	4.7	**-27%**
Notes: **CAIDI** represents the average outage duration time in hours that any customer would expect to experience over the course of a year. **SAIFI** represents the average number of interruptions a customer would expect to experience in that year. For both CAIDI and SAIFI, the lower the value, the better. A decrease in these values over time generally signifies improved reliability.							

Orange & Rockland maintained their **SAIFI** performance after the grid upgrades when major storms are excluded and improved SAIFI significantly when major storms are included:

- **Excluding major storms, Orange & Rockland maintained SAIFI performance, even while the state's performance overall worsened**. The SAIFI index for Orange & Rockland remained relatively constant after grid automation: 1.02 for 2010-2014, versus 1.03 for 2017-2022. During the same period, statewide, SAIFI increased by 13% from 0.91 to 1.03.
- **Including major storms, Orange & Rockland decreased, or improved, their SAIFI score significantly after the grid upgrades, despite statewide SAIFI worsening**. When major storms are considered, the SAIFI index for Orange & Rockland decreased by 13% from 1.60 in 2010-2014 to 1.38 in 2017-2022. This is compared to a statewide increase in SAIFI of 5% from 1.26 in 2010-2014 to 1.43 in 2017-2022.

Statewide SAIFI increased by 13%, excluding storms, and 5%, including storms. This suggests that external factors, such as increased renewable energy generation, which is intermittent, and

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[6] Electric Service Reliability Reports, New York State, Department of Public Service. Accessed: August 2024, https://dps.ny.gov/electric-service-reliability-reports

[7] Statewide averages are presented here excluding data from Con Edison, in order to highlight trends for utilities most similar to Orange & Rockland. Con Edison's underground system is less prone to interruptions than overhead systems, and Con Edison serves approximately one-third of the state's electric customers. This combination can skew the statewide metrics. To avoid distorting statewide data, the Department of Public Service reports statewide averages both with and without Con Edison.

the effects of climate change, are causing more frequent outages. Despite the increasing intensity of these external factors, Orange & Rockland has maintained a steady SAIFI when excluding major storms, and even decreased SAIFI when considering major storms. This indicates that the grid automation improvements in Orange & Rockland have improved grid resilience significantly, especially when compared to the statewide average.

Orange & Rockland maintained a relatively constant **CAIDI** after grid automation, when major storms are excluded, and significantly improved CAIDI when including major storms:

- **When excluding major storms, CAIDI remained relatively constant before and after grid automation for both Orange & Rockland and statewide**. For Orange & Rockland, CAIDI increased by 2%, from 1.6 in 2010-2014 to 1.7 from 2017-2022. Statewide, CAIDI also increased by 2%, from 1.83 in 2010-2014 to 1.86 in 2017-2022.
- **When including major storms, CAIDI improved significantly for both Orange & Rockland and statewide. Orange & Rockland's improvement is over twice the statewide average.** For Orange & Rockland, CAIDI was reduced by 63%, from 11.8 in 2010-2014 to 4.4. in 2017-2022. Statewide, CAIDI decreased by 27%, from 6.4 in 2010-2014 to 4.7 in 2017-2022.

Orange & Rockland maintained a relatively constant CAIDI when major storms are excluded and significantly improved CAIDI when major storms are included. Orange & Rockland's CAIDI improved twice as much as CAIDI improved statewide. Orange & Rockland's improvement corresponds to its grid modernization upgrades.

When reviewing indexes which include major storms, there is uncertainty as to whether temporal differences are due to annual fluctuations in the number and severity of storms or improvements in grid resilience. However, Orange & Rockland decreased SAIFI by 13% and CAIDI by 63% from 2010-2014 (before the upgrades) to 2017-2022 (after the upgrades), which are significant improvements. In addition, when Orange & Rockland's improvements are compared to the statewide index changes over the same timeframe (a 5% increase in statewide SAIFI and a 25% decrease in statewide CAIDI), it is clear that Orange & Rockland has improved its SAIFI and CAIDI indexes to a much greater extent than the statewide averages. Therefore, it is reasonable to conclude that Orange & Rockland's grid automation upgrades played an important role in supporting the utility's SAIFI and CAIDI improvements.

The cost of electricity interruptions can be monetized using the U.S. Department of Energy's (DOE's) Interruption Cost Estimate (ICE) Calculator.[8] The tool calculates the cost of interruptions for different customer types annually based on SAIFI and CAIDI values. Table 2 shows the actual cost of Orange & Rockland's electricity interruptions as an annual average for the years 2017-2022. It shows that, excluding major storms, electricity outages cost $32,453,101 annually and, including major storms, $44,698,495 annually for the years 2017-2022.

Table 2 also shows the hypothetical costs if Orange & Rockland's reliability indexes had followed the statewide average trends shown above in Table 1, instead of Orange & Rockland's actual (more improved) trend. When storms are excluded, costs would have been $3,910,509 higher annually at $36,363,609 in total; when storms are included, costs would have been $10,741,047 higher at $55,439,542 annually. Therefore, the additional improvements in

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[8] ICE Calculator, U.S. Department of Energy, Accessed: August 2024. https://icecalculator.com/home

reliability indexes shown by Orange & Rockland, in comparison to following the statewide trends, have mitigated over $10 million in costs annually. A significant portion of the reliability improvements in Orange & Rockland's service territory, and therefore cost savings, were likely supported by the utility's grid automation upgrades.

Table 2: Estimated Cost Savings of Grid Reliability Improvements[9]

Storms included/ excluded	Scenario	SAIFI	CAIDI	Annual Cost ($2024)	Annual Cost Savings ($2024)
Excluding major storms	Actual average yearly cost 2017 – 2022	1.03	1.70	$32,453,101	$3,910,509
	If O&R had followed statewide trend	1.15	1.70	$36,363,610	
Including major storms	Actual average yearly cost 2017 – 2022	1.39	4.41	$44,698,495	$10,741,0467
	If O&R had followed statewide trend	1.67	8.64	$55,439,542	

Orange & Rockland undertook a detailed analysis of the impact of the grid automation upgrades on grid reliability over three major storm events across 2020 – 2021.[10] They calculated the number of customers that had outages prevented due to the upgrades to the grid as well as the number of customers who had outages shortened (Table 10 in the appendix).

