Energy Markets & Policy
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Power Outage Economics Tool

A Prototype for the Commonwealth Edison Service Territory

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May 2024

The work described in this study was supported by the Commonwealth Edison Company under Lawrence Berkeley National Laboratory Contract Award No. AWD00004769.

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Prepared for the Commonwealth Edison Company

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The authors would like to first and foremost thank Susanna Aguilar from Commonwealth Edison. Susanna provided significant assistance throughout the project including facilitating critical interactions between Berkeley Lab, Resource Innovations, and Commonwealth Edison. In addition, Susanna provided important guidance throughout every step of the project. Simply put, this project would not have been successful without Susanna's ongoing commitment, persistence, and encouragement. We would also like to acknowledge at least one anonymous reviewer at Commonwealth Edison for providing constructive feedback on the report.

We would also like to thank Kristina LaCommare (Berkeley Lab) for her assistance with the ongoing management of this challenging project. Joe Eto, also from Berkeley Lab, provided constructive feedback throughout the project and served as an internal, expert reviewer of the final report. Dana Robson (Berkeley Lab) assisted with final formatting and addressed grammatical issues. Michael Sullivan, from Resource Innovations, provided advice throughout the project, helping design the survey instruments, sample design, and survey administration. We would also like to thank the staff at MDC Research who conducted in-depth interviews with non-residential customers.

All remaining errors and omissions are the responsibility of the authors. The findings presented and the opinions expressed throughout this document are the authors and do not represent the positions of Lawrence Berkeley National Laboratory, the University of California, the U.S. Department of Energy, or our research partner organizations.

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Synopsis

Estimates of the economic impact of widespread, long duration (WLD) power interruptions can be used to prioritize and justify significant investments in power system resilience. This report presents estimates of this type for WLDs originating within the Commonwealth Edison (ComEd) service territory. The intended audience for this research includes utility executives and technical staff, regulators, and government agencies.

This project involved surveying ComEd customers to understand how they might respond when confronted with a WLD power interruption. The research team used the survey responses to calibrate a state-of-the-art regional economic model ("POET") to estimate economic impacts to households and 38 industry sectors across 17 impacted micro-regions (individual counties or aggregations of counties) within ComEd's service territory and beyond. We ran one-day, three-day, and 14-day interruption duration scenarios each with varying geographic extents as well as estimated the benefits of deploying additional backup generation across the service territory. The results were then compared to a "business as usual" scenario assuming that no interruption occurred. There are six key findings from this analysis:

- There may be significant losses to gross output (business revenue), gross domestic product, and household consumption during WLD interruptions, especially multi-day interruptions that occur across all of ComEd, Cook county, or the suburbs of Chicago.
- The wholesale trade and transportation sectors appear to be highly sensitive to power interruptions—losses to these sectors are large relative to the losses observed across the entire economy.
- Several sector-region combinations—e.g., the transportation sector in Cook county—are very sensitive to interruptions.
- High-income households experience proportionately larger losses to consumption during a one-day power interruption, but low-income households experience proportionately larger losses during the longest power interruptions.
- Increasing the amount of backup generation deployed across ComEd's service territory provides significant *net* benefits to system-wide gross domestic product, gross output, and household consumption relative to the existing amount of backup generation already being used.
- Some micro-regions (e.g., Dekalb and Kendall counties), sectors (e.g., wholesale trade, transportation), and low-income households in Cook county may especially benefit from targeted resilience interventions.

We recommend that decision-makers consider running cost-benefit analyses using each of the economic metrics presented in this report independent of one another to evaluate the robustness of the insights that each of these estimates may provide. In addition to this report, we developed a tool that will allow ComEd staff and other decision-makers to visualize the full suite of results using an easy-to-interpret, user interface. We hope that the findings from this research effort will provide valuable insights to ComEd, policymakers across Illinois, and other stakeholders who have an interest in the resilience of the power system.

Executive Summary

Background

In 2020, Commonwealth Edison (ComEd) contacted Berkeley Lab to learn more about research being undertaken to put an economic value on resilience. Subsequently, Berkeley Lab and ComEd developed a research partnership that will ultimately allow ComEd to "evaluate the impacts of hypothetical power interruption scenarios on all customer classes and consider them in potential resilience investments" (Aguilar et al. 2021).

This project involves implementing a state-of-the art hybrid resilience valuation approach that combines: (1) techniques to elicit the direct interruption costs of non-residential customers; (2) advanced survey-based methods to identify mitigating/adaptive behaviors that residential, commercial, and industrial customers may take to reduce risk before, during, or after a power interruption occurs; and (3) a regional economic model that has been calibrated to assess the full range of economic impacts from power interruptions occurring across the ComEd service territory and beyond. The project produced estimates of the regional economic impacts of power interruptions of various geographic extents and durations, and information presented to the utility and other stakeholders in a way that is both accessible and easy to interpret.

Method

Customer interruption cost (CIC) surveys have been the most widely used method to estimate direct power interruption costs by utilities, regulators, and academic researchers. Standard CIC studies are useful for assessing the costs of short, localized power interruptions, but may not always be appropriate for estimating the impacts of widespread, long duration power interruptions. The main reason for this includes the difficulties that respondents have in imagining the direct impacts of widespread, long duration (WLD) power interruptions that they have never experienced, especially the impacts across regional economies. Thus, these survey-based estimates are often not applicable for estimating customer costs of power interruptions that last days or longer and affect entire utility service territories, and possibly multiple utilities and multi-state regions.

Another methodology for quantifying power interruption costs is regional economic modeling, which provides estimates on the scale of local or regional economies. Regional economic models are capable of analyzing WLD interruptions, particularly their indirect or "spillover" effects, which result from market interactions. That is, firms or sectors experiencing a power loss may temporarily both stop purchasing inputs from other firms and selling outputs to their customers, resulting in economic impacts above and beyond direct costs. However, these models contain large numbers of parameters describing customer behavior that have not been well-grounded empirically (Beckman et al., 2011; Koesler and Schymura, 2015; Sanstad et al., 2023). This problem, as well as the limitations of CIC surveys, has led to the development of a "hybrid" approach to interruption cost estimation that combines the strengths of the two methodologies while addressing their limitations (Baik et al. 2021). In brief, the hybrid approach entails using CIC surveys to collect region- and sector-specific data needed to assign numerical values to model parameters for both effects of outages and resilience options, or tactics, to cope with them (Rose et al. 2007). Thus, a hybridized regional economic model has the capability to analyze WLD interruption costs on a much firmer empirical grounding than has previously been achieved, thus improving WLD power interruption direct and indirect cost estimation. Figure E.1, below, depicts the difference between past approaches to estimate the economic impacts of power interruption and the hybrid approach used in this study.

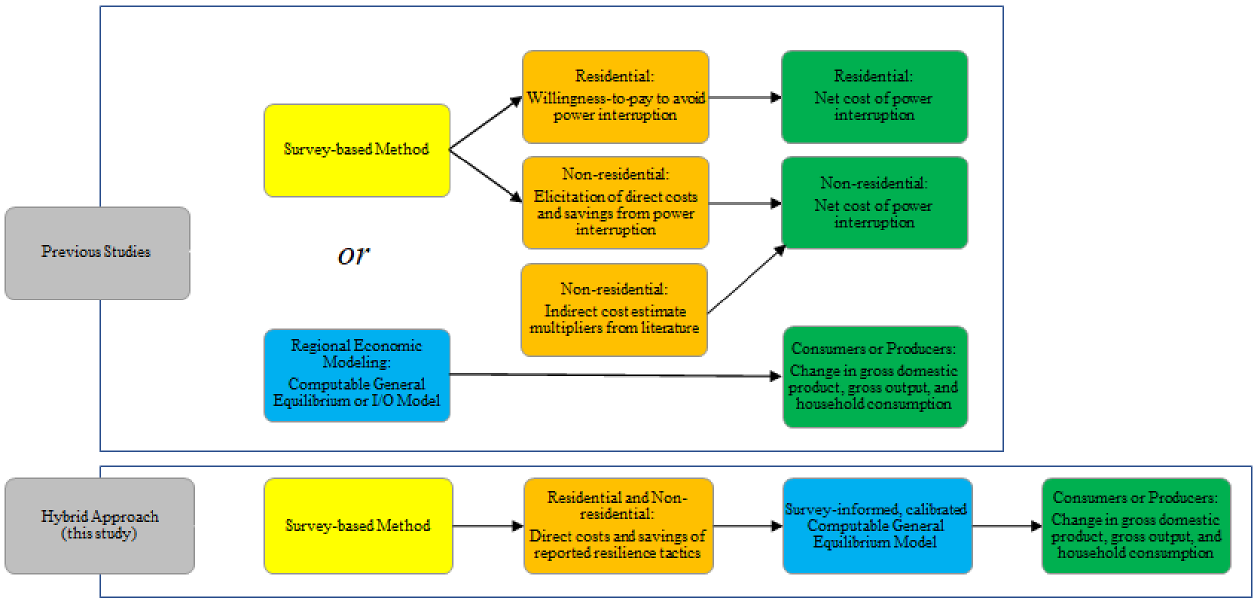


Figure ES - 1. Steps to estimate economic impacts of power interruptions: previous studies versus the hybrid approach used in this study

Samples of ComEd customers were presented with hypothetical scenarios of long-duration interruptions scenarios lasting 24 hours, three days, and two weeks, respectively. Approximately half of the customers were questioned about interruptions occurring in the summer and the other half about interruptions occurring in the winter. The interruptions were described as a complete loss of power affecting all homes and businesses within a 20-mile radius of the respondent's location. Figure ES - 1 presents the information we collected from surveys of ComEd customers to assist in the calibration of the economic model. Furthermore, these surveys of ComEd's customers allowed the research team to obtain other important insights about customers not previously known (e.g., share of customers with backup generation).

Table ES - 1. Types of costs incurred and savings realized during power interruptions by customer segments

Cost category	Residential	Non-residential
Direct	**Costs to respondents without backup generators** ● Spoilage of food **Costs to respondents regardless of backup generator operations** ● Income losses (after accounting for the household members' ability to make up for lost income)	**Costs to respondents without backup generators** ● Damage/spoilage to raw or intermediate materials **Costs to respondents regardless of backup generator operations** ● Lost revenue (after accounting for its ability to make up for lost production) Savings regardless of backup generator operations ● Savings in electricity bill due to the reduced electricity consumption
Additional	**Costs to respondents without backup generators** ● Costs of meals, delivery, lodging, and transportation **Costs to respondents with backup generators** ● Fuel costs to run backup generator	**Costs to respondents without backup generators** ● Additional costs of additional safety and security ● Costs to transfer business or other activities to other locations with power **Costs to respondents regardless of backup generator operations** ● Labor costs to make up lost production ● Additional costs to restore operation **Costs to respondents with backup generators** ● Fuel/backup generator rental costs **Savings regardless of backup generator operations** ● Savings in labor costs during power interruptions

Key findings from customer surveys

Most large commercial and industrial customers have backup generation capabilities

A key question in both the residential and non-residential surveys was whether customers had access to a backup generator. Figure ES - 2 shows the percentage of respondents who indicated they have some form of backup generation. Approximately 12% of residential respondents, 22% of small/medium business (SMB), and 71% of large commercial and industrial (LCI) respondents have backup generation.

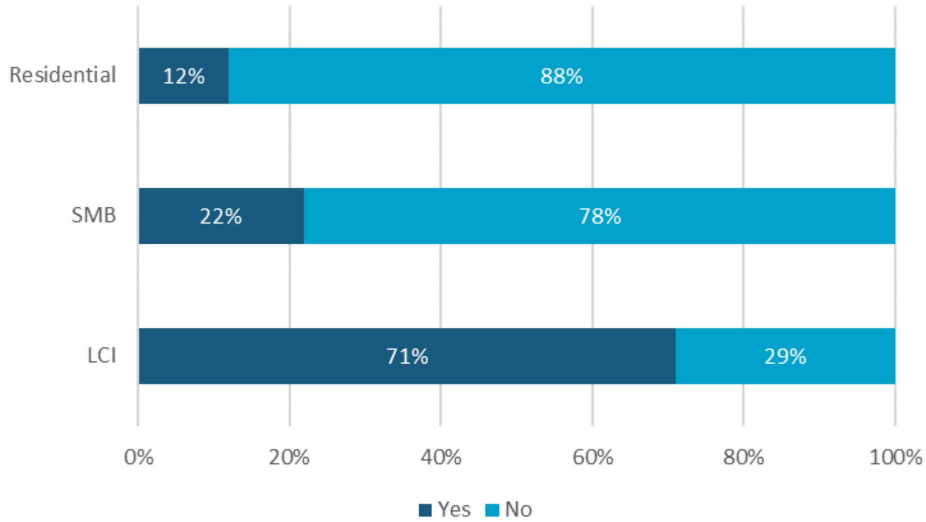


Figure ES - 2. Percentage of customers with backup generation

The vast majority of residential customers plan to temporarily relocate during 14-day interruption

Figure ES - 3 shows the percentage of residential respondents' resilience tactics by the length of power interruption. During a one-day interruption, 54% of respondents indicated they would stay home and participate in activities that do not require electricity, while 33% of respondents said they would temporarily move. However, when respondents were presented with the 14-day interruption, only 8% stated they would stay home, and 83% said they would temporarily move.

