Estimating the Economic Resiliency Benefits of Community Microgrids

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ABSTRACT

It is increasingly important that investments in energy infrastructure consider the ability of systems to withstand severe weather events. Microgrids are electric distribution systems that can operate when connected to the larger grid but can also disconnect from it and operate as an independent power system during an emergency so that they may supply electricity to the facilities they serve when the conventional grid is down. This paper describes a method designed to measure the regional economic benefits of a community microgrid in sustaining economic activity during an outage.

We conducted a pilot study of the method employing IMPLAN, a regional economic impact model, to quantify the economic activity that a microgrid would be able to sustain in the event of a regional power outage. The regional economic benefits of resiliency estimated in this pilot study represent avoided losses in market activity (i.e., monetary flows and jobs) across interrelated sectors of the regional economy. While the benefits of a microgrid project are highly dependent on the number and nature of businesses covered and the baseline risk of power outages, we find that by sustaining power during a one-day outage, the pilot study microgrid could mitigate or avoid losses of as much as $5 million in total sales. This method provides perspective on an important category of microgrid economic benefits and may be more broadly adapted to evaluate benefits of other types of electricity sector resilience efforts, for example projects that reduce the risk of outages from wildfires.

Introduction and Background

Power outages can have a variety of adverse social and economic consequences, including disruptions in business activity, transportation, communications, and access to critical services, as well as risks to human health and safety. As climate change increases the frequency and intensity of severe weather events, the risks of power outages and the associated threats to public safety and people's livelihoods likewise rise.

In recognition of the effects of outages on state residents, businesses, and communities, in January 2014, the New York State Governor's Office of Storm Recovery announced a $17 billion strategy designed to transform the state's infrastructure to enhance its ability to withstand severe weather events. An important element of the strategy is hardening the existing electrical grid and making additional investments in the development of a more resilient energy system. This included the launch of NY Prize, a $40 million competition to support the development of community microgrids throughout the state. Microgrids are electric distribution systems that can operate when connected to the larger grid but can also disconnect from it and operate as an independent power system during an emergency. This capability enables them to supply electricity to the facilities they serve when the conventional grid is down.

Industrial Economics, Inc. (IEc) worked with the New York State Energy Research and Development Authority (NYSERDA) to develop tools and methods to help evaluate the relative costs and benefits of candidate microgrid projects. This included developing a benefit-cost analysis tool that considers fixed and variable costs, energy generation and capacity cost savings, reliability improvements, power quality improvements, avoided environmental damages, and the benefits of maintaining service during extended power outages. In the benefit-cost analysis framework, the resiliency benefits are improvements in "social welfare," a measure of economic value that reflects the public's willingness-to-pay to avoid the power outage.

A 2017 report developed by researchers at Cornell University for the Electric Power Research Institute (EPRI) identifies several alternative methods for assessing resiliency benefits beyond the benefit-cost analysis framework. In particular, the report highlights that regional economic impact modeling may provide a useful, additional perspective on the benefits of resiliency (EPRI 2017). As opposed to measures of economic *value*, regional economic analysis quantifies economic *impacts*, which are measured in terms of changes in economic activity in a specified region (e.g., sales, income, or employment). This paper describes our pilot test of a method we developed for NYSERDA to evaluate the potential regional economic impacts of a microgrid in sustaining economic activity during an extended outage. These economic impacts may be considered alongside the social welfare effects of microgrid projects.

Setting and Scope

Our pilot study focuses on a proposed microgrid project that would serve the Village of Rockville Centre, New York, a 3.2 square mile community on Long Island, in Nassau County. This proposed microgrid is particularly suitable for demonstrating the regional economic benefits method because, beyond serving approximately 3,000 residential customers and critical service providers, it would serve a substantial number of commercial and industrial facilities. Specifically, the proposed microgrid would serve 16 medical facilities and 519 commercial facilities, such as supermarkets, retail stores, and gas stations. The combined 535 facilities support an estimated 8,000 employees and at least $1.2 billion in annual output. Thus, the potential for outages in this area to disrupt business activity is relatively high.

This study demonstrates how to structure an economic impact analysis of a community microgrid project and defines the assumptions required and uncertainties associated with this type of analysis. Our method relies on IMPLAN, a regional economic model commonly used by agencies and other stakeholders for policy planning and evaluation purposes.[1] We define example outage scenarios at the microgrid site for the purposes of demonstrating the data and assumptions required to quantify how the microgrid may avoid adverse effects on business activity. The analysis focuses on Nassau County, Long Island as the directly affected region (i.e., the area over which the microgrid directly affects businesses). We additionally consider how sustaining economic activity in Nassau County during an outage event affects interconnected economic sectors across the rest of New York State.