Using Orange & Rockland's figures and the ICE calculator[11], the evaluators estimate the economic benefit of preventing the customer outages, (Table 3). The economic benefits are $8,571,708, $4,874,244, and $1,118,331, for Tropical Storm Isais (2020), Christmas (2020), and Tropical Storm Ida (2021), respectively. These values are likely to be underestimated because they only consider the complete prevention of outages caused by the grid upgrades; they do not account for the significant number of customers whose outages were shortened: 73,150, 32,300,

[9] The 'Actual average yearly cost 2017 – 2022' scenario shows the average cost of electricity outages in Orange & Rockland as an average of the years 2017-2022. The cost is calculated for each year using the ICE Calculator (https://icecalculator.com/home) and the SAIFI and CAIDI values published in the NYSERDA electric service reliability reports (https://dps.ny.gov/electric-service-reliability-reports). The average cost across 2017 -2022 is then averaged. The 'If O&R had followed statewide trend' scenario estimates the cost of electricity outages if Orange & Rockland's SAIFI and CAIDI values had followed the same trend as the statewide average. The statewide % difference in CAIDI and SAIFI before (2010-2014) versus after (2017-2020) (Table 1) were applied to the CAIDI and SAIFI averages for Orange & Rockland before the grid upgrades (2010-2014). This results in estimates for Orange & Rockland's CAIDI and SAIFI values for the period after the grid upgrades (2017-2020) if they had followed the statewide average trend instead of their own, more improved trend. The estimated CAIDI and SAIFI values are then used to find the average cost of electricity outages for the years 2017-2020 for Orange & Rockland.

[10] Climate Change Resilience Plan 2023, Orange & Rockland, 2023. https://www.oru.com/en/our-energy-future/our-energy-vision/our-climate-change-resiliency-plan

[11] ICE Calculator, U.S. Department of Energy, Accessed: August 2024. https://icecalculator.com/home

3,475 customers for Tropical Storm Isaias, Christmas 2020, and Tropical Storm Ida, respectively (Table 10 in the appendix).[12]

Table 3: Estimated Cost Savings from Grid Upgrades for Three Major Storm Events[13]

Storm Event	Storm Year	Customers with Outages Prevented	Cost Savings ($2024)
Tropical Storm Isaias	2020	64,000	$8,571,708
Christmas 2020	2020	36,400	$4,874,244
Tropical Storm Ida	2021	8,370	$1,118,331
Total			**$14,564,283**

The frequency and severity of storms is projected to increase. Orange & Rockland state in their 2023 Climate Change Vulnerability study: "*There is high confidence that the probability of coincident extreme events will likely continue to increase in both frequency and intensity in the future. When extreme events occur concurrently or sequentially to other events, efforts to respond become more difficult, and the impacts can become intensified or cascading.*"[14] As the frequency and severity of storms increases due to climate change, strengthening the grid to withstand storm events through projects like Orange & Rockland's grid automation upgrades is even more critical and will avoid even more costs in the future.

3. Economic Benefits and Follow-on Investment

Across the two projects, NYSERDA provided $3 million for Orange & Rockland's grid automation upgrades ($1M in 2015, $2M in 2016). In addition to NYSERDA's investment, Orange & Rockland contributed approximately $8.7 million ($3.4M in 2015, $5.3M in 2016), making the total cost for both the initial pilot and expansion project approximately $20.6 million in 2024 dollars.[15] Economic benefits that have resulted from the grid upgrades include (Table 4):

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[12] The shortening of customer outages could not be monetized in the analysis because of a lack of information. Only information on the number of customers whose outages were shorted is quantified. However, the ICE calculator requires the reduced length of customer outages in minutes or hours.

[13] In 2020, 437,924 customer outages including storms and 222,505 outages excluding storms, therefore 437,924 – 222,505 = 215,419 customer outages due to storms (2020 Electric Reliability Performance Report, New York State, Department of Public Service, 2020). Assumed 90% of outages residential and 10% commercial, 193,877 residential outages and 21,542 commercial outages due to storms. Using the average 2020 CAIDI of 1.67 and a SAIFI of 1 (as all customers in the calculation experienced outages), the evaluators calculated cost of storm related outages to be $28,853,369. If the customer outages associated with Tropical Storm Isaias and Christmas 2020 had not been avoided, outage costs associated with storms would be $13,445,952 higher: $8,571,708 (Tropical Storm Isaias) + $4,874,244 (Christmas 2020) (Table 3).

[14] Orange & Rockland, Climate Change Resilience Plan, 2023, page 57.

[15] Milestone Deliverable #1 + 2 – Contracts #10474 + #28823 Central Rockland Smart Grid Automation Project, Orange & Rockland, (Internal Document).

- **$1.4 million from deferring the construction of a $5 million substation from 2021 to 2029**. Improved grid efficiency plus the introduction of automatic switches enabled Orange & Rockland to defer the construction of a substation by eight years. Assuming a weighted average cost of capital of 7%[16] and future annual inflation of 2.108%,[17] the capital expenditure deferral results in financial benefits of about $1.4 million.[18]
- **At least $14.5 million from resiliency improvements.** This value represents the cost savings from preventing customer outages in three major storm events (Tropical Storm Isaias, Christmas 2020, and Tropical Storm Ida). As this value does not capture non-storm related reliability improvements, shortages in customer outages, or other major storms beyond these three, the total resiliency-based cost savings are likely to be much greater.

Table 4: Costs and Benefits of Accelerated Smart Grid Distribution Automation Program

Costs	**Value ($2024)**
NYSERDA's cost for the first (pilot) project	$1,956,947($2015: $1,000,000)
Orange & Rockland's cost share for the first (pilot) project	$6,696,673($2015: $3,422,000)
NYSERDA's cost for the second (expansion) project	$3,259,098 ($2016: $2,000,000)
Orange & Rockland's cost share for the second (expansion) project	$8,662,990 ($2016: $5,316,188)
Total cost of grid upgrades	**$20,575,708**
Benefits	**Value ($2024)**
Deferred cost of substation construction	$1,387,528
Reliability improvements across three major storm events	$14,564,282
Total economic benefits	**$15,627,247**

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[16] Orange and Rockland Utilities, Inc. Consolidated Financial Statements December 31, 2023 and 2022, Orange & Rockland, 2023. https://cdne-dcxprod-sitecore.azureedge.net/-/media/files/oru/documents/investors/financial-reports/2023-year-end.pdf?rev=0825acf7ced841e295abcc934660ea29&hash=EBCEE83F5140F4DBD21B0E15DA048B69

[17] Inflation Expectations, Federal Reserve Bank of Cleveland, September 2024. https://www.clevelandfed.org/indicators-and-data/inflation-expectations

[18] In 2021, the capital expenditure required was $5 million (2021 dollars). To calculate the present value of an equivalent capital expenditure in 2029, in 2021 dollars, the evaluators use a nominal discount rate of seven percent, actual inflation in 2022 and 2023 as measured by the GDP Implicit Price Deflator [https://fred.stlouisfed.org/series/GDPDEF#0], and the projected rate of inflation from 2024 through 2029 as published by the Federal Reserve Bank of Cleveland [https://www.clevelandfed.org/indicators-and-data/inflation-expectations]. Averaging the actual and projected rates of annual inflation over the period of analysis yields an average inflation rate of 3.091%. The Fisher Equation converts nominal discount rates and inflation rates into a real discount rate ($(1+i) / (1 + pi) - 1 = r$, where i is nominal discount rate, π is inflation, and r is the real discount rate). In this instance, a nominal discount rate of seven percent and an inflation rate of 3.091% yields a real discount rate over the period of analysis of 3.648%. Therefore, the present value of $5 million in 2029, in 2021 dollars, is $3,753,885. In other words, Orange & Rockland gained $1,246,115 (in 2021 dollars) by delaying the capital expenditure to 2029. Compounding the value of $1,245,115 to 2024 dollars using the real discount rate of 2.108% yields $1,387,528, which is the current value of the savings created by delaying the capital expenditure from 2021 to 2029.