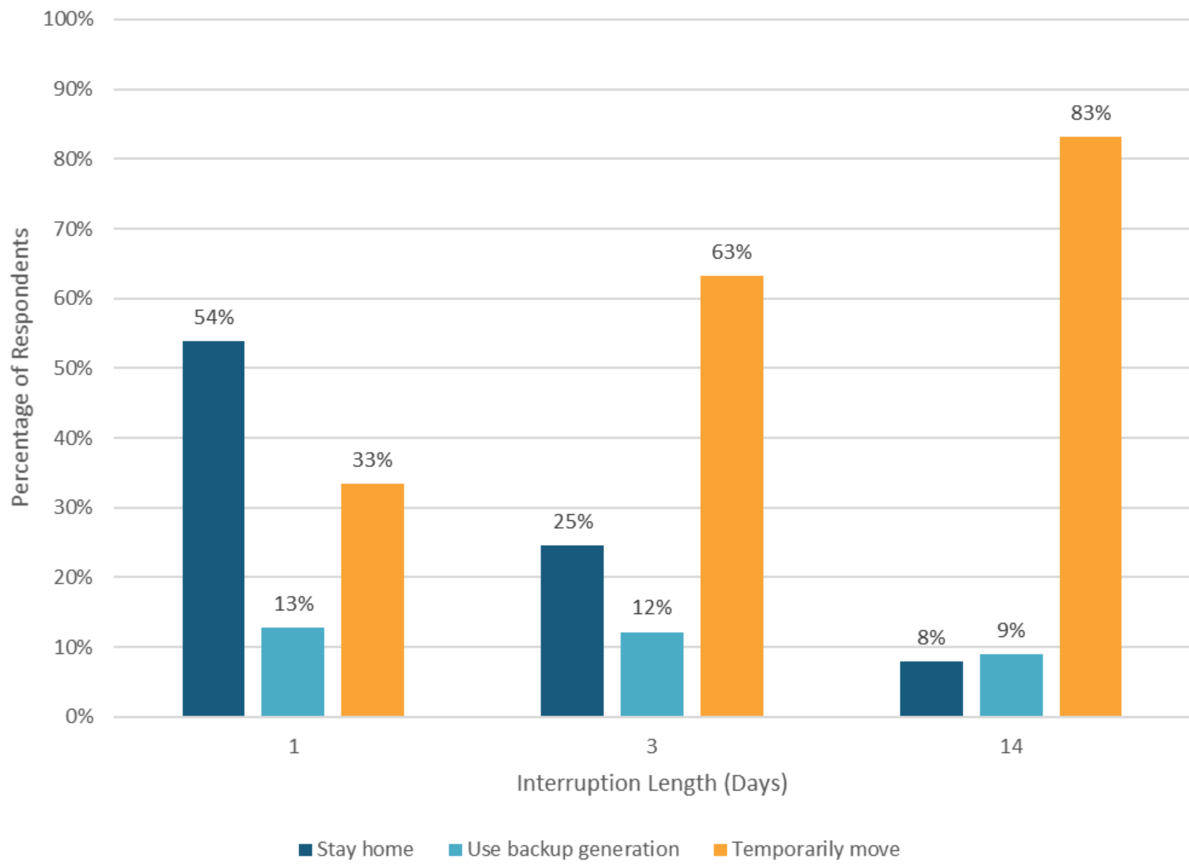


Figure ES - 3. Residential resilience tactics by interruption duration

The percentage of non-residential customers shutting down facilities decreases as interruption duration increases

SMB and LCI respondents selected one of four different resilience tactics for each interruption duration. Figure ES - 4 and Figure ES - 5 show the percentage of SMB and LCI respondents that picked each tactic by interruption duration, respectively. The most common tactic selected by SMB respondents for each interruption duration was to temporarily shut down the facility. However, when presented with an outage scenario of one day versus 14-days, the percentage of respondents who selected to shut down their facilities fell from 49% to 39%. In turn, some respondents shifted their tactic to renting backup generation or transferring operations to another facility based on the outage length. These two resilience tactics allow a business to continue functioning, although the level of production may be lower than normal. The percentage of respondents who would use backup generation already onsite stays constant regardless of the interruption duration.

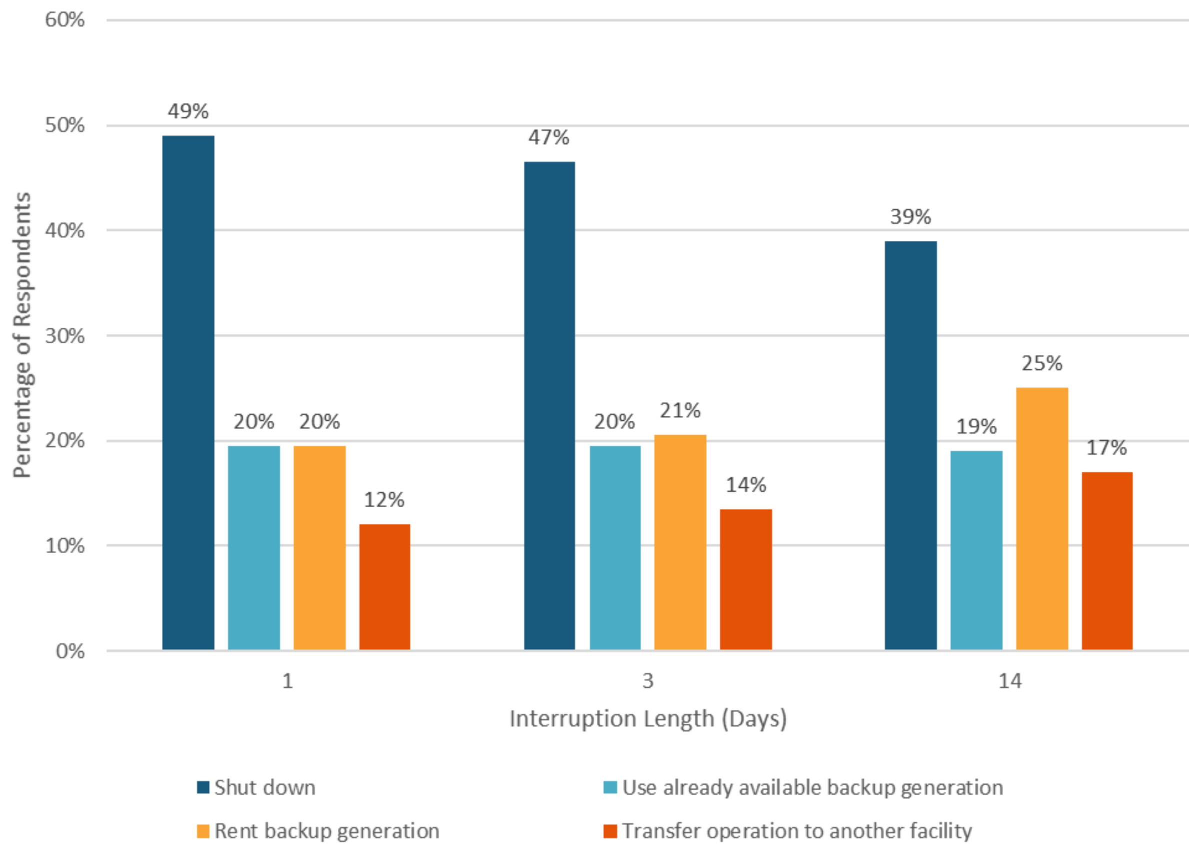


Figure ES - 4. SMB resilience tactic by interruption duration

The resilience tactics selected by LCI respondents show a similar pattern to SMB respondents. Namely, shutting down the facility is the most common tactic, but respondents select it less frequently when presented with longer durations. The percentage of respondents who indicated they would shut down the facility drops from 54% for a one-day interruption to 31% for a 14-day interruption. While the percentage of respondents who rent backup generation increases from 10% for a one-day interruption to 26% for a 14-day interruption. Interestingly, there are a handful of respondents who indicated that they would transfer operations for a three-day interruption, but rent backup generation for a 14-day interruption. This counterintuitive finding may warrant further exploration in a future study to determine whether it is a sampling issue or an actual observed behavior. As shown in the figure below, the percentage of respondents who indicated they would transfer operations falls from 16% for a three-day interruption to 11% for a 14-day interruption.

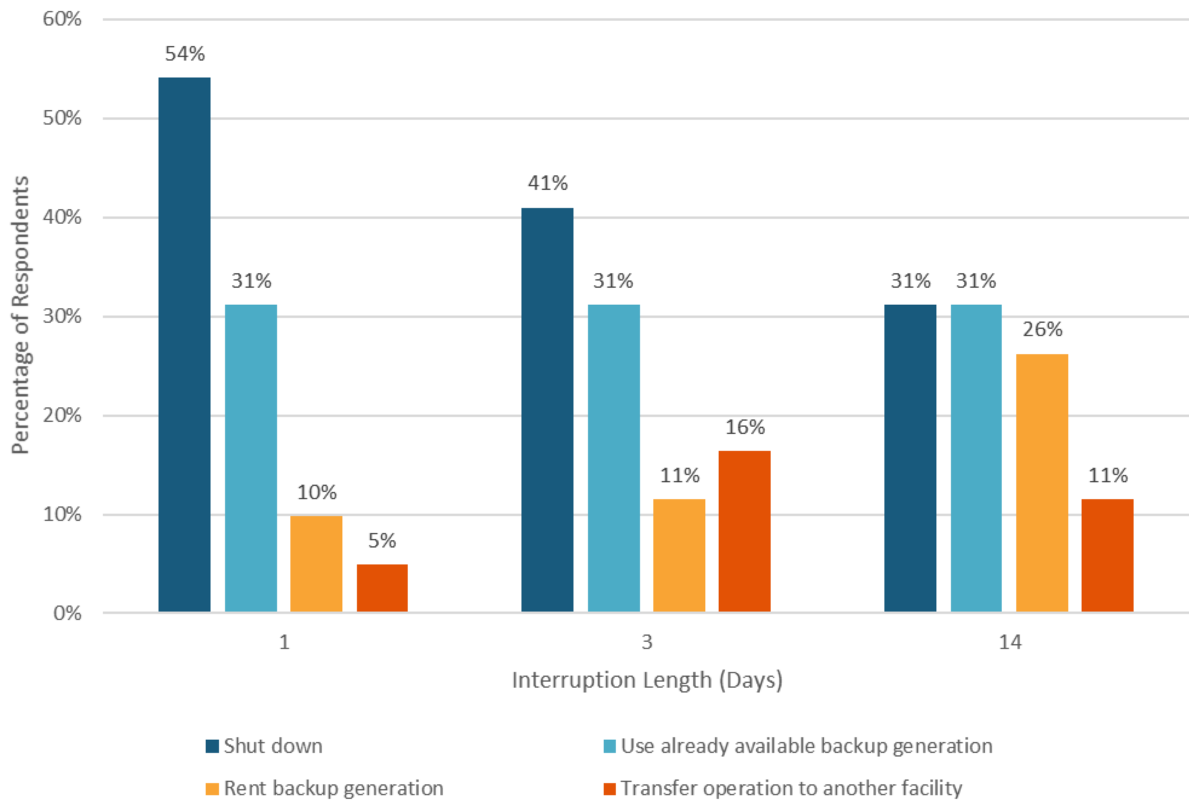


Figure ES - 5. LCI resilience tactic by interruption duration

Key findings from POET model

We report economic impacts using a series of metrics including: changes to gross output (i.e., industry revenue), gross domestic product (or industry value-added), and household consumption (see Table ES - 2, below) and relative to a "business as usual"[1] (i.e., no interruption scenario).

Table ES - 2. Key economic impact metrics produced in this analysis[2]

Category	Description of economic impact metric	Interpretation
Gross output	% change and dollars of gross output by industry sector, geographic extent of interruption, impacted region, and interruption duration	% and dollar change in business revenue relative to business as usual

[1] Business as usual represents the total economic activity that would occur over a three-month period for each of the counties and sets-of-counties that we list in Table 5-1 *had the power interruption(s) never occurred.*

[2] The POET model also produces a number of other metrics which are not reported in this manuscript, including industry sector-level "value-added". Value-added is expressed in both % and dollar change and is equivalent to sector-level gross output minus the costs of intermediate inputs. Value-added is reported via the POET visualization tool, but not in this report.

Category	Description of economic impact metric	Interpretation
Gross (regional) domestic product	% and dollar change in gross domestic product by geographic extent of interruption, impacted region, and interruption duration	% and dollar change of the total value of final goods and services generated by the economy relative to business as usual
Change in household consumption	% and dollar change in equivalent variation by geographic extent of power disruption, impacted region, nine household income categories, and interruption duration	Average lost consumption attributed to power disruption (alternatively, this is the amount of a subsidy to households to make them indifferent to the power disruption) relative to business as usual

These and other economic model results are presented in a number of different ways including by:

1. duration of the interruption (one, three, and 14-days)
2. geographic extent of the power interruption (ten micro-regions including all of ComEd's service territory)
3. impacted micro-region (17 micro-regions spanning all of Illinois, Wisconsin, and Indiana)
4. 38 industrial sectors
5. three aggregate, population-weighted household income groupings
6. higher-than-existing penetration levels of backup generation

We feature a selected number of key findings in the discussion that follows. The results presented throughout this section reflect the changes that may occur following a three-month period for the economy to return to equilibrium after a power disruption of one, three, or 14-days.

Service territory-wide losses to gross output (i.e. business revenue) and GDP are expected if all of ComEd, Cook, Dupage, Lake, Will, or rural portions of ComEd are without power

Figure ES - 6 shows that a scenario in which the entire service territory is without power ("All of ComEd") would lead to $2.7 (or -0.9% relative to business as usual), $4.2 (-1.3%), and $8.5 billion (-2.7%) in output losses for the one day, three day, and 14-day interruptions, respectively. However, if only Grundy and Kankakee, Dekalb and Kendall, McHenry, or Kane counties are without power, then businesses across the service territory may observe increased revenue.[3]

[3] This increase in revenue across the service territory is possibly due to the fact that (1) neighboring micro-regions step in to provide the goods and services that, for example Grundy and Kankakee would have provided; and (2) there is a reallocation of lower wage laborers from interrupted industries to labor-intensive industries located in unaffected areas thereby increasing industry output in corresponding micro-regions.