Regional Economic Analysis Framework

Commercial and industrial enterprises in a geographic region are interconnected in that they supply goods and services to each other, as well as to consumers. Consequently, changes in one economic sector tend to have a proportionally greater impact on the regional economy as a whole. This is commonly referred to as a “ripple effect” or a “multiplier effect.” Input-output (I/O) models provide a means of quantifying multiplier effects by capturing industry-to-industry market transactions, therefore allowing users to translate changes in productivity (e.g., output) in a given economic sector or sectors into changes in demand for goods and services across the broader regional economy. IMPLAN draws upon I/O data from several federal and state agencies, including the Bureau of Economic Analysis and the Bureau of Labor Statistics. These data describe the interrelationships between industry producers and consumers. The IMPLAN model combines these I/O data, which describe market monetary flows, with “social accounts” that describe non-market monetary flows, such as payments made between households, or between households and governments. The IMPLAN data describing both the market and non-market monetary flows in a regional economy are generally characterized as a Social Accounting Matrix.

[1] Originally developed by the U.S. Forest Service and Federal Emergency Management Agency, the IMPLAN model is now owned by IMPLAN, based in Huntersville, NC. Additional information is available at www.implan.com.

Regional economic impacts can be described as direct, indirect, or induced, depending on the nature of the change:

- **Direct effects** represent the known (or predicted) changes in economic output attributable to a specific initial change in supply or demand. In the case of a microgrid, for example, the initial change would be the preservation of electric service during an outage for the facilities the project would serve. The direct effects would be the amount of economic activity (e.g., gross revenue) that the microgrid would be able to sustain at these facilities.
- **Indirect effects** are changes in output in industries that supply goods and services to those that are directly affected by the initial change. For example, a microgrid that enabled a supermarket to remain open might create economic benefits for the produce, meat, dairy, grocery, and dry goods wholesale vendors who serve the store.
- **Induced effects** reflect changes in household spending arising from changes in income (which are the result of direct and indirect effects). For example, a microgrid that permits individuals to continue to work during an extended outage might affect those individuals' income, and thus their spending on goods and services in the surrounding community.

The sum of the direct, indirect, and induced effects is the total estimated regional economic impact. These impacts are reported in terms of changes in economic output, value added, labor income, and employment by sector within a specified region, as follows:

- **Output** represents the value of industry production (i.e., sales). Output is the sum of value added and "intermediate inputs," where intermediate inputs are the goods and services produced by one industry that will be incorporated into the production of another industry.
- **Value Added** is defined as the difference between an industry's or establishment's total output and the costs of its intermediate inputs. This measure is analogous in many ways to the measurement of gross domestic product (GDP) but at a regional level.
- **Labor Income** includes wages, worker benefits, and proprietor income. The impact of outages on this measure is a general indication of the effect of reduced economic activity on payments to the operators and employees of affected businesses.
- **Employment** refers to total annual average jobs. This includes self-employed and wage and salary employees, and all full-time, part-time, and seasonal jobs, based on a count of full-time/part-time averages over twelve months.

Based on this framework, our method evaluates how sustaining business activity during an outage may reduce or avoid losses in output, value added, labor income, and employment not only for the local businesses served by the microgrid (direct effects), but more broadly by interconnected businesses in the region and across the state (indirect and induced effects).

Methodology

Our approach to modeling the resiliency benefits of the proposed Village of Rockville Centre microgrid involves gathering and processing economic data to characterize the facilities that would be served by the microgrid, conducting economic impact modeling in IMPLAN, developing outage scenarios, and modeling the economic impacts associated with these outage scenarios.

Characterizing the Affected Facilities

The inputs to the IMPLAN model are changes in annual output for each affected industry sector. The changes in annual output in this case are the avoided losses in sales during the period that the microgrid would enable businesses to continue operating when the conventional grid is down. Accordingly, the initial data required for the analysis are the nature of the 535 facilities affected (i.e., the relevant industry sector) and the output of the facilities served by the proposed microgrid. Ideally, the analysis would be based on facility-specific data and reflect the fraction of annual revenues that would have been generated during the outage period. In this case, however, we did not have this level of detailed information characterizing the affected facilities. We therefore apply a “scaled representation” approach of the region covered by the proposed microgrid. This requires assumptions about the type and annual output of each facility based on county-level data available from IMPLAN and the U.S. Census Bureau’s County Business Patterns. Specifically, the approach assumes that the distribution of commercial activity in Nassau County is representative of the commercial activity for the facilities served by the proposed microgrid.