Orange & Rockland have committed significant follow-on investment for continued smart grid automation upgrades under the New York Accelerated Smart Grid Distribution Automation Program. The additional investments (Table 5) total $99,170,000 from 2025 – 2044, 19 times more than the initial NYSERDA investment. Within this program, Orange & Rockland plan to expand the installation of sensors, processors, and communication networks. The goal is to be able to disaggregate customers into sections of 250 customers or less, resulting in fewer customers affected by outages. A particular focus of the follow-on investment is improving resilience to extreme weather events, given that extreme weather events are projected to increase in frequency and strength.

Table 5: Orange & Rockland's Planned Follow-on Investment in NY Accelerated Smart Grid Distributed Automation Program[19]

Years	**2025 - 2029**	**2030 – 2034**	**2035 – 2044**
Investment plan	$60,620,000	$13,450,000	$25,100,000

In addition to the economic benefits within Orange & Rockland's service territory, the grid modernization investments have also benefited the utility's equipment suppliers. For example, G&W Electric,[20] a provider of voltage sensors used for grid automation in Orange & Rockland, found that:

"The partnership with our valued customer Orange & Rockland Utilities (ORU) revealed to be a great opportunity for improving G&W Electric's newly launched high-accuracy voltage sensor.

The real test bed revealed opportunities for product improvements that had not been detected previously during the standard lab validation which allowed the G&W Electric team to address these areas for improvement."[21]

These benefits, although not able to be quantified in this case study, demonstrate the wider value of the project to suppliers of novel and developing technologies, both in expediting the development of new technologies and developing new business areas.

[19] Climate Change Resilience Plan 2023, Orange & Rockland, 2023. https://www.oru.com/en/our-energy-future/our-energy-vision/our-climate-change-resiliency-plan

[20] Accusense Voltage Sensor, G&W Electric, Accessed: September 2024. https://www.gwelectric.com/products/high-accuracy-sensors/accusense-voltage-sensor/

[21] G&W Testimonial, G&W, August 2023, (Internal Document).

4. Environmental and Health Benefits

NYSERDA's Smart Grid program enabled Orange & Rockland to delay the construction of a new substation by eight years. The substation was originally planned to be built in 2021. However, due to the increased efficiency afforded by the grid automation upgrades and the switch from manual to automated switching, power could be restored more quickly and customer interruption hours reduced. These grid and performance improvements meant a new substation was now not required until 2029.[22]

Delaying the construction of the substation is environmentally beneficial because the environmental impact of the energy and construction sectors is decreasing as the grid becomes greener and efficiency improves. These improvements mean that the greenhouse gas emissions associated with building a substation in the future are likely to be significantly lower than they would have been in 2021.

Greenhouse gas emissions which are emitted during the extraction, manufacture, and/or construction of a product are called embodied carbon emissions (see the call-out box for more information). In the case of building a substation, these are the carbon emissions associated with the mining of raw building materials (metal, cement, etc.), manufacture of substation parts, and construction of the facility (e.g., operating a crane). The total embodied carbon emissions associated with constructing a new substation have been calculated in multiple studies; the average

What is embodied carbon?

Embodied carbon refers to all the emissions produced across the supply chain in order to make something. In the context of constructing a substation, this includes:

- Raw materials (metal, cement, etc.)
- Manufacturing of substation parts
- Transporting parts from the manufacturing locations to the construction site
- Activities associated with construction (e.g., operating a crane)

These emissions are also called upstream, or cradle-to-gate emissions. New York State's Embodied Carbon Guidance defines embodied carbon for construction projects as "*The emissions that result from the mining, harvesting, processing, manufacturing, transportation, installation and use of the products and materials that are used, as well as end-of-life emissions associated with the disposal of those materials.*"

For more information, see https://ogs.ny.gov/executive-order-22-embodied-carbon-guidance

Environmentally Extended Input Output (EEIO) analysis can be used to trace emissions across a product's supply chain. This analysis uses the USEEIO database.

For more information, see https://www.epa.gov/land-research/us-environmentally-extended-input-output-useeio-models

[22] If the following thresholds cannot be met, then a new substation is required: transformers can run for 4 hours on Long Term Emergency Rating; 60% or more of load lost must be restored from existing substation transformers; 40% or less of load lost must be restored within 24 hours using a portable substation; and customer-hours of interruption must be less than 60,000. Smart Grid Distribution Automation Using Model-Centric Control with Cost/Benefit Analysis Presentation, Orange & Rockland, (Internal Document).

emissions associated with building a substation in the U.S. in 2021 are an estimated 39,812 metric tons CO_2e.[23]

In 2029 the embodied carbon emissions associated with building the same substation are projected to be 13% lower than in 2021, assuming current trends continue (Table 6). This means that the CO_2e will be reduced by 5,274 tons, from 39,812 to 34,538 tons in total. This decrease in carbon emissions is explained both by increasing efficiencies and decarbonization across supply chains and greening of the grid in New York State and more widely.

The electricity grid in New York State is expected to become significantly cleaner by 2030 with its carbon emission intensity falling from about 0.17 CO_2/MWh in 2022 to 0.06 CO_2/MWh in 2029, a decrease of 65%.[24] This means all electricity consumed in New York State to build the substation will have significantly lower carbon emissions impact in 2029 than in 2021. For the parts of the substation supply chain which occur outside of New York State and/or the USA, the trend is similar, with global electricity greenhouse gas emissions intensity projected to decrease by 2.4% annually.[25] This means all activities associated with substation construction, both within and outside of New York State, are likely to have significantly lower carbon emissions in the future.

How are emissions reductions valued?

Reductions in CO_2 emissions are valued using the social cost of carbon (SCC). The SCC is a measure of the value (in dollars) of the long-term societal damages resulting from emitting one ton of CO_2 in a given year; these damages include impacts to human health, agricultural productivity, and property damage, among others.

Social cost of carbon estimates for New York State are developed by the New York State Department of Environmental Conservation (DEC) and published in the 'Establishing a Value of Carbon' guidance. The guidance is periodically updated with the most recent revision in 2023.

The DEC indicates that the social cost of carbon should increase over time (over and above the effects of inflation) due to accelerating climate impacts and anticipated economic growth, which will make future impacts of carbon emissions more costly.