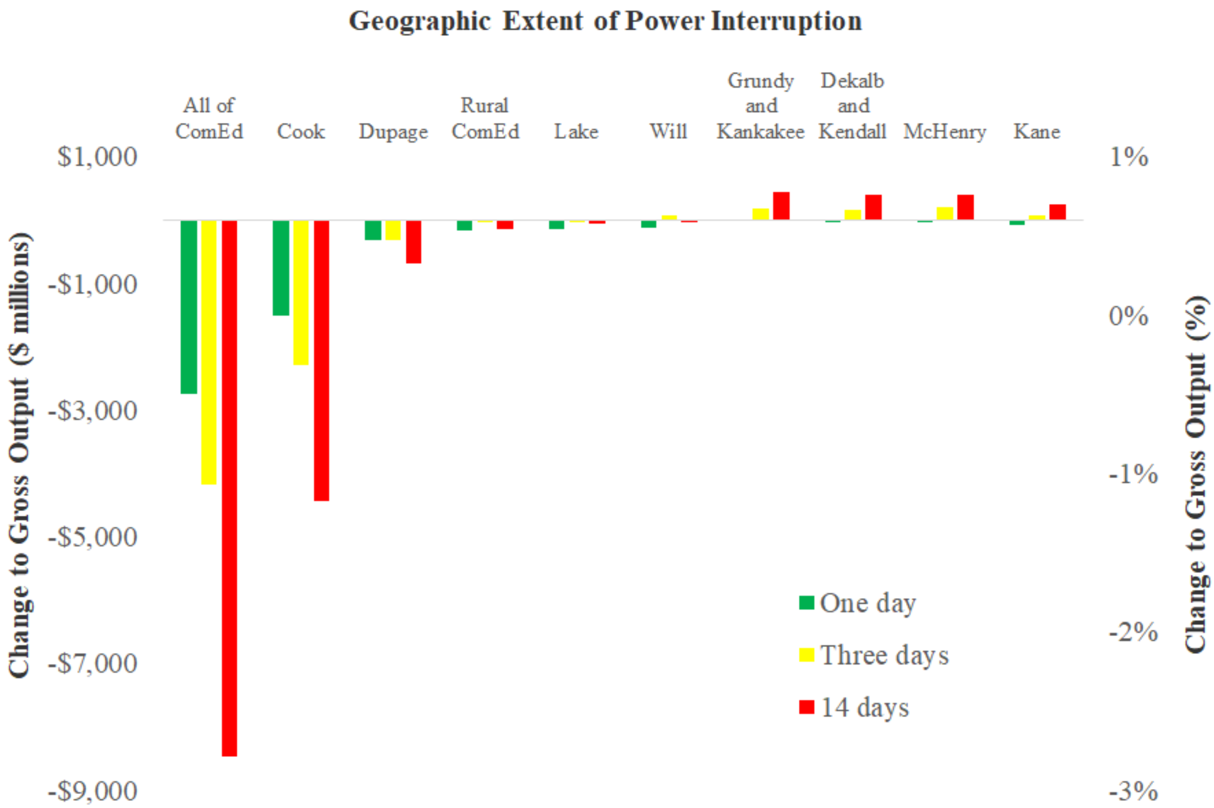


Figure ES - 6. Change in overall gross output for all of ComEd's service territory

We project that there will be significant losses to service territory-wide gross domestic product if an interruption impacted all of ComEd's service territory or if Cook, Dupage, Lake, Will, Kane, or the rural portions of ComEd's service territory are without power independent of each other. Figure ES - 7 shows that a scenario in which the entire service territory is without power would lead to $2.2 (or -1.3% relative to business as usual), $4.3 (-2.6%), and $17.1 billion (-10.4%) in GDP losses for the one day, three day, and 14-day interruptions, respectively. Changes to GDP would be relatively modest if the interruptions occur across McHenry, Grundy and Kankakee, or Dekalb and Kendall counties.

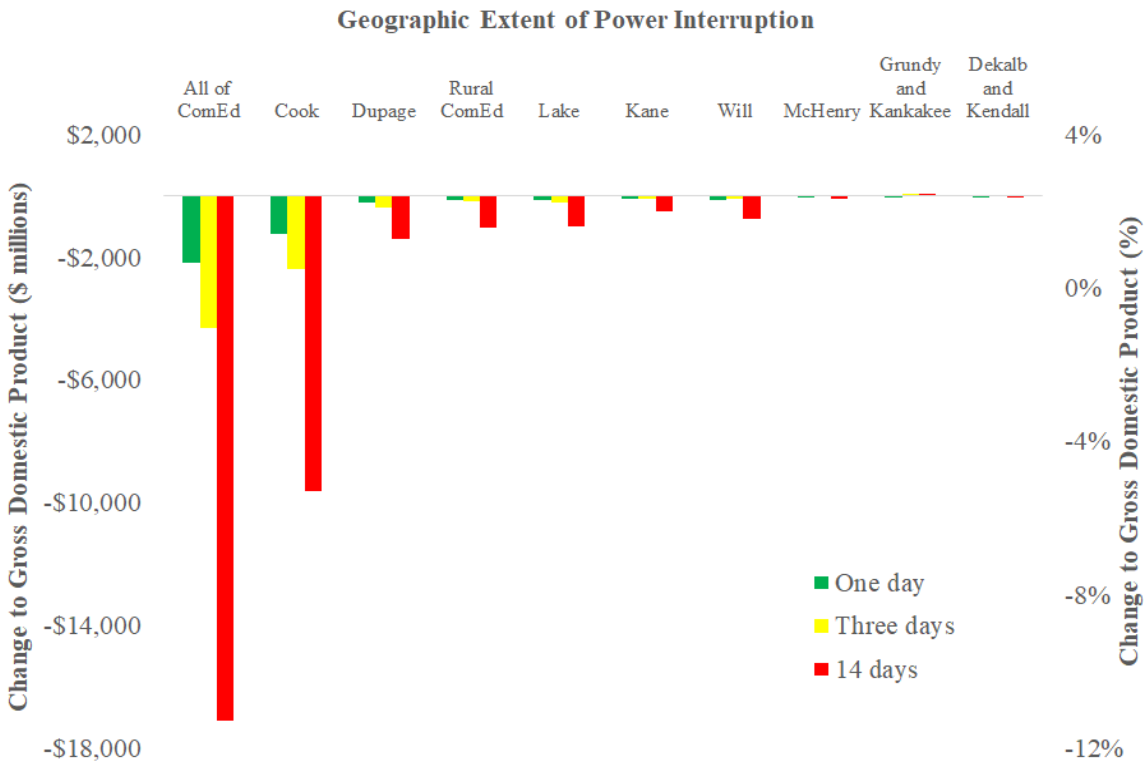


Figure ES - 7. Change in overall gross domestic product for all of ComEd's service territory

The wholesale trade and transportation sectors appear to be highly sensitive to power interruptions—losses to these sectors are large relative to the losses observed across the entire economy.

There are two relevant metrics to gauge sectors that are most sensitive to interruptions. First, we use the dollar value of sectoral output loss to identify sectors that have the highest influence on the overall economy. Second, we use the percent of sector output lost to identify sectors that are particularly sensitive to interruptions. The main focus of this analysis is on service territory-wide outcomes for a service territory-wide interruption. In general, this scenario produces the highest absolute levels of economic losses and hence it is worthwhile to examine in detail (see columns two and three in Table ES - 3). The five sectors that have highest output losses relative to the overall economy include: wholesale trade, transportation, manufacturing, retail trade, and finance and insurance services. The five sectors that have the highest percentage of sector output lost include: wholesale trade, transportation, warehousing and storage, and electric power generation, transmission and distribution. *The finding associated with the electric power sector may be related to the specific location of power infrastructure within ComEd's territory and its outsized role in the economic output in those counties*[4]*.* Interestingly, two sectors (wholesale trade and transportation) have both large losses relative to the overall economy

[4] Text reported in *italics* throughout this section reflect hypotheses or speculative statements that require additional research to confirm.

and high percentages of sector output lost. These highly influential and important sectors suggest that targeting resilience interventions to them may be warranted to offset the economic losses caused by power interruptions.

Table ES - 3. Industry sectors most affected by a 14-day, service territory-wide interruption

Sector	High output losses relative to the overall economy?	High percentage of sector output lost?
Wholesale trade	✓	✓
Transportation	✓	✓
Manufacturing	✓	
Retail trade	✓	
Finance and insurance services	✓	
Warehousing and storage		✓
Electric power transmission and distribution		✓
Electric power generation		✓

Several sector-region combinations—e.g., the transportation sector in Cook county—are very sensitive to interruptions

These sector-region combinations are estimated to experience significant losses–see Table ES - 4. For example, the electric power transmission and distribution sector may experience significant losses if long power interruptions occur within Dekalb and Kendall, Grundy and Kankakee, Kane, and McHenry counties. *This finding may be related to the specific location of power infrastructure within ComEd's territory and its outsized role in the economic output in those counties.*

Table ES - 4. Sector-region combinations with largest output losses during a 14-day interruption occurring within micro-region

Industry sector	Geographic extent of power interruption								
	Cook	Dekalb and Kendall	Dupage	Grundy and Kankakee	Kane	Lake	McHenry	Will	Rural ComEd
Electric power transmission and distribution		✓		✓	✓		✓		
Electric power generation							✓		
Water and sewer							✓		
Agriculture	✓					✓			
Transportation	✓	✓					✓		✓
Wholesale trade		✓					✓		
Warehousing and storage		✓		✓				✓	✓
Mining						✓			

Losses to household consumption increase with the duration of the power interruption

As expected, average losses to household consumption[5] increase as the duration of power interruptions increases (see Figure ES - 8). For example, a 14-day, system-wide interruption results in a nearly 15% loss in household consumption across all income groupings. This loss translates to a subsidy of $16.7 billion needed to make households across ComEd's service territory indifferent to a power interruption of this duration and geographic extent.

[5] Losses to household consumption is also known as equivalent variation and it represents a subsidy of income to make all households' consumption indifferent to the power disruption. For example, -1.0% implies that an average household would need to receive a payment of 1% of their household income to be indifferent to the power interruption.

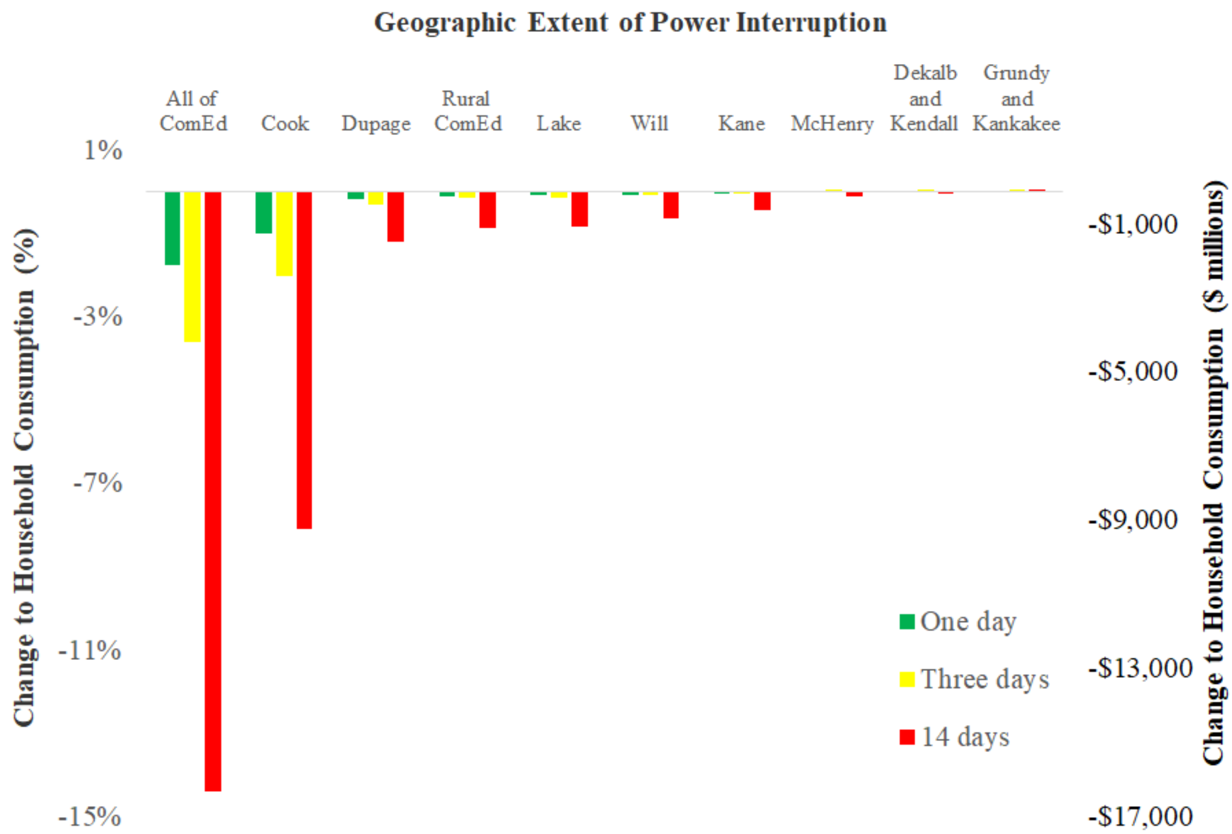


Figure ES - 8. Average change to annual household consumption for all of ComEd's service territory[6]

High-income households experience proportionately larger losses to consumption during a one-day power interruption, but low-income households experience proportionately larger losses during the longest power interruptions

Next, we examine consumption loss patterns across different household income groups and geographic extents of the interruption. For this analysis, we group all households into three income groups:

(1) annual income below $50,000 ("low income")
(2) annual income between $50,000 and $100,000 ("medium income")
(3) annual income above $100,000 ("high income")

With the exception of a power interruption occurring in rural ComEd, the highest income group is expected to have the largest losses to consumption during a one-day interruption (see Figure ES - 9).

[6] This is equivalent variation, which represents a subsidy of income to make all households indifferent to the power disruption. For example, -1.0% implies that an average household would need to receive a payment of 1% of their household income to be indifferent to the power interruption.