We assign the commercial facilities in Rockville Centre that would be served by the proposed microgrid with North American Industry Classification System (NAICS) codes defining the relevant economic sector based on the county-level distribution of commercial businesses. We then crosswalk the NAICS codes with relevant IMPLAN sector codes. IMPLAN data for Nassau County provide information on total annual output and employment for these economic sectors. We use this information, combined with the data regarding the numbers of businesses in each sector in the County, to calculate the average annual revenues for each facility and sector served by the microgrid.

Modeling A Scalable One-Day Outage Scenario

We first modeled a one-day outage “shock” that would cause a complete shutdown of all of the facilities (i.e., a 100 percent loss of economic activity for one day) that would be covered by the microgrid. The direct effect of the one-day outage is the reduction in annual output associated with the business interruptions. This “simple case” analysis quantifies the direct effects (i.e., the inputs to the IMPLAN model) of the microgrid project assuming the following:

- Economic activity is evenly distributed throughout the year, so that the change in annual output for each affected industry sector is, on average, 1/365th of the estimated annual output for that sector.
- Without the microgrid, 100 percent of facilities served by the microgrid would lose power for the day. Further, these facilities would lose 100 percent of economic activity for the day and would not be able to make up for this lost economic activity after the outage.
- With the microgrid, all facilities would maintain full service and would continue operations.

The direct effects of the one-day outage are the inputs to the model using IMPLAN Pro software. We defined the primary region as Nassau County and considered the effects on interconnected businesses outside of the county across the rest of New York State in a multi-regional modeling framework. Table 1 summarizes the regional economic benefits of the proposed microgrid in terms of avoided losses of economic activity in Nassau County. The results suggest that for the specified one-day outage scenario, the microgrid could preserve total value added of more than $3.1 million and economic output of over $5.0 million in Nassau County.

Table 1. Regional economic benefit of microgrid in Nassau County, one-day outage scenario

Impact Type	Employment (Job-Years)	Labor Income ($)	Total Value Added ($)	Output ($)
Direct Effect	18.5	$1,016,028	$1,801,497	$2,878,631
Indirect Effect	7.0	$416,186	$704,062	$1,188,481
Induced Effect	6.6	$354,718	$618,039	$965,535
Total Effect	32.1	$1,786,932	$3,123,597	$5,032,647

It is likely that the benefits would extend beyond Nassau County to surrounding areas in New York State. Table 2 captures these leakage impacts for the simplified, one-day outage scenario. The results suggest that the microgrid could sustain total value added of more than $170,000 and economic output of over $290,000 in the rest of New York State.

Table 2. Regional economic benefit of microgrid in the rest of New York State, one-day outage scenario

Impact Type	Employment (Job-Years)	Labor Income ($)	Total Value Added ($)	Output ($)
Direct Effect	0.0	$0	$0	$0
Indirect Effect	0.7	$66,929	$115,424	$198,470
Induced Effect	0.5	$32,837	$56,923	$94,020
Total Effect	1.2	$99,766	$172,348	$292,490

As the IMPLAN model describes linear relationships across economic sectors, these results may be scaled to evaluate different outage duration scenarios. The outage scenarios may also integrate information or assumptions regarding the extent to which businesses may be able to continue operating during an outage (e.g., by relying on emergency generators) or otherwise mitigate losses.

Developing Outage Scenarios

We defined outage scenarios for the proposed microgrid, coordinating with the Village of Rockville Centre's Electric Department. The Electric Department provided information about historical storms and other extended outages in the area, including outage durations, geographic scope, system recovery, and the frictional period needed to get fully up and running after an outage. Ultimately, the department recommended modeling outages lasting three, five, and seven days as the likely impacts of a major storm.

We estimate the economic impacts of outages lasting three, five, and seven days, all with the simplified assumption of a 100 percent loss of economic activity in the absence of the proposed microgrid. For each scenario, we linearly scale the results of the one-day outage to match the scenario's weighted average economic activity loss (measured in days). For each of these scenarios, Table 3 summarizes the total regional economic impacts (direct, indirect, and induced effects) within Nassau County, while Table 4 displays the "leakage" impacts for the rest of New York State. In Nassau County, we find that the proposed microgrid could preserve $9.4 million for the three-day scenario to $22 million for the seven-day scenario in total value added, and $15 million for the three-day scenario to $35 million for the seven-day scenario in total economic output. For the leakage impacts to the rest of New York State, the microgrid could sustain total value added ranging from $0.5 million for the three-day scenario to $1.2 million for the seven-day scenario, and total economic output ranging from $0.9 million for the three-day scenario to $2.0 million for the seven-day scenario.