For more information, see https://extapps.dec.ny.gov/docs/administration_pdf/vocguidrev.pdf

[23] Patel et al., "Considerations in Designing a Low Carbon Substation"; Li et al., *The Proceedings of the 17th Annual Conference of China Electrotechnical Society*; Wei et al., "A 2015 Inventory of Embodied Carbon Emissions for Chinese Power Transmission Infrastructure Projects"; Liu et al., "Carbon Emission Evaluation Method and Comparison Study of Transformer Substations Using Different Data Sources"; Liu et al., "Carbon Emission Accounting during the Construction of Typical 500 kV Power Transmissions and Substations Using the Carbon Emission Factor Approach."

[24] Projected Emission Factors for New York State Grid Electricity, NYSERDA, August 2022. https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Publications/Energy-Analysis/22-18-Projected-Emission-Factors-for-New-York-Grid-Electricity.pdf

[25]Renewables 2023: Analysis and forecast to 2028, International Energy Agency, January 2024. https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf

The Social Cost of Carbon (SCC) is a way of measuring the long-term societal costs of emitting greenhouse gases[26] (see the call-out box for more detailed information). Table 6 shows that deferring substation construction reduces the SCC from \$6.63 million to \$5.32 million (using the 2% discount rate), indicating that \$1.31 million of damages caused by building the substation are avoided by deferring construction from 2021 until 2029. As explained above, the embodied carbon associated with constructing a new substation in 2029 is expected to be lower than in 2021, resulting in lower CO_2 emissions. Full SCC calculations for multiple discount rates are shown in Table 11 in the appendix.

Table 6: Deferred Substation Embodied Emissions and Social Cost of Carbon

	2021	2029	Difference (2021 vs. 2029)
Greenhouse Gas Emissions (tons CO_2e)	39,812	34,538	5,274
Social Cost of Carbon – Millions \$2021 (2% Discount Rate)	\$6.63	\$5.32	\$1.31

In addition to the deferral of embodied carbon emissions, the operational emissions associated with running the substation over its lifetime will also be deferred. As the grid will be cleaner in the future, any electricity required for the operation of the substation will produce less carbon emissions when deferred by eight years. In addition, with eight years of additional technology development, a substation built in 2029 is likely to run more efficiently than a 2021 model, meaning that the power consumption and associated greenhouse gas emissions are also likely to be lower.[27]

Alongside carbon emission reductions, delaying substation construction is also likely to reduce the emissions of criteria air pollutants. Emission of air pollutants from construction has shown a significant downward trend over the last few decades.[28] Figure 5 (in the appendix) shows the downward trend in $PM_{2.5\ eq}$ emissions from building a substation from 2007 to 2012. The reduction in air pollution from construction is due to new regulation and improvement in manufacturing and building technologies.

Assuming the same downward trend in criteria air pollution as shown in Figure 5, building the substation in 2021 would have produced 11,839 kg $PM_{2.5\ eq}$ versus 7,791 in 2029 (Figure 6 in the appendix). Therefore, delaying substation construction could mitigate approximately 4,000 kg $PM_{2.5\ eq}$. Approximately 25% of this total is $PM_{2.5}$ emissions from construction and will therefore be in Orange & Rockland counties in New York State. The remaining 75% of emissions is from

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[26] New York State emissions factors are updated periodically. For this analysis, the Evaluation Contractor referenced the following: Establishing a Value of Carbon, New York State Department of Environmental Conservation, June 2021. https://extapps.dec.ny.gov/docs/administration_pdf/vocguidrev.pdf

[27] The Future of Substation Engineering: Industry Trends and Advancements, Solve Now, May 2023. https://solvenow.us/the-future-of-substation-engineering-industry-trends-and-advancements/

Electricity Grids and Secure Energy Transitions Enhancing the foundations of resilient, sustainable and affordable power systems, International Energy Agency, November 2023. https://iea.blob.core.windows.net/assets/ea2ff609-8180-4312-8de9-494bcf21696d/ElectricityGridsandSecureEnergyTransitions.pdf

[28] Progress Cleaning the Air and Improving People's Health, U.S. Environmental Protection Agency, April 2024. https://www.epa.gov/clean-air-act-overview/progress-cleaning-air-and-improving-peoples-health

activities along the supply chain (e.g., transportation, manufacture of building materials), meaning the emission reduction will be spread across the United States.

Reducing $PM_{2.5}$ emissions will benefit local populations by reducing negative respiratory and cardiovascular effects, thereby improving health and lowering health and social care costs. The benefits of reducing $PM_{2.5}$ emissions can be monetized by using the U.S. Environmental Protection Agency CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)[29] or the U.S. Environmental Protection Agency's Benefits Mapping and Analysis Program's (BENMap) sector-based $PM_{2.5}$ benefit per ton estimates.[30] Both tools estimate the health impacts of regional changes in air pollution and the economic effects of the changes. For this case study, the evaluators used the COBRA tool to monetize the emission reductions in Orange & Rockland, and the BENMap tool for emissions across the U.S.

Table 7 shows the estimated projections for emissions of $PM_{2.5}$ if the substation was built in 2021 versus 2029 and Table 8 shows the monetized values. The estimated benefit of the $PM_{2.5}$ reductions is $1.02 million for the emissions reduction in Orange and Rockland counties in New York State and $1.90 million for the emissions reductions across the entire U.S. Therefore, the total monetized benefit of substation deferral for $PM_{2.5}$ is $2.92 million. These monetized benefits are likely an underestimate as they only account for $PM_{2.5}$ and do not account for volatile organic carbon (VOCs) which are also expected to be reduced with the deferral of substation construction.

Table 7: Monetized benefits from reductions in PM2.5 from delaying substation construction from 2021 to 2029

Geography	**Kg PM2.5**		
	2021 projection	**2029 projection**	**Reduction in emissions**
Emissions in Orange and Rockland Counties in New York State	2871	1890	982
Emissions across the U.S.	8968	5902	3066

[29] CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA), U.S. Environmental Protection Agency, Accessed Oct 2024. https://cobra.epa.gov/

[30] Benefits Mapping and Analysis Program (BenMAP), U.S. Environmental Protection Agency, Accessed Oct 2024. https://www.epa.gov/benmap/sector-based-pm25-benefit-ton-estimates

Table 8: Cost of PM2.5 Pollution and Financial Benefit of Delaying Substation Construction

Geography	Cost of PM2.5 Pollution ($M 2024)						
	2021 Construction			2029 Construction			Difference (2029 versus 2024 average)
	Low	High	Average	Low	High	Average	
Emissions in Orange and Rockland Counties in New York State[31]	$1.49	$3.19	$2.34	$0.85	$1.79	$1.32	$1.02
Emissions across the U.S.[32]	$2.75	$5.90	$4.32	$1.55	$3.31	$2.43	$1.90
Total benefit of delayed substation construction related to PM2.5 emissions							**$2.92**

5. Safety Benefits

The grid upgrades also reduced the number of truck rolls required during major storm events. A truck roll occurs when the utility sends a technician to a field site or customer location to resolve an issue (e.g., a fallen power line). Sending line crews into the field to restore power during or after a major storm can entail safety risks. Reducing the number of truck rolls reduces hazards associated with the risk of injury for line crews, the risk of traffic accidents, and air pollution associated with vehicle emissions from the trucks. For three major storm events, Orange & Rockland quantified the number of truck rolls that were avoided as a direct result of the grid upgrades. They found that for Tropical Strom Isaias (2020), Christmas (2020), and Tropical Storm Ida (2021), 502, 217, and 36 truck rolls, respectively, were avoided.[33] As these are only the truck rolls saved across three storm events, the total number of truck rolls saved is likely to be much higher.