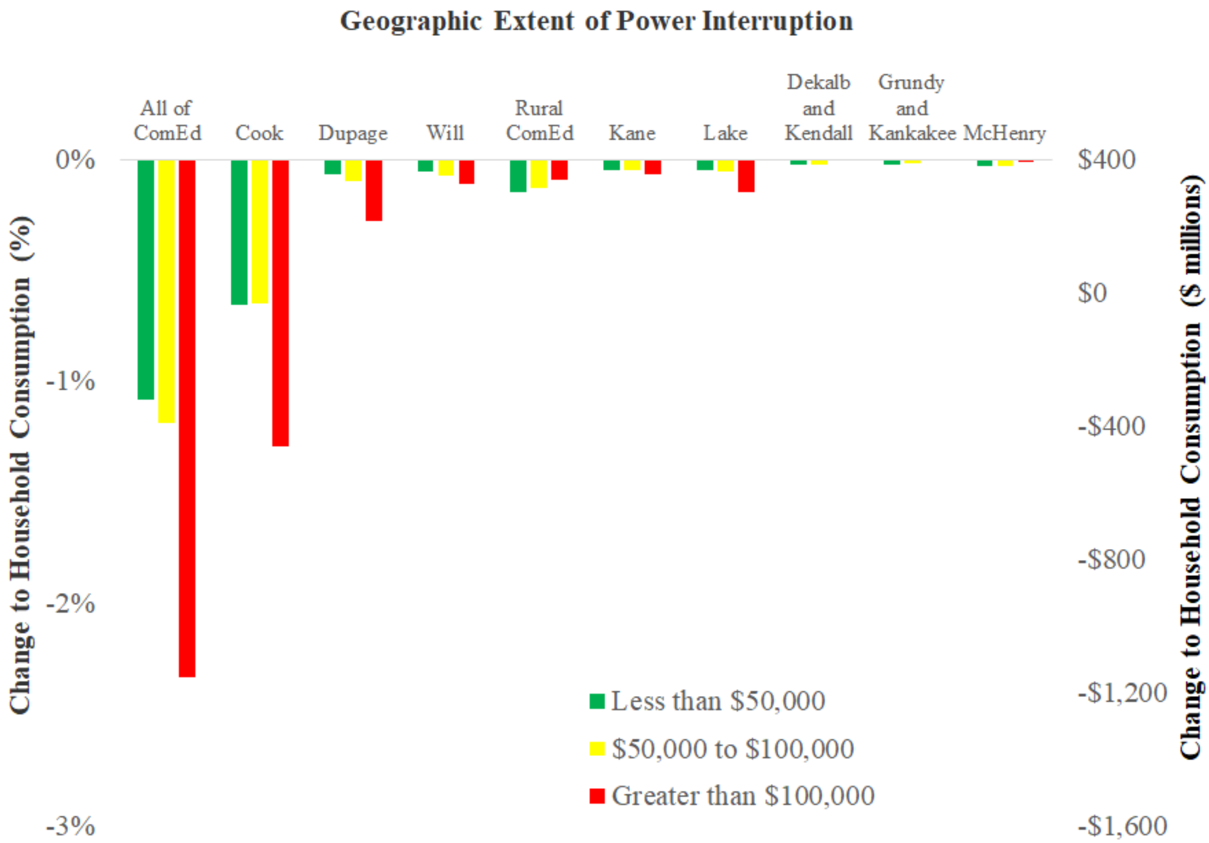


Figure ES - 9. Losses to annual household consumption during a one day power interruption by income grouping

However, as interruptions durations increase, consumption losses for lower income households increase to a point in which they exceed high income households during the 14-day interruption (see Figure ES - 10). *It is not immediately clear why income groups have different consumption losses for each interruption duration, but it may be related to the choice of resilience tactics reported by survey respondents. As we learned from the survey responses, most respondents did not leave the affected area during a one-day power interruption. However, survey responses imply that high income households are more likely to relocate during longer duration power interruptions and consume goods and services in micro-regions not impacted by the power interruption. Conversely, low income earners may be less able to relocate and are therefore able to consume less during longer duration power interruptions.*

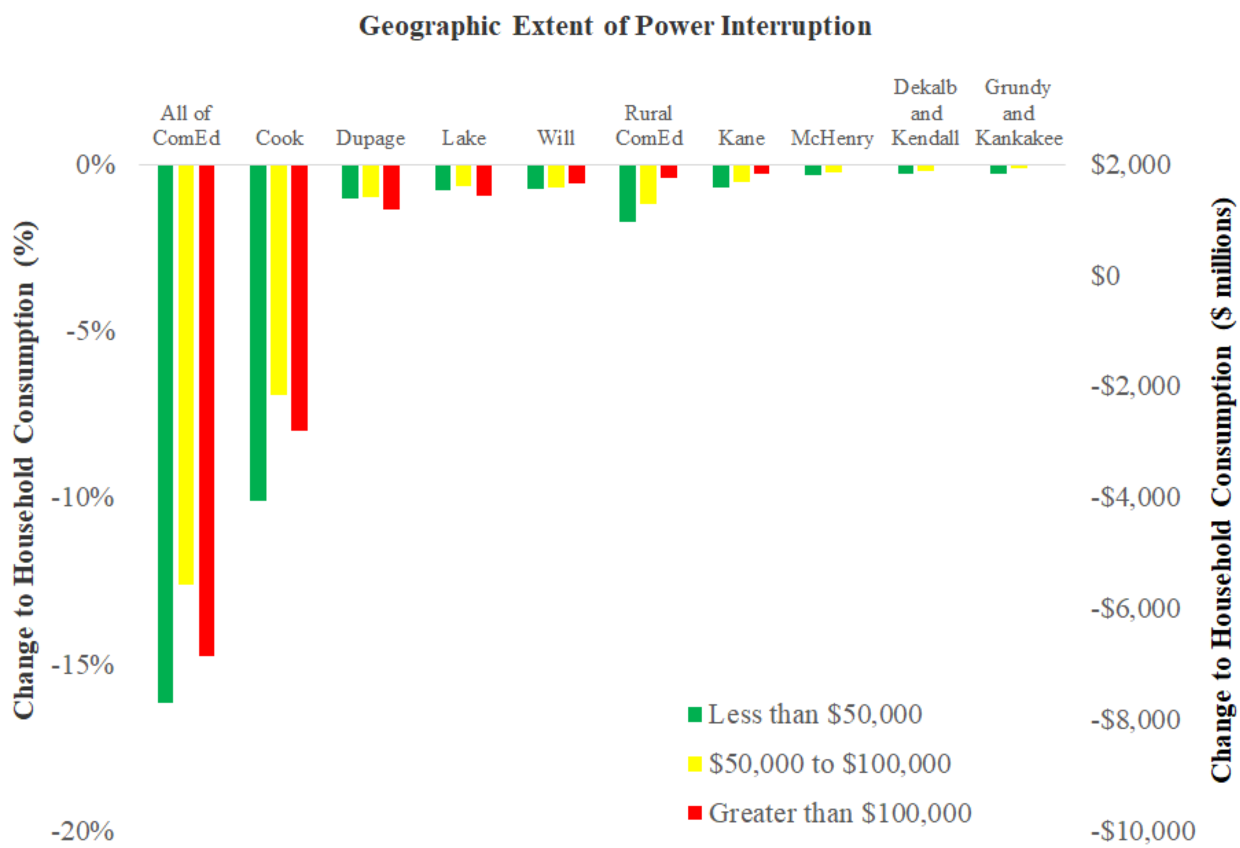


Figure ES - 10. Losses to annual household consumption during a 14-day power interruption by income grouping

Increasing the amount of backup generation deployed across ComEd's service territory provides significant *net* benefits to system-wide gross domestic product, gross output, and household consumption relative to the existing amount of backup generation already being used

We ran a scenario that doubles the penetration of backup generation (note: the scenario accounts for the procurement and operational cost of backup generation). We were able to evaluate how higher levels of backup generation led to changes in gross output, gross domestic product, and household consumption. These avoided losses are essentially net benefits–the benefits of higher levels of backup generation minus its procurement and operational costs–of doubling the amount of backup generation above existing levels. For example, avoided losses to gross output of $305 million, $606 million, and $1.2 billion are possible for a one day, three day, and 14-day service territory-wide interruption–these values represent net benefits of 11 to 15% of overall gross output (see Table ES - 5). It should be noted that there are cases of intra-region interruptions in which the costs of deploying more backup generation exceed the avoided losses to gross output in the region. The net benefits of deploying additional backup generation are negative for three and 14-day interruptions occurring only within either Dekalb and Kendall, Grundy and Kankakee, or McHenry counties. In these cases, the additional costs of procuring (renting) and operating increased levels of backup generation exceed the benefits that these additional levels of backup generation would provide to these counties.

Table ES - 5. *Avoided* service territory-wide losses to gross output due to higher levels of backup generation ($ millions and % loss avoided)

Duration	Geographic extent of power interruption									
	Cook	Dekalb and Kendall	Dupage	Grundy and Kankakee	Kane	Lake	McHenry	Will	Rural ComEd	All of ComEd
One day	$177.3 (12%)	$0.2 (3%)	$32.8 (11%)	$0.3 (4%)	$7.5 (11%)	$15.9 (12%)	$0.3 (13%)	$9.2 (8%)	$15.7 (10%)	$305.2 (11%)
Three days	$329.4 (14%)	-$2.6 (-2%)	$61.4 (20%)	-$5.0 (-3%)	$16.0 (22%)	$28.3 (125%)	-$5.7 (-3%)	$11.0 (12%)	$30.3 (128%)	$606.2 (15%)
14-days	$580.1 (13%)	-$5.4 (-1%)	$49.6 (7%)	-$5.4 (-1%)	$57.4 (22%)	$66.7 (133%)	-$18.4 (-5%)	$36.7 (107%)	$104.0 (74%)	$1,182.7 (14%)

However, increasing the amount of backup generation deployed across ComEd's service territory leads to net benefits to system-wide gross domestic product for all interruption extents and durations (see Table ES - 6). Avoided system-wide losses to gross domestic product range from $291 million (one day) to $614 million (three day) to $1.9 billion (14-day)–or 11 to 14% of overall gross domestic product. Interestingly, avoided losses to gross domestic product are extremely high relative to total GDP in some places (e.g., a 14-day power interruption originating in Dekalb and Kendall counties). Furthermore, installing higher amounts of backup generation will likely result in *avoided* losses to household consumption.

Table ES - 6. *Avoided* service territory-wide losses to gross domestic product due to higher levels of backup generation ($ millions and % loss avoided)

Duration	Geographic extent of power interruption									
	Cook	Dekalb and Kendall	Dupage	Grundy and Kankakee	Kane	Lake	McHenry	Will	Rural ComEd	All of ComEd
One day	$170.9 (14%)	$2.5 (14%)	$29.0 (13%)	$1.4 (55%)	$11.4 (16%)	$17.5 (14%)	$3.7 (16%)	$12.1 (12%)	$15.4 (11%)	$290.5 (13%)
Three days	$337.4 (14%)	$6.0 (19%)	$58.8 (17%)	$0.5 (1%)	$27.4 (39%)	$37.1 (20%)	$4.7 (11%)	$23.5 (24%)	$36.5 (20%)	$614.0 (14%)
14-days	$1,028.1 (11%)	$24.5 (101%)	$110.7 (8%)	$12.5 (16%)	$122.0 (25%)	$140.4 (15%)	$13.2 (14%)	$98.8 (14%)	$137.3 (14%)	$1,873.4 (11%)

Table ES - 7 shows that a service territory-wide interruption that has been partially mitigated by backup generation will lead to average increases in household consumption–across all income categories–of 0.3% (one day) to 0.5% (three day) to 1.6% (14-day). In dollar terms, these avoided losses (i.e., net economic benefits) of higher penetration of backup generation range from $287 million (one day) to $1.8 billion (14-days).

Table ES - 7. *Avoided* losses to consumption for households attributed to power interruptions ($ millions and % loss avoided)

Duration	Geographic extent of power interruption									
	Cook	Dekalb and Kendall	Dupage	Grundy and Kankakee	Kane	Lake	McHenry	Will	Rural ComEd	All of ComEd
One day	$169.3 (0.2%)	$2.4 (0.0%)	$28.8 (0.0%)	$1.2 (0.0%)	$11.1 (0.1%)	$17.1 (0.0%)	$3.6 (0.0%)	$11.9 (0.0%)	$15.0 (0.0%)	$287.4 (0.3%)
Three days	$334.7 (0.3%)	$5.7 (0.0%)	$58.7 (0.0%)	$0.5 (0.0%)	$26.7 (0.1%)	$36.7 (0.1%)	$4.6 (0.0%)	$23.2 (0.0%)	$36.0 (0.1%)	$609.0 (0.5%)
14-days	$1,000.7 (0.9%)	$23.4 (0.0%)	$108.1 (0.1%)	$12.5 (0.1%)	$117.7 (0.1%)	$137.7 (0.1%)	$13.4 (0.0%)	$97.3 (0.0%)	$134.5 (0.1%)	$1,824.3 (1.6%)

Implications for enhancing resilience

Some micro-regions (e.g., Dekalb and Kendall counties), sectors (e.g., wholesale trade, transportation), and low-income households may especially benefit from targeted resilience interventions.

Avoided losses to gross domestic product from increased penetration of backup generation are extremely high relative to total GDP in some places (e.g., a 14-day power interruption originating in Dekalb and Kendall counties). This finding suggests that prioritizing the installation of backup technologies in specific locations may be preferred to a widespread strategy of increasing backup generation across the entire service territory.

Five sectors consistently represent the largest share of total economic losses regardless of interruption duration: (1) wholesale trade; (2) transportation; (3) manufacturing; (4) retail trade; and (5) financial and insurance services. Sectors that are most sensitive to a one-day interruption include (1) wholesale trade (2) retail trade, and (3) warehousing/storage. However, the sectors that are the most sensitive to a 14-day interruption are (1) transportation, (2) electric power, (3) wholesale trade, (4) retail trade, and (5) healthcare. Wholesale trade and the transportation sector have both high absolute economic impact in dollars as well as being highly sensitive to interruptions. Regulators and planners may want to design post-event interventions to help these sectors recover, especially critical public services including the transportation, electric power, and the healthcare sectors. Targeted interventions for the wholesale and retail trade sectors–perhaps with higher degrees of backup generation–could also mitigate the relatively high impact of long duration interruptions in these sectors.