Table 3. Regional economic benefit of microgrid in Nassau County: three-, five-, and seven-day outage scenarios

Outage Scenario	Employment (Job-Years)	Labor Income ($)	Total Value Added ($)	Output ($)
Three-Day Outage	96.3	$5,360,796	$9,370,791	$15,097,941
Five-Day Outage	160.5	$8,934,660	$15,617,985	$25,163,235
Seven-Day Outage	224.7	$12,508,524	$21,865,179	$35,228,529

Table 4. Regional economic benefit of microgrid in Rest of New York State: three-, five-, and seven-day outage scenarios

Outage Scenario	Employment (Job-Years)	Labor Income ($)	Total Value Added ($)	Output ($)
Three-Day Outage	3.6	$299,298	$517,044	$877,470
Five-Day Outage	6.0	$498,830	$861,740	$1,462,450
Seven-Day Outage	8.4	$698,362	$1,206,436	$2,047,430

It is most likely not always the case that an outage results in a total loss in economic activity for the full duration of the outage. A common issue highlighted in the power outage economics literature is whether and how to incorporate the resiliency of an economy to an outage. The definition of resiliency put forth by Sanstad (2016) is, "the capacity of consumers, firms, and markets to temporarily adjust, adapt, or otherwise compensate for the loss of electricity in ways that mitigate economic impacts." A few studies attempt to account for resiliency, reducing the extent to which an outage resulted in economic activity losses (see, for example: Kunz et al. 2013; Rose, Oladosu, and Liao, 2007; Rose, Oladosu, and Salvino, 2005; and Rose et al. 1997). Some of these studies estimate resiliency based on surveys of businesses to determine how a 100 percent loss in power affected business operations during an outage (see, for example: Burrus et al. 2002 and Rose et al. 1997). Other studies either do not incorporate a resiliency factor or test hypothetical assumptions for resiliency, noting that the lack of information to inform an assumption is a limitation of the study (see Greenberg, Lahr, and Mantell 2007).

The literature generally finds that resilience of an economy to an outage event is not only site-specific, but also industry-specific, event-specific, and potentially even business-specific. These studies did not identify common assumptions for factoring resiliency into a regional economic analysis of power outages. Based on these literature review findings, we developed our method to allow for analyst-specified assumptions for resiliency of the economy as a whole, if that information should be available. However, even absent a data-driven assumption for resiliency, the method allows users to compare relative impacts of specified outage scenarios across candidate sites. Specifically, we incorporate scaling factors into our method to account for other variables, such as phased-in recovery of power across the system, the economy's ability to maintain some level of economic activity without power, and the economy's ability to make up for lost economic activity following an outage event. The following scaling factors move beyond the "simplified" assumption of 100 percent loss of economic activity for the entire duration of an outage:

- **Recovery Factor:** This reflects the percent of all businesses whose power has been restored during the period of interest.
- **Resiliency Factor:** This reflects the percent of normal economic activity maintained by businesses without power or, alternatively, the percent of lost economic activity that businesses without power can recover following the outage event.

Based on these factors, we calculate an “overall economic activity level” during the period of interest, using the following equation:

$$\textbf{Overall Economic Activity Level} = \textbf{\%Recovery} + [\textbf{\%Resiliency} * (\textbf{100\%} - \textbf{\%Recovery})]$$

Figure 1 represents the overall economic activity level for a given outage period based on the combined effects of the recovery factor and resiliency factor for that outage period.

		Resiliency Factor										
		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Recovery Factor	0%	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
	10%	10%	19%	28%	37%	46%	55%	64%	73%	82%	91%	100%
	20%	20%	28%	36%	44%	52%	60%	68%	76%	84%	92%	100%
	30%	30%	37%	44%	51%	58%	65%	72%	79%	86%	93%	100%
	40%	40%	46%	52%	58%	64%	70%	76%	82%	88%	94%	100%
	50%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
	60%	60%	64%	68%	72%	76%	80%	84%	88%	92%	96%	100%
	70%	70%	73%	76%	79%	82%	85%	88%	91%	94%	97%	100%
	80%	80%	82%	84%	86%	88%	90%	92%	94%	96%	98%	100%
	90%	90%	91%	92%	93%	94%	95%	96%	97%	98%	99%	100%
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure 1. Combined effects of Recovery Factor and Resiliency Factor on overall economic activity level during an outage

Based on the duration and overall economic activity level (“EAL”) for each outage period, we calculate a weighted average economic activity loss, measured in days, for the overall outage as follows:

$$\textbf{Weighted Average Economic Activity Loss} = \sum_{k=0}^{n}[\boldsymbol{Duration} * (\mathbf{100}\% - \%\boldsymbol{EAL})]$$