[31] The U.S. Environmental Protection Agency's CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA) tool was used to calculate financial benefits for Emissions in Orange and Rockland Counties. 'Other Industrial Processes' and 'Construction' was selected for the sector and subsector, respectively. A 2% discount rate is assumed to align with the Social Cost of Carbon midpoint discount rate for New York State (Establishing a Value of Carbon, New York State Department of Environmental Conservation, June 2021). Values in $2023, inflated to $2024 using Producer Price Index (https://www.bls.gov/ppi/).

[32] U.S. Environmental Protection Agency Benefits Mapping and Analysis Program (BenMAP) sector-based $PM_{2.5}$ benefit per ton (BPT) estimates were used to calculate financial benefits for emissions across the U.S. The average BPT across sectors was used. A 2% discount rate is assumed to align with the Social Cost of Carbon midpoint discount rate for New York State (Establishing a Value of Carbon, New York State Department of Environmental Conservation, June 2021). Values in $2019, inflated to $2024 using Producer Price Index (https://www.bls.gov/ppi/).

[33] Climate Change Resilience Plan 2023, Orange & Rockland, 2023. https://www.oru.com/en/our-energy-future/our-energy-vision/our-climate-change-resiliency-plan

6. Total Benefits of NYSERDA Funding for Orange & Rockland's Smart Grid Improvements

Multiple economic, social, and environmental benefits were created by NYSERDA's and Orange & Rockland's investment in grid modernization (Table 9):

- **$1.4 million from deferring the construction of a $5 million substation from 2021 to 2029** (explained in detail in the Economic Benefits and Follow-on Investment section).
- **At least $14.5 million from resiliency improvements** (explained in detail in the Reliability Benefits and Economic Benefits and Follow-on Investment sections). **The resiliency improvement benefits are expected to recur for future storm events.**
- **$0.8 million in societal wellbeing from mitigated carbon dioxide emissions** as a result of delaying the substation construction from 2021 to 2029 (explained in detailed in the Environmental and Health Benefits section).
- **$2.9 million in health benefits from reduced air pollution** as a result of delaying the substation construction from 2021 to 2029 (explained in detailed in the Environmental and Health Benefits section).

Table 9: Costs and Benefits of Accelerated Smart Grid Distribution Automation Program

Costs and Benefits	Value (2024)
Cost item	
NYSERDA cost	$5,216,045 ($2015: $1M, $2016: $2M)
Orange & Rockland cost share	$15,359,662 ($2015: $3.4M, $2016: $5.3M)
Total cost of grid upgrades	**$20,575,708**
Benefits	
Deferred cost of substation construction (one-time benefit)	$1,387,528
Reliability improvements across three major storm events in 2020-2021 (additional reliability benefits are expected in the future as the frequency and severity of storms worsen due to climate change)	$14,564,282
Social cost of carbon for avoided CO_2 emissions (one-time benefit from deferred substation construction)	$1,305,717
Health benefits from reduced air pollution (one-time benefit from deferred substation construction)	$2,918,252
Total economic benefits (without SCC or health benefits from reduced air pollution)	**$15,951,810**
Total social wellbeing benefits (with SCC and health benefits from reduced air pollution)	**$20,175,778**
Benefit/Cost Ratios	
Economic benefit/cost ratio (without SCC or health benefits from reduced air pollution)	3.1
Total social wellbeing benefit/cost ratio (with SCC and health benefits from reduced air pollution)	3.9

These benefits sum to roughly $16 million, considering only economic benefits, and roughly $20 million, including both economic and social wellbeing benefits. When these benefits are compared with the project costs in a benefit/cost ratio, the ratios are 3.1 when considering economic benefits only, and 3.9 when social wellbeing benefits are also considered. These ratios demonstrate the significant return on NYSERDA's initial investment. When benefits that cannot be monetized in this analysis are also considered, such as improved safety from reduced truck rolls, the benefits of the project are even greater.

8. Conclusions

This case study analyzes and quantifies the key benefits of Orange & Rockland's grid modernization program. Benefits include improved grid reliability, economic cost savings, avoided CO_2 and air pollution emissions, and improved safety. NYSERDA's investment has also allowed equipment suppliers to further develop their technologies. Since the NYSERDA-funded projects, Orange & Rockland has committed to significant follow-on investment to expand the full-scale transmission and distribution automation program to the remainder of their service territory.

9. Sources

1. 2022 Electric Reliability Performance Report, New York State, Department of Public Service, 2022.
2. Electric Service Reliability Reports, New York State, Department of Public Service. Accessed: August 2024, https://dps.ny.gov/electric-service-reliability-reports
3. ICE Calculator, U.S. Department of Energy, Accessed: August 2024. https://icecalculator.com/home
4. Climate Change Resilience Plan 2023, Orange & Rockland, 2023. https://www.oru.com/en/our-energy-future/our-energy-vision/our-climate-change-resiliency-plan
5. 2020 Electric Reliability Performance Report, New York State, Department of Public Service, 2020.
6. Milestone Deliverable #2 – Contract #28823 Central Rockland Smart Grid Automation Project, Orange & Rockland, (Internal Document).
7. Orange and Rockland Utilities, Inc. Consolidated Financial Statements December 31, 2023 and 2022, Orange & Rockland, 2023. https://cdne-dcxprod-sitecore.azureedge.net/-/media/files/oru/documents/investors/financial-reports/2023-year-end.pdf?rev=0825acf7ced841e295abcc934660ea29&hash=EBCEE83F5140F4DBD21B0E15DA048B69
8. Inflation Expectations, Federal Reserve Bank of Cleveland, September 2024. https://www.clevelandfed.org/indicators-and-data/inflation-expectations
9. Gross Domestic Product: Implicit Price Deflator, Federal Reserve Bank of St. Louis, August 2024. https://fred.stlouisfed.org/series/GDPDEF#0
10. Accusense Voltage Sensor, G&W Electric, Accessed: September 2024. https://www.gwelectric.com/products/high-accuracy-sensors/accusense-voltage-sensor/
11. G&W Testimonial, G&W, August 2023, (Internal Document).
12. Smart Grid Distribution Automation Using Model-Centric Control with Cost/ Benefit Analysis Presentation, Orange & Rockland, (Internal Document).
13. Projected Emission Factors for New York State Grid Electricity, NYSERDA, August 2022. https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Publications/Energy-Analysis/22-18-Projected-Emission-Factors-for-New-York-Grid-Electricity.pdf
14. Renewables 2023: Analysis and forecast to 2028, International Energy Agency, January 2024. https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf
15. Establishing a Value of Carbon, New York State Department of Environmental Conservation, June 2021. https://extapps.dec.ny.gov/docs/administration_pdf/vocguidrev.pdf