High income households may experience significant losses to consumption during a one-day power interruption, but low-income households experience the greatest losses during the longest power interruptions. Furthermore, the differences in household consumption loss across regions and durations may help inform targeted interventions for certain income groups. For example, lower income households in Cook county may benefit more from resilience interventions compared to lower income households in Lake or Dupage counties.

Incorporating results into cost-benefit analyses

The results from this study could be used to inform future integrated planning and cost-benefit analyses undertaken by regulatory staff, utility staff, or other policymakers. One step in the overall valuation proposition of resilience investments and/or tactics involves calculating the benefits of tactics to enhance power system or customer resilience. One important type of benefit is an avoided economic loss to residential and non-residential customers due to reductions in the frequency and/or duration of one or more power interruptions. Proper accounting of the benefits provided by a resilience investment requires a number of assumptions that will need to be made by policymakers including, but not limited to the:

- likelihood of future power interruptions of varying durations and geographic extents;
- reduction in interruption risk due to the investment;
- economic impacts of power interruptions before and after the investment;
- lifespan of the investment, and;
- discount rate.

Household consumption levels before and after an investment are the preferred metric to estimate resilience benefits within a cost-benefit framework

Although gross output, gross domestic product (or industry value-added), and household consumption are all useful metrics to evaluate the benefits of resilience investments, one metric–*household consumption (i.e., equivalent variation)*–is our preferred metric for estimating one of the key benefits of investments in resilience. Consumption captures both impacts to households and firms simultaneously and is most closely aligned with the concept of overall welfare of the economy. For example, assume that there is a service territory-wide, 14-day power interruption. In this case, households across ComEd would need to be compensated $16.7 billion to make them indifferent to that same power interruption ($116 billion under business as usual minus $99.3 billion for 14-day interruption; see Figure E.8). It follows that a decision-maker should not consider a service territory-wide investment of more than $16.7 billion to mitigate the impacts of a 14-day interruption.

Using multiple economic impact metrics can help test the robustness of a cost-benefit analysis outcome

Nonetheless, we recommend that decision-makers consider running cost-benefit analyses using each of the economic metrics presented in this report independent of one another to evaluate the robustness of the insights that each of these estimates may provide. For example, positive and significant benefits regardless of economic metric used would indicate that resilience investments targeting a particular micro-region, industry sector, and/or household income group may be particularly beneficial.

Important considerations when evaluating the benefits of resilience tactics

Two issues that this work does not address are (1) the frequency, duration, and the geographic extent of *future* interruptions and (2) what level of mitigation a given resilience investment—beyond the doubling of backup generation—provides to mitigate the impacts of power interruptions. The stream of benefits that accrues from the sum of all mitigated interruptions that occur within the lifetime of a resilience investment is the total economic benefit of that resilience project. In the example above, it is socially beneficial to spend up to $16.7 billion to mitigate the impacts of a single 14-day interruption that occurs within the lifetime of the investment. However, it may also be socially beneficial to spend more than $16.7 billion considering that interruptions that last fewer than 14-days may also occur, and even more frequently, and these may also be partially or fully mitigated. In contrast, it may also be beneficial to spend less than $16.7 billion for a resilience investment that partially mitigates a 14-day interruption. It is important to note that capital investments that improve resilience for one type of hazard may not ensure resilience to all hazards. And no investments will completely eliminate the risk of power interruptions in the future–it is financially and technically infeasible to ensure that all customers at all times have perfectly reliable electricity service.

Key uncertainties and research needs

There are a number of limitations and ongoing research needs associated with this demonstration project. These limitations and research needs are discussed in more detail within Section VIII, but we include the highest priority issues below:

- Low survey response rates for non-residential customers may mean some of the information we collected is not representative of the population of businesses
- Backup generation rentals may not be widely-available during widespread, long duration interruptions
- Sectoral and micro-region-level impacts must be evaluated in greater detail in order to develop specific and targeted resilience interventions
- Computational limitations prevented the assignment of resilience tactics to all 38 industry sectors
- Not all societal impacts of power interruptions were captured in the model, including pollution-related costs from running backup generators

The findings from this research effort are meant to provide valuable insights to ComEd, policymakers in Illinois, and other stakeholders who have a vested interest in the future of the power system. Nevertheless, it recognized that effectively communicating the complexities involved in estimating impacts from power interruptions, the methods, survey responses, and results presented to a wide-range of audiences is an evolving practice.

1. Study Motivation and Introduction

Society depends on electric power for many individual, household, commercial, and public activities, making our individual and collective vulnerability to power disruptions a key question for electric utility planning. Most electric power interruptions, which often originate at the distribution system-level, cause little disruption to daily life. However, widespread, long duration power interruptions (WLD), including those caused by extreme weather, can result in substantial economic impacts to society. It is essential to consider the costs of power interruptions when making decisions about power system reliability and resilience. Proposed investments in the power system, which can be expensive, are often approved by regulators based on the benefits that they provide to ratepayers and society as a whole. There has been relatively little research conducted to estimate the direct and indirect economic impacts of WLD power interruptions. These direct and indirect impacts include economic losses within the immediate area of the interruption, but also increased economic activity in areas that provide additional goods and services to affected customers. Customer costs from short-term, limited geographic-scale power interruptions have been estimated by utilities using survey-based elicitation techniques. Berkeley Lab's Interruption Cost Estimate (ICE) Calculator, which is based on that survey data, has been extensively used by regulators, utilities, and other stakeholders to justify investments in reliability[7]. Unfortunately, the ICE Calculator was not designed to estimate the costs of WLD power disruptions or the value of investments in power system resilience[8].

Regional economic models have been used to estimate the direct and indirect impacts of power interruptions, but the outcomes from these tools are often difficult for stakeholders to interpret, do not fully consider customer behavior, and often do not produce results that are useful for local/regional planning (Larsen et al. 2019). For these reasons, previous estimates generated from these types of models have not been used in regulatory settings to estimate the value of both "blue sky" reliability as well as "dark sky" resilience investments.

In 2020, Commonwealth Edison (ComEd) contacted Berkeley Lab to learn more about research being undertaken to put an economic value on resilience. Subsequently, Berkeley Lab and ComEd developed a research partnership that will ultimately allow ComEd to "evaluate the impacts of hypothetical power interruption scenarios on all customer classes and consider them in potential resilience investments" (Aguilar et al. 2021).

[7] The North American Electric Reliability Corporation (NERC) defines power system reliability using two concepts: (1) adequacy and (2) operating reliability: "Adequacy is the ability of the electric system to supply the aggregate electric power and energy requirements of the electricity consumers at all times, taking into account scheduled and reasonably expected unscheduled interruptions of system components. Operating reliability is the ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system components" (NERC 2007).

[8] Presidential Policy Directive 21 defines resilience as the "ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents" (The White House 2013).

This project involves implementing a hybrid resilience valuation approach that combines: (1) advanced survey-based techniques to identify mitigating/adaptive behaviors that residential, commercial, and industrial customers indicate they will take to reduce risk before, during, or after a power interruption occurs; (2) techniques to elicit the direct interruption costs to non-residential customers; and (3) a regional economic model that has been calibrated to assess the full range of economic impacts from power interruptions occurring across the ComEd service territory (see Figure 1-1) and beyond.

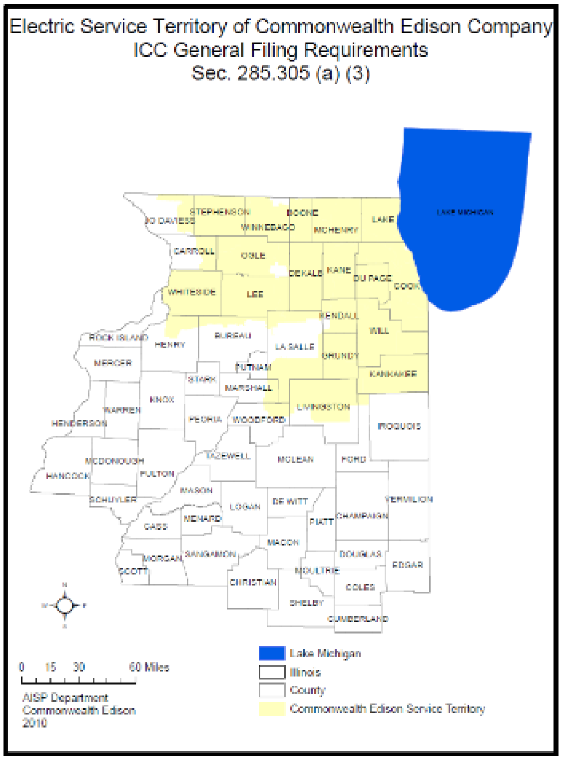


Figure 1-1. Commonwealth Edison service territory (ComEd 2010)

The outcome of this project is to estimate the full economic impacts of power interruptions of various geographic extents and durations. Specifically, we provide answers to the following questions:

- What are the overall changes to industry activity from power interruptions of varying geographic extent and duration?
- What are the industry sectors most affected by service territory-wide interruptions? What industry sectors are the most economically-resilient to service-territory wide interruptions?
- What regions are more sensitive to service territory-wide interruptions, and which ones are more inherently economically-resilient?
- How do sectoral and regional economic output impacts compare across interruption durations? Are there sector-region combinations that respond differently to increasing durations compared to other sector-region combinations?
- How are different household income groups impacted by power interruptions of varying extent and duration?

- Are household income groups in certain regions more sensitive to interruptions than in other regions?
- What are the economic benefits of a higher adoption of backup generation?
- What do the results imply for improving resilience in the ComEd service territory?
- How could the results from this study be incorporated into a traditional cost-benefit framework to evaluate investments in resilience?

The information that follows is organized into seven sections. We start, in Section II, by discussing our method for estimating economic impacts of WLD power disruptions, including the need to collect information from ComEd's customers. Next, in Section III, we discuss utility customer survey design, sampling, and administration. Section IV reports the responses collected from ComEd's customers, and Section V introduces the Power Outage Economics Tool (POET) regional economic model, including a discussion of the customer-informed calibration that was performed. Sections VI and VII present the interruption scenarios considered and the results of the regional economic modeling, respectively. Finally, we conclude with a discussion of analysis caveats and future research possibilities.

2. Hybrid Method for Estimating Economic Impacts of Widespread, Long Duration Power Disruptions

2.1 Past studies estimating the impacts of power disruptions

Customer interruption cost (CIC) surveys have been the most widely used method to estimate direct power interruption costs by utilities, regulators, and academic researchers. CIC studies classify electricity customers into three groups based on their consumption characteristics and the types of interruption impacts they experience: residential, small/medium business (SMB) and large commercial & industrial (LCI). Surveys of residential customers, whose interruption costs relate to, e.g., spoiled food, lost income, inability to use appliances, or lack of air conditioning, ask about respondents' willingness-to-pay for a hypothetical backup electricity service. Surveys of non-residential customers elicit the value of lost production, interruption-related costs, and interruption-related savings, and calculate total power interruption costs for a set of interruption scenarios. These residential and non-residential impacts are called "direct" costs.

Numerous CIC studies have supported reliability planning associated with avoiding shorter duration interruptions of limited geographical extent. Generally speaking, this refers to interruptions lasting less than one day and in most cases no more than a few minutes or less to a few hours, and affecting only a localized area within a utility service territory. Recent examples include Sullivan et al. (2012) and Collins et al. (2019). Lawrence Berkeley National Laboratory (Berkeley Lab) and Nexant, Inc. (now Resource Innovations, Inc.) aggregated 34 studies conducted for utilities across the U.S. using meta-analysis and estimated CIC functions. This work is the basis for the Berkeley Lab's ICE Calculator, an online tool designed for use by utilities, regulators, and others in estimating interruption costs or the avoided costs resulting from investments in power system reliability (Sullivan, Schellenberg, and Blundell 2015; Schellenberg and Larsen 2018).

Another methodology for quantifying power interruption costs is regional economic modeling, which provides estimates on the scale of local or regional economies (REMs) (Sanstad 2016). The three REM types most commonly used for this purpose are (1) macro-econometric models, which are systems of statistical forecasting equations with parameters estimated using historical time series data (e.g., Greenberg et al. 2007); (2) input-output (I–O) models, which are systems of linear equations representing all inter-industry relationships or flows in an economy in matrix form (e.g., Industrial Economics 2018); and (3) computable general equilibrium (CGE) models, which are comprehensive numerical representations of economies in the form of non-linear algebraic equations or mathematical structures based on microeconomic principles (e.g., Rose et al. 2005; Rose et al. 2007; Sue Wing and Rose 2020).

2.2 Regional economic modeling as the preferred approach

There are two primary reasons that conventional CIC survey methods have been for the most part applied only to direct cost analysis of short duration, localized power interruptions. First, residential customers, in particular, have difficulty imagining their willingness-to-pay to avoid a long-duration power interruption that they have never experienced. Second, surveys are not designed to estimate indirect or “spillover” effects of interruptions as their impacts propagate across regional economies. These result from market interactions, whereby firms or sectors experiencing a power loss may temporarily both stop purchasing inputs from other firms and selling outputs to their customers, resulting in economic impacts above and beyond direct costs. Thus, traditional survey-based estimates are generally not well-suited to estimating direct and indirect costs of power interruptions that last days or longer and affect entire utility service territories, and possibly multiple utilities and multi-state regions (EPRI 2017; Larsen et al. 2019; Sanstad et al. 2023).

In addition, traditional CIC survey methods have not directly taken into account the adaptive actions that electricity customers may take to mitigate the impacts they experience from power interruptions. The most important example of such actions is the use of backup generators as a temporary source of electricity during an interruption. Other examples include relocating (households) or moving production to a non-affected location (firms).

Regional economic models are capable of analyzing WLD interruptions, particularly their indirect effects. This is especially important for cost analysis inasmuch as it has been found in modeling analyses of WLD power interruptions that indirect economic impacts may greatly exceed direct impacts (Sanstad 2016; Sue Wing et al. 2021). Moreover, of the three types of REMs, CGE models are preferred because they can in principle also represent adaptive or resilience-enhancing actions that households and firms undertake to mitigate their vulnerability to interruptions.