This method additionally allows for varying the Recovery and Resiliency Factors over time during the outage period. For example, Table 5 demonstrates how a seven-day outage scenario may divide the duration of the outage into discrete time periods characterized by differing levels of recovery (percent of business with power restored) and resilience (percent of normal activity sustained or reclaimed). For this hypothetical seven-day outage, the first outage period, which lasts three days, has no economic activity (a 100 percent loss). In the second outage period, which lasts for days four and five, the region regains 50 percent of its economic activity. In the final outage period, which lasts days six and seven, the region is operating at 63 percent of its baseline economic activity level. For the entire seven-day outage, the weighted average economic activity loss is equivalent to a total loss of 4.75 days of economic activity.

Table 5. Estimating weighted average economic activity loss (days) for a seven-day outage scenario

Outage Period	Outage Duration (Days)	Recovery Factor	Resiliency Factor	% Overall Economic Activity Level
#1	3	0%	0%	0%
#2	2	50%	0%	50%
#3	2	50%	25%	63%
Total	7	-	-	-
Weighted Average Economic Activity Loss (Days)				*4.75*

This weighted average economic activity loss during the seven-day outage is then used to scale the "simple case" one-day outage scenario results to quantify the regional economic impacts of the specified seven-day outage scenario. Using the scaling factors can provide more representative and nuanced estimates of the economic impacts of the microgrid. For example, without the scaling factors, the "simple" seven-day outage assuming a full loss of economic activity would result in a total value added loss of $22 million and lost economic output of $35 million in Nassau County. In contrast, the seven-day outage scenario described in Table 5, which incorporates scaling factors for the percent of businesses that regain power during the outage and the percent of businesses without power that maintain economic activity, finds that a seven-day outage could instead result in a total value added loss of $15 million and lost economic output of $24 million.

Conclusions and Discussion

This pilot study demonstrates a method for evaluating the regional economic impacts of a proposed microgrid in the Village of Rockville Centre, New York. We find that economic activity within the area that would be served by the microgrid is high. On an average day, the facilities the microgrid would serve account for an estimated $5.0 million in output, $3.1 million in value added, and $1.8 million in labor income in Nassau County. Successful operation of the microgrid in the event of a major outage would help to avoid the loss of some, if not all, of this economic activity.

The method requires effort to build a model reflective of the regional economy at a specific microgrid site. Because regional economic impact analysis is designed to capture market transactions, it is best suited to evaluating microgrids that would serve a relatively large number of commercial and industrial enterprises (as opposed to residences and critical service providers). At a basic level, the regional economic analysis of community microgrid projects requires information on the nature of the businesses (commercial and industrial) and institutions covered. Ideally, this would include numbers and sizes (in terms of average annual sales) of businesses by economic sector (NAICS code). Absent this information, we employed a scaled representation approach for the pilot study, assuming representation of economic sectors proportional to the broader county-level mix for Nassau County. More information on the businesses covered by the grid, however, would improve the precision of the results and reduce the level of effort require to develop the direct impacts to input into IMPLAN.

In addition to requiring information on the nature and size of businesses covered by the grid, our approach relies on a proportionality of losses assumption, effectively assuming economic activity is distributed evenly over the course of a year in order to determine the direct impact of a one-day outage. While even distribution of economic activity over time is often not the case, this is the most practical assumption given uncertainty regarding how economic activity is distributed across a full year, as well as when a hypothetical outage may occur.

Finally, the resiliency and recovery factor assumptions employed to model outage scenarios represent a key uncertainty. While our method incorporates sufficient flexibility to analyze the sensitivity of results to different assumptions, real data to inform the assumptions for these factors are limited. Nevertheless, the results, even as a simple demonstration assuming a 100 percent loss in economic activity for a one-day outage, provide useful insight into the relative regional economic benefits of potential microgrid projects.

Acknowledgements

The authors wish to acknowledge NYSERDA for sponsoring this study. In particular, the guidance of NYSERDA's Program Manager, Mike Razanousky, is greatly appreciated. We also would like to acknowledge the contributions of Rockville Centre's NY Prize team in helping to shape our analysis, and in particular to thank Philip Andreas of the Rockville Centre Electric Department, Arthur Castelli of RRT SIGMA Engineering, and Patrick Venable of the New York Independent System Operator (NYISO) for their insights in supporting development of outage scenarios for the Rockville Centre study. The authors additionally appreciate the opportunity to present this research to the International Energy Program Evaluation Conference and the helpful review provided by Paula Gruendling at the California Public Utilities Commission.

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