16. Electricity Grids and Secure Energy Transitions Enhancing the foundations of resilient, sustainable and affordable power systems, International Energy Agency, November 2023. https://iea.blob.core.windows.net/assets/ea2ff609-8180-4312-8de9-494bcf21696d/ElectricityGridsandSecureEnergyTransitions.pdf

17. The Future of Substation Engineering: Industry Trends and Advancements, Solve Now, May 2023. https://solvenow.us/the-future-of-substation-engineering-industry-trends-and-advancements/

18. Progress Cleaning the Air and Improving People's Health, U.S. Environmental Protection Agency, April 2024. https://www.epa.gov/clean-air-act-overview/progress-cleaning-air-and-improving-peoples-health

19. The Proceedings of the 17th Annual Conference of China Electrotechnical Society, Li et al., 2023.

20. Considerations in Designing a Low Carbon Substation, Patel et al., 2024. https://ieeexplore.ieee.org/abstract/document/10556131

21. A 2015 Inventory of Embodied Carbon Emissions for Chinese Power Transmission Infrastructure Projects, Wei et al, 2020. https://www.nature.com/articles/s41597-020-00662-4

22. Carbon Emission Evaluation Method and Comparison Study of Transformer Substations Using Different Data Sources, Liu et al., 2023. https://www.mdpi.com/2075-5309/13/4/1106

23. Carbon Emission Accounting during the Construction of Typical 500 kV Power Transmissions and Substations Using the Carbon Emission Factor Approach., Liu et al., 2024. https://www.mdpi.com/2075-5309/14/1/145

24. US Environmentally-Extended Input-Output (USEEIO) Models, U.S. Environmental Protection Agency, October 2023. https://www.epa.gov/land-research/us-environmentally-extended-input-output-useeio-models

25. CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA), U.S. Environmental Protection Agency, Accessed Oct 2024. https://cobra.epa.gov/

26. Benefits Mapping and Analysis Program (BenMAP), U.S. Environmental Protection Agency, Accessed Oct 2024. https://www.epa.gov/benmap/sector-based-pm25-benefit-ton-estimates

Appendix: Detailed Methodology

Reliability Benefits

Figure 2 shows the full range of reliability statistics for Orange & Rockland, excluding major storms, from 2018 to 2022.

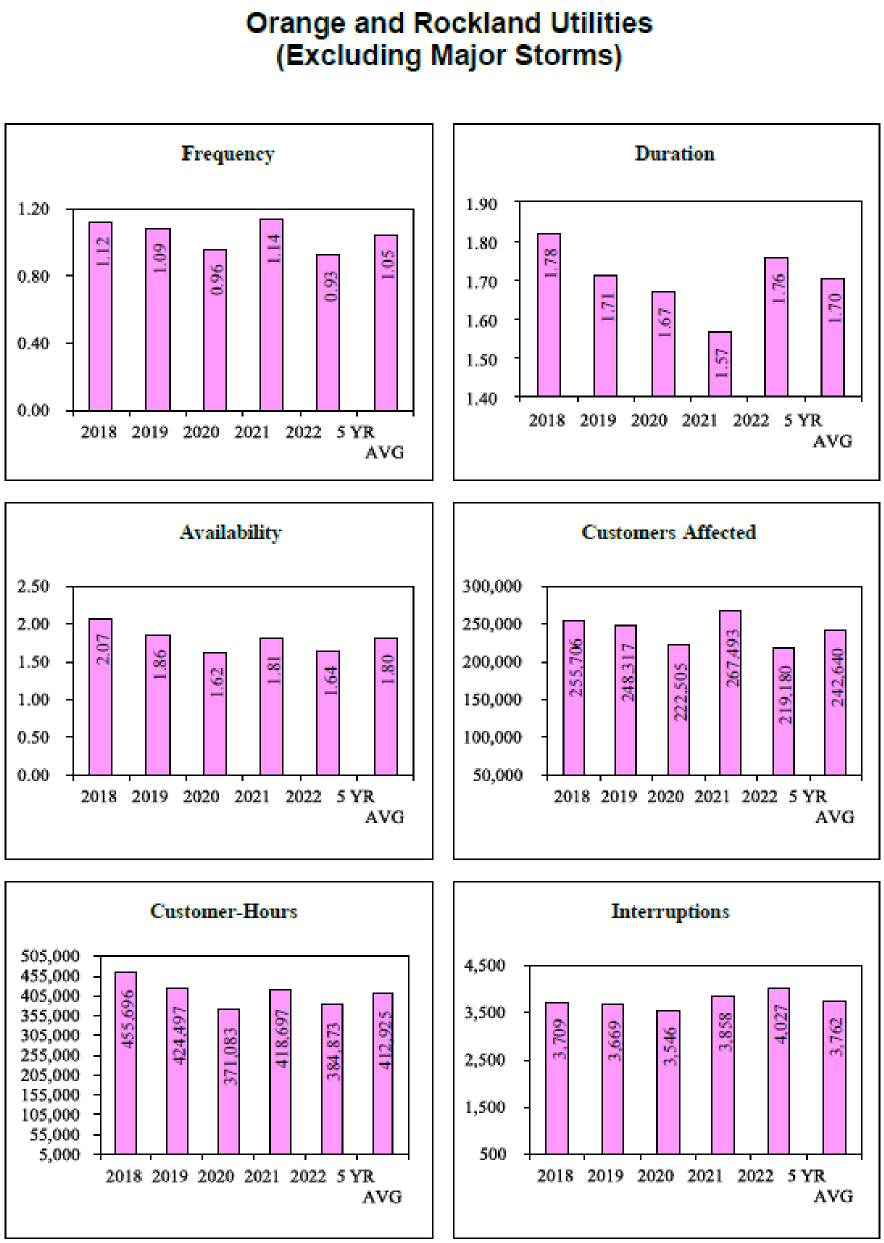

Figure 2: Orange & Rockland Full Reliability Metrics 2018 - 2022[34]