2.3 A hybrid REM-survey approach

Notwithstanding their advantages, CGE models are complex and data-intensive. They contain large numbers of parameters describing customer behavior that are not well-grounded empirically (Beckman et al., 2011; Koesler and Schymura, 2015; Sanstad et al., 2023). However, researchers have been developing techniques to extend CIC estimation to longer durations (Baik et al. 2020), and to expand the scope of customer surveys to include adaptive, resilience-enhancing behavior.

These developments have facilitated development of a “hybrid” approach to interruption cost estimation that combines the strengths of the two methodologies while addressing their limitations (Baik et al. 2021). Specifically, the hybrid approach entails using state-of-the-art CIC survey methods to collect region- and sector-specific direct costs, resilience tactics, and other information needed to assign numerical values to CGE parameters for both effects of longer-duration outages and resilience options, or tactics, to cope with them (Rose et al. 2007). A hybridized CGE model has the capability to analyze WLD interruption costs, but on a much firmer empirical grounding than has previously been achieved, thus improving WLD power interruption direct and indirect cost estimation. Figure 2-1, below, depicts the difference between past approaches to estimate the economic impacts of power interruption and the hybrid approach used in this study.

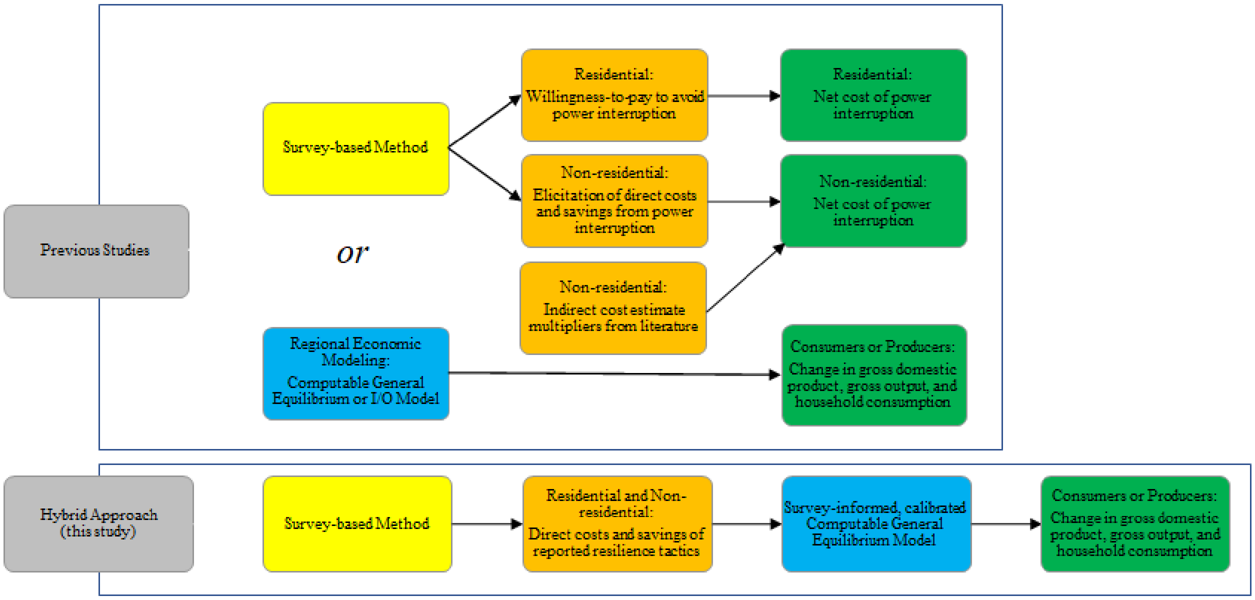


Figure 2-1. Steps to estimate economic impacts of power interruptions: previous studies versus the hybrid approach used in this study

3. Survey Design, Sampling, and Administration

As noted above, the analysis of data collected via surveys is the conventional approach to measuring direct customer costs from short-duration, localized power interruptions. The present study both extended survey techniques to analyzing longer-duration interruptions and broadened the scope of the information gathered from customers. First, instead of being queried on willingness-to-pay to avoid interruptions, residential customers are asked about the specific direct costs they would incur - e.g., from food spoilage or income loss. Second, both residential and non-residential customers are also asked in detail about their potential adaptive, resilience-enhancing actions in the event of an interruption - e.g., the use of back-up generation, temporary relocation of place-of-residence or industrial production. Representative samples of customers are asked to estimate the economic losses they would experience given various hypothetical interruption scenarios characterized by duration and time-of-year. Various statistical techniques are then used to identify and describe the relationships between interruption attributes and customer economic losses.

For this report, a survey study of this type was conducted in the ComEd service territory in order to provide quantitative information for assigning values to parameters of a CGE model in a "hybridization," as described above. The following sections describe the survey design, sample design, and administration of the customer interruption cost surveys used in this study.

3.1 Survey design and interruption scenarios presented to customers

Samples of ComEd customers were presented with three hypothetical long-duration interruption scenarios lasting 24 hours, three days, and two weeks. Approximately half of the customers were questioned about interruptions occurring in the summer and the other half about winter scenarios. The interruptions were described as a complete loss of power affecting all homes and businesses within a 20-mile radius. Each interruption was said to occur suddenly and without warning, but the customer would be notified by their utility within a few hours of the onset how long it would take for power to be restored (24 hours, three days, or two weeks). For each hypothetical scenario, customers were asked to select the action they would take in response to the interruption and then estimate the costs they would incur based on that action.

Residential customers were given one of three possible choices for how they would respond in each of the three interruption scenarios:

1. Stay home and do activities that do not require electricity
2. Stay home and operate backup power systems
3. Temporarily move to a location that has power (outside the impacted area in a 20-mile radius)

Respondents provided information about how electrical power interruptions affect their households, such as the ability to operate heating systems, the type of home, members of the household, and annual household income.

Non-residential customers, SMB and LCI, were given four choices for how they would respond to each of the three interruption scenarios:

1. Shut down their facility except for safety and security staff
2. Continue to perform tasks that do not require electricity or operate on backup power systems
3. Temporarily shut down the facility until backup power systems can be rented
4. Transfer operations to locations outside the area affected by the interruption

Based on their response, non-residential customers estimated the value of lost production, interruption-related costs, and interruption-related savings. The value of lost production is the amount of revenue the surveyed business would have generated in the absence of the interruption minus the amount of revenue it was able to generate given that the interruption occurred. Interruption-related costs are additional production costs directly incurred because of the interruption, such as labor to make up for lost production, costs to restart operations, replacement of inventory or products lost due to the interruption, and cost to operate backup generation equipment. interruption-related savings are production cost savings resulting from the interruption. When production or sales cannot take place, there are economic savings resulting from the fact that inputs to the production or sales process cannot be used. Examples include unpaid wages during the interruption, value of raw materials not used, fuel not used, and scrap value of any damaged materials. The survey instruments used in this study for all customer classes are included in Technical Appendix A.

3.2 Customer population and sampling strategy

The study team had a goal of receiving 600 completed surveys for residential customers, 200 for SMB customers, and 80 for LCI customers. Before detailing the sample design methodology and how these sample points were distributed among geography and industry, it is important to note that a "customer" refers to a unique combination of "customer number" and "service address" in ComEd's customer database. For residential customers, there was generally only one account ID associated with each unique combination. For non-residential customers, there could be multiple addresses for a single account ID. When customers completed an interruption cost survey, they provided cost estimates for a specific service address.

ComEd provided customer characteristics, including monthly electricity use and zip code, for the entire residential, SMB, and LCI customer populations. Before drawing the samples of customers from the population to participate in the survey, each customer's annual electricity use was analyzed to identify how to classify the non-residential customers (as SMB or LCI) and if any customers should be removed from the potential sample based on low or no reported annual electricity usage. Earlier value of service (VOS) studies suggest that the residential, SMB, and LCI response rates were anticipated to be 10%, 5%, and 20%, respectively. However, during the actual administration of the survey, the response rate for LCI was re-estimated to 10%, resulting in the draw of an additional sample of LCI customers. Table 3-1 summarizes the population and sample counts for each customer segment by geographic area. Table 3-2 summarizes the population and sample size for SMB and LCI customers by industry sector. The breakdown of industry sectors started with two-digit NAICS classification codes, which were further narrowed down by electricity-intensive industries in ComEd's service territory and other sub-sectors of interest.

Table 3-1. Sample design summary by geographic area

Area	Population count			Sample count (recruited)		
	Residential	SMB	LCI	Residential	SMB	LCI
Rural	235,269	17,024	182	2,110	1,891	114
Suburban	1,219,878	86,715	1,204	2,110	2,153	338
Urban	2,075,837	125,112	1,717	2,110	2,174	356
Total	**3,530,984**	**228,851**	**3,103**	**6,330**	**6,218**	**808**

Table 3-2. SMB and LCI sample design summary by industry sector

Industry sector	Population counts		Sample counts (recruited)	
	SMB	LCI	SMB	LCI
Agricultural, construction, and mining	13,217	66	790	55
Electric distribution, nat. gas, and water	925	41	183	26
Manufacturing	12,448	900	831	129
Wholesale trade, transportation	18,129	369	727	97
Retail	27.198	201	740	66
Telecommunications, finance, data processing	88,732	732	720	108
Education	5,951	304	708	106
Hospitals and healthcare	1,237	98	271	69
Restaurants, entertainment, other services	53,941	285	798	83
Government	7,073	107	450	69
Total	**228,851**	**3,103**	**6,218**	**808**

3.3 Survey administration and responses

This section summarizes the data collection procedures for each customer class. Pre-tests of the surveys were administered to a sub-sample of customers for two weeks, from March 3, 2022 to March 16, 2022. The pre-test was conducted to ensure that respondents understood the interruption scenario descriptions and survey questions and to test that the recruitment approach would achieve the anticipated response rates discussed earlier. The surveys were administered to the remaining sample for nine weeks, from April 20, 2022 to June 21, 2022. Table 3-3 provides an overview of the survey implementation approach by customer class.

Table 3-3. Survey implementation approach by customer class

Customer class	Initial sample design target	Recruitment method	Data collection approach	Incentive provided
Residential	600	Letter/Email	Internet Survey	$5
SMB	200	Telephone	Phone interview	$100
LCI	80	Telephone	Phone interview	$150

3.4 Residential customers

The residential survey was administered using an internet platform, and distributed to the target respondents in two waves. In the first wave, respondents received a $5 bill and a cover letter on ComEd stationery explaining the purpose of the study and requesting their participation. This letter also contained a URL and unique respondent ID number so that respondents could complete the survey online. Customers for which ComEd had email addresses were also sent emails explaining the study and containing a unique URL, which customers could use to access their survey directly. The letters and emails included a customer support phone number that respondents could call to verify the legitimacy of the survey and ask questions. To participate in the survey, the respondents had to be at least 25 years old, have lived in ComEd service territory for two years or more, and be aware or responsible for their home's electricity bills. About three weeks after the initial recruitment wave was sent out, customers who had not filled out the survey received one communication via email and another via postal mail to remind them to complete the survey.

A pre-test of the residential survey was administered to a sub-sample of 330 customers. The full launch of the survey was administered to the remaining 6,000 customers. In total, the residential survey received 829 responses, exceeding the target of 600 completions. Table 3-4 summarizes the number of responses received for the residential survey.

Table 3-4. Residential survey responses by geographic area

Area	Sample count (recruited)	Target number of responses	Responses		Response rate
			Count	Percent	
Rural	2,110	200	266	32%	13%
Suburban	2,110	200	354	43%	17%
Urban	2,110	200	209	25%	10%
Total	**6,330**	**600**	**829**	**100%**	**13%**

3.5 Small- and medium-sized business customers

The SMB survey was conducted via phone interviews. Customers were mailed a paper letter introducing them to the study, informing them that a survey recruiter would be contacting them via phone, and providing a toll-free number they could use to contact the survey recruiter directly. Customers for whom ComEd had email addresses that were not on the utility's 'Do Not Contact' list were also sent emails with the same information. SMB customers were recruited by telephone to ensure that the appropriate individuals for answering questions related to energy and interruption issues for that company were identified; and to secure a verbal agreement from them to complete the survey. Telephone interviewers explained the purpose of the survey and indicated that an incentive would be provided as payment upon the successful completion of the survey.

All sampled customers were telephoned to solicit their participation. Customers who were not contacted were left messages asking them to return the call. Up to five attempts were made to make contact with the customers before it was assumed that they would not respond.

A pre-test of the SMB survey was administered to a sub-sample of 196 customers. Due to response rates not meeting expectations in the pre-test, the incentive was raised from $50 to $100. The full launch of the survey was administered to the remaining 6,022 customers. Table 3-5 and Table 3-6 summarize the number of responses received for the SMB survey by geographic area and industry sector, respectively.

Table 3-5. SMB survey responses by geographic area

Area	Sample count (recruited)	Target number of responses	Responses		Response rate
			Count	Percent	
Rural	1,891	66	74	37%	4%
Suburban	2,153	67	62	31%	3%
Urban	2,174	67	64	32%	3%
Total	**6,218**	**200**	**200**	**100%**	**3%**

Table 3-6. SMB survey responses by industry sector

Industry sector	Sample count (recruited)	Target number of responses	Responses		Response rate
			Count	Percent	
Agricultural, construction, and mining	790	20	26	13%	3%
Electric distribution, nat. gas, and water	183	20	2	1%	1%
Manufacturing	831	20	36	18%	4%
Wholesale trade, transportation	727	20	22	11%	3%
Retail	740	20	19	10%	3%
Telecommunications, finance, data processing	720	20	26	13%	4%
Education	708	20	19	10%	3%
Hospitals	271	20	5	3%	2%
Restaurants, entertainment, other services	798	20	26	13%	3%
Government	450	20	19	10%	4%
Total	**6,218**	**200**	**200**	**100%**	**3%**

3.6 Large commercial and industrial customers

The LCI survey was also conducted as a phone interview. ComEd account representatives first contacted customers and identified the best person at each sampled business to call and recruit for the study. Next, an experienced telephone recruiter contacted the appropriate representative at each of the sampled facilities to ask if they would participate in the study. The target respondent was usually a plant/building manager or engineering manager – someone who was familiar with the costs associated with running the business or operating the facility. Once the target respondent was identified and agreed to participate, the scheduler set up an appointment with the field interviewer. The interview was scheduled at the convenience of the customer. A financial incentive of $150 was offered for the completion of the interview. On the agreed upon date, an interviewer called the customer to conduct the in-depth interview.

The recruitment effort for the pre-test sample of 436 LCI customers did not yield the anticipated response rate. To boost the number of responses, an additional sample of 376 LCI customers was drawn to raise the total sample to contact to 812. The additional sample size was determined to balance the goal of receiving additional completed responses with the impacts to both customers and ComEd business operations. The response rate increased modestly from initial levels, but remained low compared to previous VOS studies conducted by Resource Innovations, Inc. Ultimately, interviewers were able to collect completed responses from 61 LCI customers out of an initial sample design target of 80.

Table 3-7 and Table 3-8 summarize the number of responses received for the LCI survey by geographic area and industry sector, respectively.

Table 3-7. LCI survey responses by geographic area

Area	Sample count (recruited)	Target number of responses	Responses		Response rate
			Count	Percent	
Rural	114	26	14	23%	12%
Suburban	338	27	30	49%	9%
Urban	356	27	17	28%	5%
Total	**808**	**80**	**61**	**100%**	**8%**

Table 3-8. LCI survey responses by industry sector

Industry sector	Sample count (recruited)	Target number of responses	Responses		Response rate
			Count	Percent	
Agricultural, construction, and mining	55	8	8	13%	15%
Electric distribution, nat. gas, and water	26	8	1	2%	4%
Manufacturing	129	8	5	8%	4%
Wholesale trade, transportation	97	8	6	10%	6%
Retail	66	8	3	5%	5%
Telecommunications, finance, data processing	108	8	11	18%	10%
Education	106	8	6	10%	6%
Hospitals	69	8	6	10%	9%
Restaurants, entertainment, other services	83	8	6	10%	7%
Government	69	8	9	15%	13%
Total	**808**	**80**	**61**	**100%**	**8%**

4. Customer Survey Responses

4.1 Post-survey adjustments

This section provides details about how the survey data was initially cleaned and used to calculate the costs described in the sections below. First, we describe the different costs and savings that respondents experience. Next, we describe how each of those costs was calculated.
The costs incurred and savings realized from power interruptions are classified as *direct* or *additional*.

Table 4-1 summarizes the cost and saving components by customer segment. Additional cost and savings components are specific to certain resilience tactics, but all customers report direct costs. Accordingly, these cost estimates are specifically used in the calibration of the POET model, which is designed to estimate the full economic impact of power interruption to households and industrial sectors–and the broader regional economy.

Table 4-1. Types of costs incurred and savings realized during power interruptions by customer segments

Cost category	Residential	Non-residential
Direct	**Costs to respondents without backup generators** ● Spoilage of food **Costs to respondents regardless of backup generator operations** ● Income losses (after accounting for the household members' ability to make up for lost income)	**Costs to respondents without backup generators** ● Damage/spoilage to raw or intermediate materials **Costs to respondents regardless of backup generator operations** ● Lost revenue (after accounting for its ability to make up for lost production) **Savings regardless of backup generator operations** ● Savings in electricity bill due to the reduced electricity consumption
Additional	**Costs to respondents without backup generators** ● Costs of meals, delivery, lodging, and transportation **Costs to respondents with backup generators** ● Fuel costs to run backup generator	**Costs to respondents without backup generators** ● Additional costs of additional safety and security ● Costs to transfer business or other activities to other locations with power **Costs to respondents regardless of backup generator operations** ● Labor costs to make up lost production ● Additional costs to restore operation **Costs to respondents with backup generators** ● Fuel/backup generator rental costs

		Savings regardless of backup generator operations ● Savings in labor costs during power interruptions

To start, all survey responses were reviewed thoroughly for completeness and for any potential outliers. Special effort was devoted to methodically infilling missing responses, whenever possible, to maximize the sample size and allow a more detailed analysis of the data.

Most of the cost and savings data were obtained using open-ended "direct questions." The survey asks each respondent to provide estimates for each cost and saving category (e.g., "How much would you avoid on your electricity bill from this power interruption?"). In instances that a cost or savings estimate could not be directly calculated from a response, additional intermediary steps were taken to arrive at a value. The following sections provide greater detail about each cost and savings category and process to clean and/or calculate the data.

4.2 Residential customers

For residential customers, the cost and savings data were calculated at the household level. This includes costs and savings not only incurred by a survey respondent but for all members of the household.

Food spoilage

Value of spoiled food was assessed using two different methods. For the respondents who decided to stay in their homes, we directly asked about the approximate value of spoiled food and used the responses without any adjustments. For the respondents who decided to move to different locations temporarily, we estimated the values using the following steps:

1. We estimated the value of perishable food stored in refrigerators and freezers separately. If respondents skipped these questions, we assumed the values were $0.
2. Following the Centers for Disease Control and Prevention's (CDC) recommendation, we assumed that the food stored in the refrigerator would start to decay after four hours without electricity (CDC, 2022). Under that assumption, we assumed that 75% of the approximate value of perishable food stored in their refrigerators would be lost at the end of the one-day power interruption (and the remaining 25% was consumed).
3. For the longer interruptions, we assumed that the food stored in freezers would start to decay after 48 hours without electricity. Under that assumption, we assumed that 75% of the approximate total value of perishable food stored in their refrigerators and freezers would be lost at the end of the power interruptions—and the remaining 25% would be consumed.

Lost income

The total household lost income was calculated based on the number of household members currently working and whether their income was salaried or hourly wages. The procedure for calculating the total household lost income was performed for the following three scenarios:

1. Respondents who had no one currently working in their household were given a lost income of $0.
2. Respondents with one working person in their household had the lost income calculated directly from the survey questions.
3. The total lost income for respondents with more than one working person in their household was calculated by adding the individual respondent's lost income and the lost income from other hourly workers in the household who indicated they would not be paid because of the interruption. Non-respondent household members who were paid a yearly salary were assumed to have a lost income of $0. This assumption is based on salaried employees not losing income due to power outages.

After calculating the total household lost income, the data were checked for implausibly high values. These values were likely the result of respondents misreading or misunderstanding the survey question, which asked for the respondents' average monthly income. Given the very large values of some answers, it is likely that a few respondents entered their yearly income instead. These outlier values were detected using the 98th percentile of total lost income responses and flagged as outliers. Through this process, 25 out of 829 income-related responses were flagged as outliers.

Costs of meals, lodging, and transportation

There are a few cost components that were asked on a daily basis: cost of meals and delivery, cost of meals and transportation, and cost of meals and lodging. It became evident that some respondents provided the total costs rather than their daily costs. We used the following approaches to address these incorrect responses:

1. We first determined the number of household members. If the respondents did not provide the number of household members, we assumed the household size to be one.
2. For the cost of meals and delivery and the cost of meals and transportation, we assumed the upper bound of the daily cost to be $150 (determined using the 1.5 Interquartile Range rule (i.e., 1.5 times interquartile range above the third quartile)) multiplied by the number of household members. If the estimates provided by the respondents were higher than the upper bound, we assumed that the respondents provided the total costs.
3. For the cost of meals and lodging, we assumed the upper bound of the daily cost to be $370 (determined using the 1.5 Interquartile Range rule (i.e., 1.5 times interquartile range above the third quartile)) multiplied by the number of household members. If the estimates provided by the respondents were higher than the upper bound, we assumed that the respondents provided the total costs.
4. If the response was flagged for providing total costs (as opposed to daily costs), then we divided the total cost by the number of interrupted days.

Cost of transportation

In the residential survey, we asked the respondents how much it would cost to move their family members to other locations with power and transport them back after the power interruption. The responses were, however, such that we inferred that some respondents misinterpreted the question, leading them to provide implausibly high values. This was either due to the inclusion of lodging costs during the power interruption or a desire to relocate to far-off regions that exceeded the actual requirements, despite the geographic scope of the power interruption being limited to areas within a 20-mile radius of the respondents' residence. To address the issue, we overrode the one-time transportation cost for the one-day, three-day, and fourteen-day interruptions to $20, $24, and $40 for all respondents who chose to relocate.

Fuel costs to run backup generators

The respondents who wanted to power critical appliances and devices using backup generators incurred costs of running their backup generators. To estimate the fuel and/or borrowing cost of backup generators, we used the following approach:

1. Using the electric appliances the respondents would power during the power interruptions, we estimate the expected energy served in kWh.
2. Using the types of backup generators the respondents had, we multiplied the unit cost of fuel (propane generator: $0.45/kWh, diesel or gasoline generator: $0.535/kWh, natural gas generator: $0.25/kWh; data obtained from EIA 2023A-2023C) with the expected energy served. The results served as a proxy for the total fuel costs.
3. For customers not owning their own backup generation, we estimated the rental cost by estimating the most likely size of a generator that would meet 75% of the end uses that the respondent indicated required backup. We multiply this size in kW by an estimated rental cost of $20/kW-day that we obtained from a topical review of rental prices at firms in the Illinois area. Finally, total rental costs were calculated by multiplying the daily rental cost by the total duration of the interruption as determined by the duration scenario (i.e., one, three, or 14-days).

Finally, we identified outliers who did not provide valid power interruption costs. These outlier respondents consisted of those who skipped the resilience tactic selection questions even once (20 outliers out of 829 responses) and those who skipped all of the cost estimation questions for the given scenario (31 outliers out of 829). The respondents with invalid responses were excluded from the analysis. See Table 4-2 below for the numbers of respondents recruited (i.e., sample count), those who participated in the survey, and the responses deemed valid.

Table 4-2. Count of survey responses and included in the analysis by geographic area

Area	Sample count (recruited)	Target	Responses collected	Valid responses	% invalid
Rural	2,110	200	266	244	8.3%
Suburban	2,110	200	354	319	9.9%
Urban	2,110	200	209	190	9.1%
Total	**6,330**	**600**	**829**	**753**	**9.2%**

4.3 Non-residential customers

For each interruption scenario, non-residential respondents were asked to estimate a series of individual costs and savings resulting from the interruption, including avoided labor costs, cost of additional safety and security, damage to inventory and feedstock, lost revenue, savings on the respondent's electric bill, and the cost of backup generation.

Infilling missing responses

In some cases, respondents were unable to estimate one or more of these itemized costs. Leaving these missing survey responses as zero could lead to underestimating the cost and savings facing firms during power interruptions. We estimated the most critical cost and savings values, including the daily cost of backup generation, the value of lost revenue, and electric bill savings by using the respondent's average energy demand, stated type and capacity of backup generator, annual total revenue and other metrics.

Adjusting implausible estimates

A second concern with cost and savings estimates from survey data is respondents giving inaccurate estimates of their true costs and savings during a power interruption. This may result from hypothetical bias, strategic response, respondents misunderstanding the survey question, or imputation error from the survey administrator. More specifically, we were concerned about respondents who may have grossly overestimated specific cost and savings values.

To address this issue, we evaluated how plausible each respondent's cost and savings estimates were, based on the respondent's observed characteristics (e.g., number of employees, average electricity demand, average annual revenue). Each estimated cost or savings value was divided by these metrics– the respondent's average energy demand (in kW), the respondent's reported annual revenue (in USD), and the respondent's total number of employees. This procedure led to three normalized values for each cost or savings estimate given by the respondent: ($ cost or savings)/(kW of average demand), ($ cost or savings)/($ annual revenue), and ($ cost or savings)/(employee).

If a respondent's reported answer to a given cost or savings question exceeded 1.5 times the 75th percentile of the distribution of normalized values of the entire survey population after normalization by two or three of the three metrics, the respondent's reported answer was determined to be implausibly high based on the firm's given characteristics. For example, one of the values respondents were asked to estimate was their savings in labor costs as a result of a one-day power interruption. For this question, respondents were asked to report a dollar value. For each respondent, this dollar value was then divided by the respondent's average demand, the respondent's reported annual revenue, and the respondent's reported number of total employees, yielding three normalized versions of this value. Next, for each respondent, each of these normalized metrics was compared against its distribution in the survey population. If two or three of these normalized estimates both independently exceeded 1.5 times the 75th percentile of their respective distributions for the survey population, the respondent's reported savings would be considered implausibly high and flagged for adjustment.

For respondents flagged for adjustment, the self-reported estimates were then replaced by the median kW-normalized value within the respondent's industry, rescaled by the respondent's actual average demand. We used this normalized value to replace implausible self-reported estimates because the total revenue and the total number of employees were not reported by all respondents whereas average electricity demand was available because it was provided directly by ComEd. Second, we used the *within-industry* median as the replacement value as opposed to the median population value to account for differences in kW-normalized costs and savings across industries. However, industry-specific values were not used in identifying implausibly high estimates due to the small sample size per industry. Figure 4-1 describes this process for one of the cost values non-residential respondents were asked to estimate–lost revenue as a result of a one-day long power interruption. This figure highlights the process used to identify implausible responses for this specific question, but the same methodology was applied to all other savings and cost questions.