[34] Electric Service Reliability Reports, New York State, Department of Public Service. Accessed: August 2024, https://dps.ny.gov/electric-service-reliability-reports

Table 10 shows the detailed analysis undertaken by Orange & Rockland in their 2023 Climate Change Resilience Plan for three storm events in 2020-2021.[35]

Table 10: Detailed Analysis on the Impact of Grid Automation Improvements on the Reliability Impacts of Three Storm Events[36]

Storm Event	Tropical Storm Isaias (August 2020)	Christmas 2020	Tropical Storm Ida (September 2021)
How many customer outages were avoided by Distribution Automation?	66 Auto-Loops and 21 Reclosers operated, preventing outages to: 64,000 customers	32 Auto-Loops and 9 Reclosers operated, preventing outages to: 36,400 customers	8 Auto-Loops and 2 Reclosers operated, preventing outages to: 8,370 customers
How many customer outages were shortened by remote switching?	237 switch steps were executed, shortening outages to 73,150 customers	152 switch steps were executed, shortening outages to 32,300 customers	20 switch steps were executed, shortening outages to 3,475 customers
Safety related switching steps	265	65	16
How many truck rolls were saved?	502	217	36

Environmental Benefits

Figure 3 shows the historical and projected embodied carbon emissions of constructing a substation from 2007 to 2029. The values are derived from a literature review of life cycle assessment (LCA) studies calculating the embodied carbon emissions of substation construction alongside additional modelling to ensure spatial specificity and to add the temporal dimension.

The literature review found five relevant LCA studies.[37] All five studies calculated comparable values for the total embodied carbon emissions associated with substation construction. One

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[35] Climate Change Resilience Plan 2023, Orange & Rockland, 2023. https://www.oru.com/en/our-energy-future/our-energy-vision/our-climate-change-resiliency-plan

[36] Climate Change Resilience Plan 2023, Orange & Rockland, 2023. https://www.oru.com/en/our-energy-future/our-energy-vision/our-climate-change-resiliency-plan

[37] The Proceedings of the 17th Annual Conference of China Electrotechnical Society, Li et al., 2023.

Considerations in Designing a Low Carbon Substation, Patel et al., 2024. https://ieeexplore.ieee.org/abstract/document/10556131

A 2015 Inventory of Embodied Carbon Emissions for Chinese Power Transmission Infrastructure Projects, Wei et al, 2020. https://www.nature.com/articles/s41597-020-00662-4

Carbon Emission Evaluation Method and Comparison Study of Transformer Substations Using Different Data Sources, Liu et al., 2023. https://www.mdpi.com/2075-5309/13/4/1106 study, Wei et al[38], calculated the embodied carbon emissions of 37 substations and the average of these was taken for use in this analysis.

Wei et al. uses Environmentally-Extended Input-Output (EEIO) analysis to calculate embodied carbon emissions. The evaluators converted the EEIO values used in the Wei et al. study to U.S. EEIO values,[39] making the results specific to a substation built in the U.S. The U.S. EEIO is the EEIO model published by the U.S. Environmental Protection Agency. There are U.S. EEIO models for several years: 2007, 2012, and 2021. These models can be used to calculate what the construction emissions would have been if the substation was built in that year (blue line in). By assuming the same downward trend in emissions from 2007-2021 continues, the evaluators projected the embodied carbon emissions of building a substation in 2029 (orange line in Figure 3).

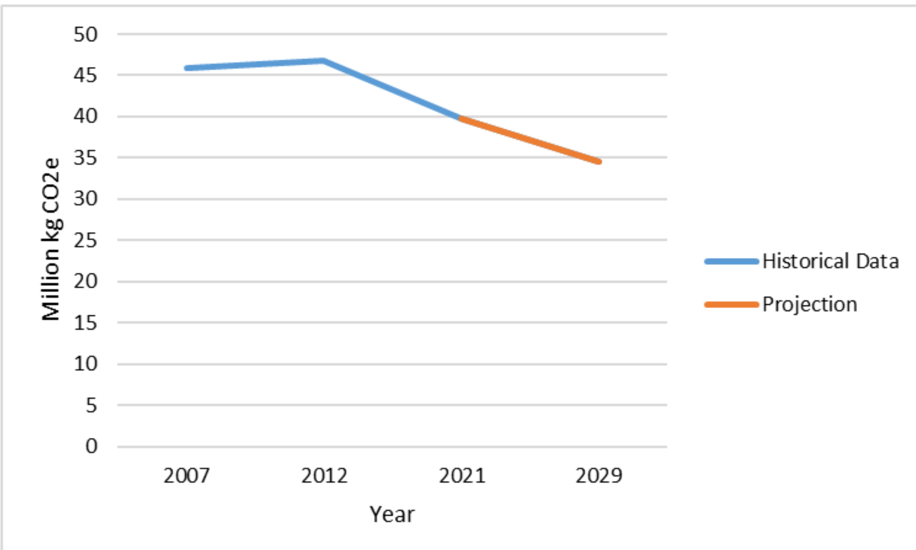

Figure 3: Projected embodied carbon emissions in 2019

Figure 4 shows the projected decrease in emission intensity per MWh of electricity generated in New York State through 2030.

Carbon Emission Accounting during the Construction of Typical 500 kV Power Transmissions and Substations Using the Carbon Emission Factor Approach., Liu et al., 2024. https://www.mdpi.com/2075-5309/14/1/145

[38] A 2015 Inventory of Embodied Carbon Emissions for Chinese Power Transmission Infrastructure Projects, Wei et al, 2020. https://www.nature.com/articles/s41597-020-00662-4

[39] US Environmentally-Extended Input-Output (USEEIO) Models, U.S. Environmental Protection Agency, October 2023. https://www.epa.gov/land-research/us-environmentally-extended-input-output-useeio-models

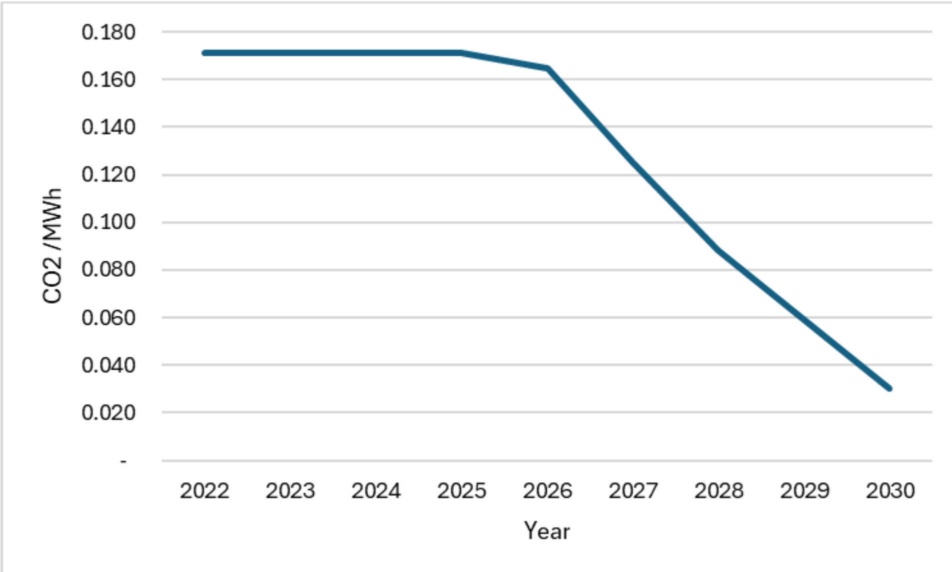

Figure 4: Annual Average of State-wide Full Fuel Cycle CO_2 Emissions Factors[40]

Table 11 shows the results of the Social Cost of Carbon (SCC) calculations for building the substation in 2021 versus 2029 across a spectrum of discount rates (1, 2, and 3%). A 2% discount rate should be considered the central scenario.[41]

Table 11: Social Cost of Carbon 1, 2, and 3% Discount Rates

Data	**2021**	**2029**
Greenhouse Gas Emissions (tons CO_2e)	39,812	34,538
Social Cost of Carbon Millions 2021$ (1.0% Discount Rate)	$22.09	$16.79
Social Cost of Carbon Millions 2021$ (2.0% Discount Rate)	$6.63	$5.32
Social Cost of Carbon Millions 2021$ (3.0% Discount Rate)	$2.79	$2.36

Using the raw data provided in Wei et al.[42], the evaluators used the U.S. EEIO[43] models for 2007 and 2012 to calculate the embodied human respiratory effects in $PM_{2.5}$ eq that would have been incurred if the substation had been built in 2007 or 2012 (Figure 5). Assuming the same downward trend in emissions persists to 2029, the emissions of building the substation in 2021

[40] Projected Emission Factors for New York State Grid Electricity, NYSERDA, August 2022. https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Publications/Energy-Analysis/22-18-Projected-Emission-Factors-for-New-York-Grid-Electricity.pdf. The evaluators selected the full fuel cycle emissions factors for CO_2.

[41] Establishing a Value of Carbon, New York State Department of Environmental Conservation, June 2021. https://extapps.dec.ny.gov/docs/administration_pdf/vocguidrev.pdf

[42] A 2015 Inventory of Embodied Carbon Emissions for Chinese Power Transmission Infrastructure Projects, Wei et al, 2020. https://www.nature.com/articles/s41597-020-00662-4

[43] US Environmentally-Extended Input-Output (USEEIO) Models, U.S. Environmental Protection Agency, October 2023. https://www.epa.gov/land-research/us-environmentally-extended-input-output-useeio-models

and 2029 can be calculated (Figure 6). Note that as both the 2021 and 2029 values are projected, the differential between them has high uncertainty, however, it is the best approximation given the data constraints.

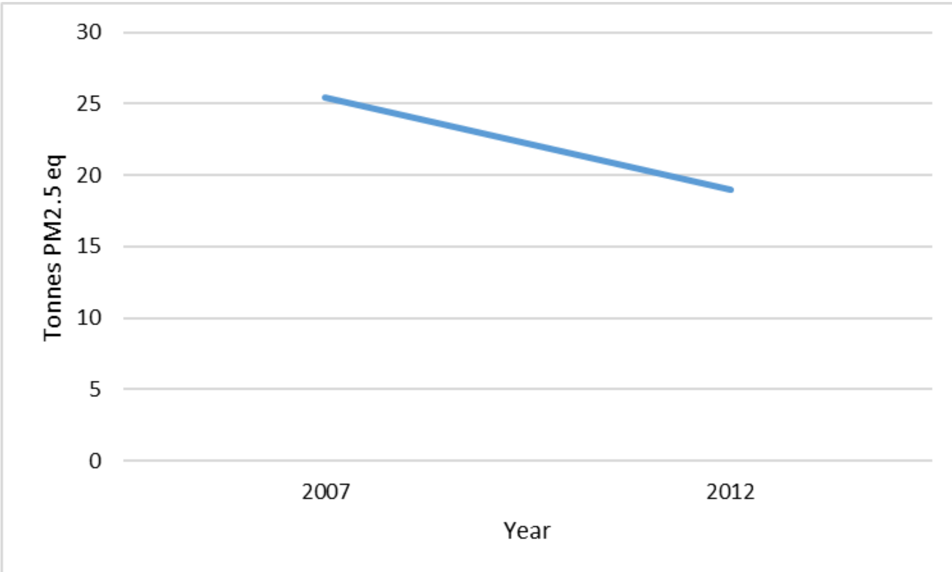

Figure 5: Average substation embodied human respiratory effects[44]

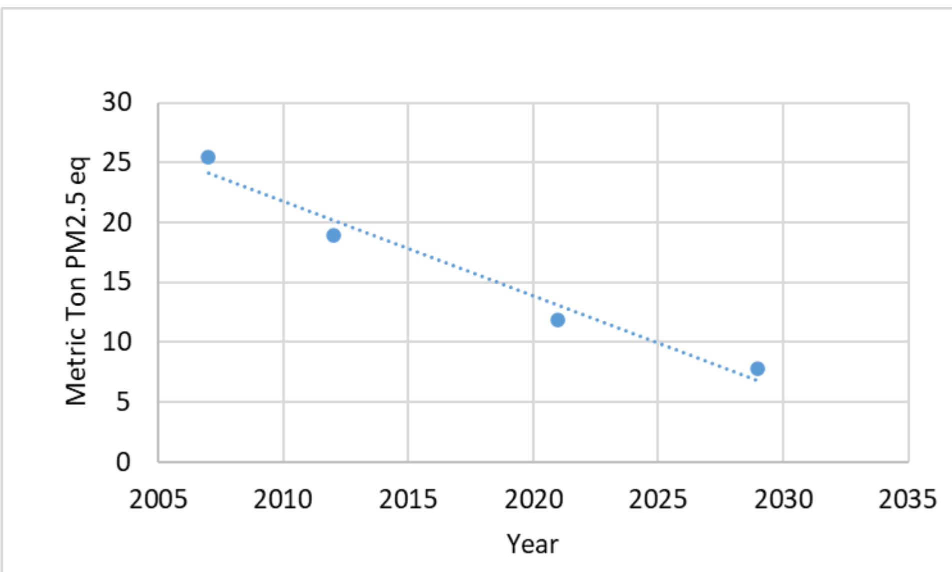

Figure 6: Projection of average substation embodied human respiratory effects

[44] US Environmentally-Extended Input-Output (USEEIO) Models, U.S. Environmental Protection Agency, October 023. https://www.epa.gov/land-research/us-environmentally-extended-input-output-useeio-models