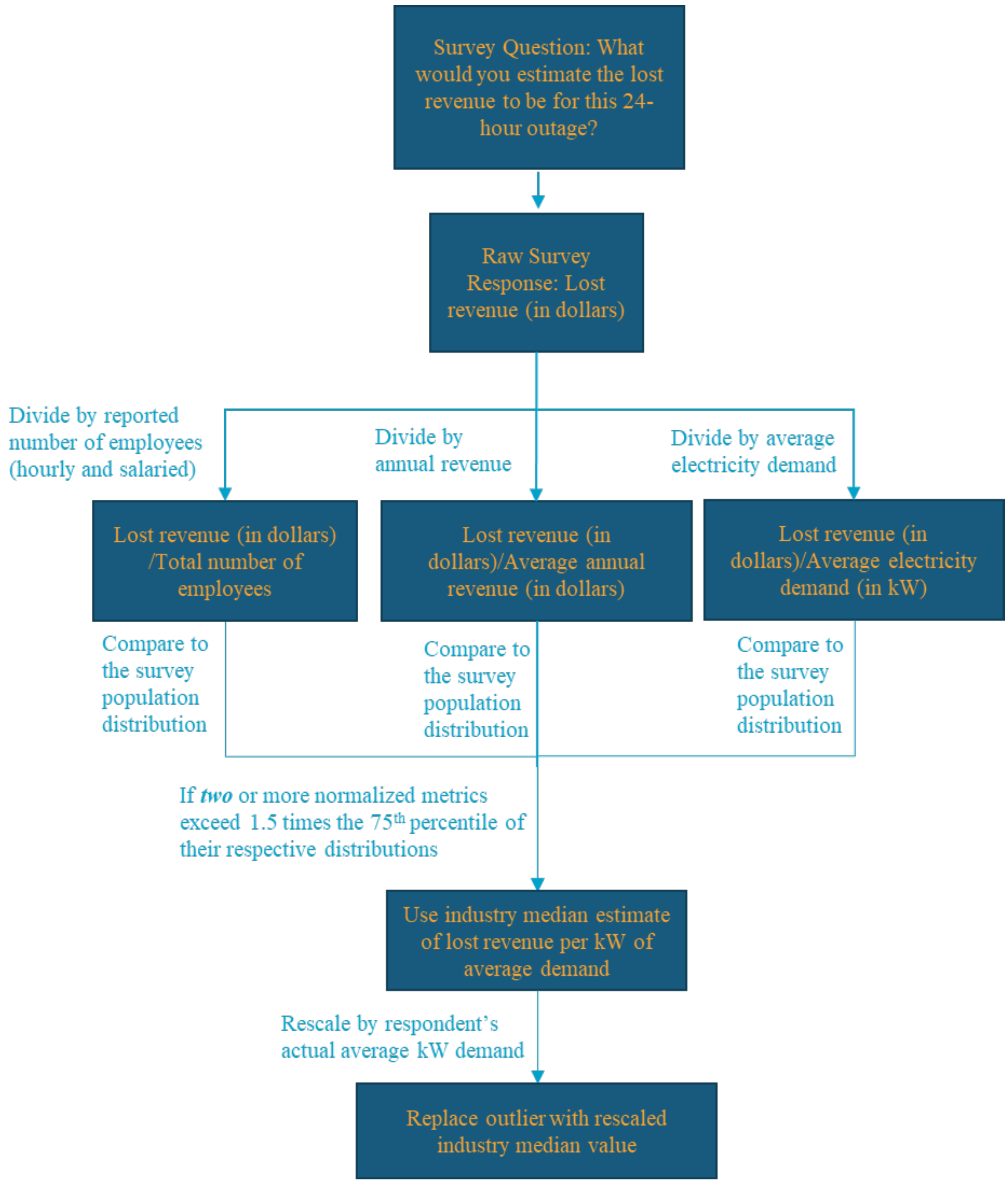


Figure 4-1. Methodology for adjusting non-residential outliers for costs and savings questions

4.4 Customers' backup generation and their fuel source

A key question in both the residential and non-residential surveys was whether customers had access to a backup generator. Figure 4-2 shows the percentage of respondents who indicated they have some form of backup generation. Approximately 12% of residential respondents, 22% of SMB, and 71% of LCI respondents have backup generation.

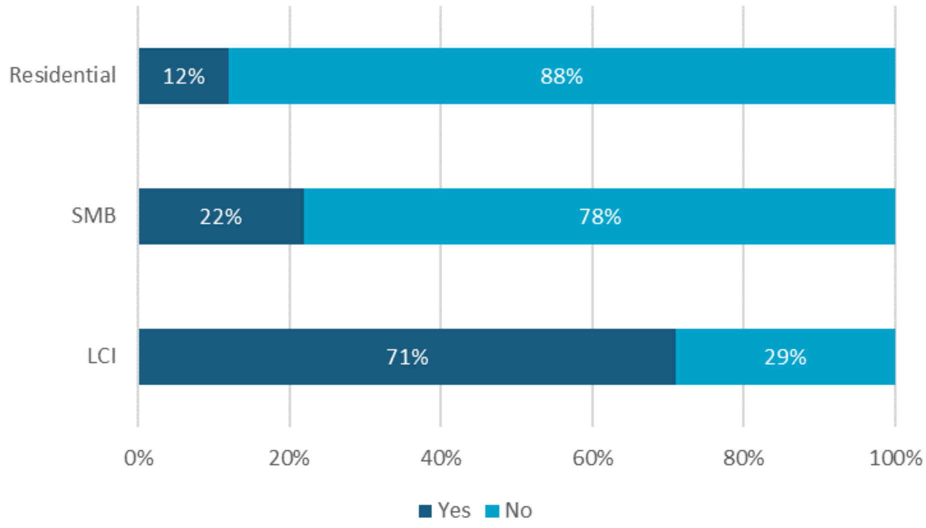


Figure 4-2. Percentage of customers with backup generation

Figure 4-3 presents the fuel source for respondents' backup generators. The most common fuel source for all three customer groups was diesel or gasoline (54-63% of all backup generation). For residential and SMB, this was followed by natural gas and propane; none of the LCI customers reported having a propane-fueled backup generator.

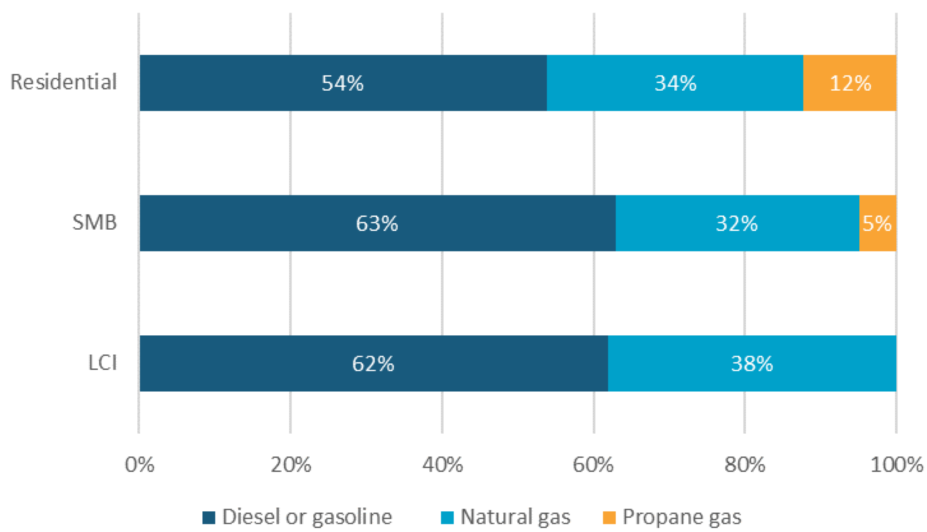


Figure 4-3. Fuel source for backup generators

Residential customers

Figure 4-4 shows the percentage of residential respondents' resilience tactics by the length of power interruption. During a one-day interruption, 54% of respondents indicated they would stay home and participate in activities that do not require electricity, while 33% of respondents said they would temporarily move. However, when respondents were presented with the 14-day interruption, only 8% stated they would stay home, and 83% said they would temporarily move. When comparing outage length, as the duration increases and more customers opt to evacuate their homes, residential customers are expected to face higher daily and total costs, including relocation expenses (e.g., transportation, food, and lodging). Finally, the percentage of respondents who indicated they would use backup generation stays relatively stable regardless of the interruption duration. The percentage of respondents using backup generation falls from 13% for a one-day interruption to 9% for a 14-day interruption. The decrease in percentage is likely from customers not having enough fuel onsite to power their generators during a 14-day interruption, so they would eventually have to relocate to an area unaffected by the power interruption.

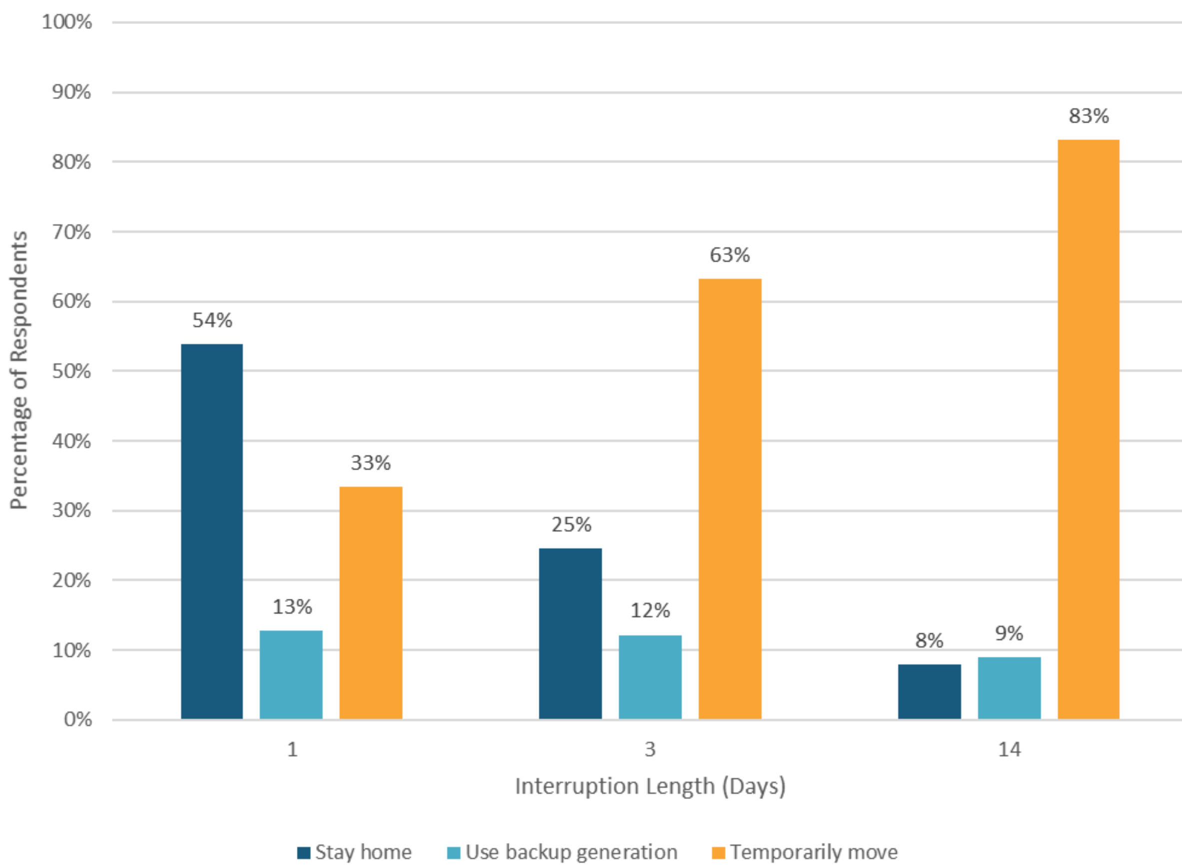


Figure 4-4. Residential resilience tactics by interruption duration

Figure 4-5 shows the resilience tactics for residential respondents broken down by income level. The respondents are binned into four income categories based on their total annual household income before taxes. Interestingly, respondents in the lowest income bracket, those with a household income of less than $50,000, are more likely to temporarily move during a one-day interruption than respondents in other income brackets. As expected, respondents in the lowest income bracket are also less likely to have backup generation compared to those with higher household incomes.

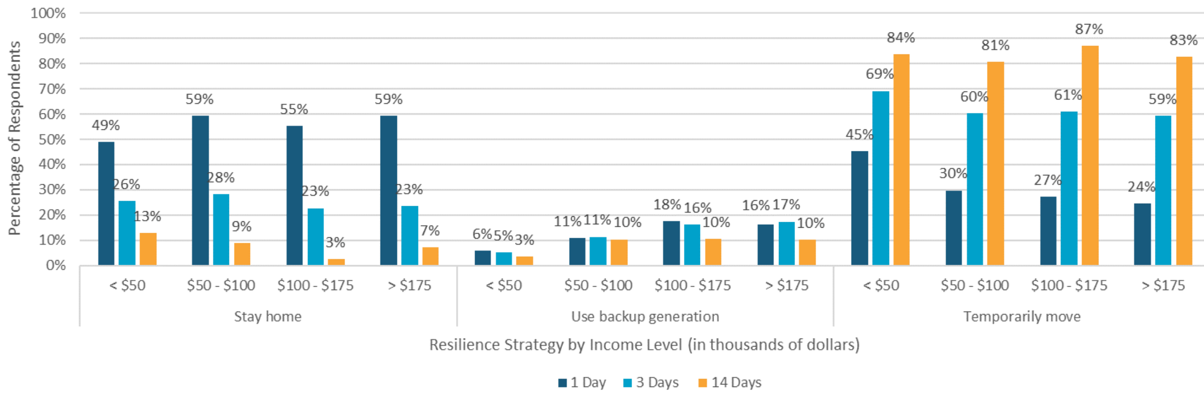


Figure 4-5. Residential resilience tactic by interruption duration and income level

Non-residential customers

SMB and LCI respondents selected one of four different resilience tactics for each interruption duration. Figure 4-6 and Figure 4-7 show the percentage of SMB and LCI respondents that picked each tactic by interruption duration, respectively. The most common tactic selected by SMB respondents for each interruption duration was to shut down the facility. However, when presented with an outage scenario of one day versus 14-days, the percentage of respondents who selected to shut down their facilities fell from 49% to 39%. In turn, some respondents shifted their tactic to renting backup generation or transferring operations to another facility based on the outage length. These two resilience tactics allow a business to continue functioning, although the level of production may be lower than normal. The percentage of respondents who would use backup generation already onsite stays constant regardless of the interruption duration.

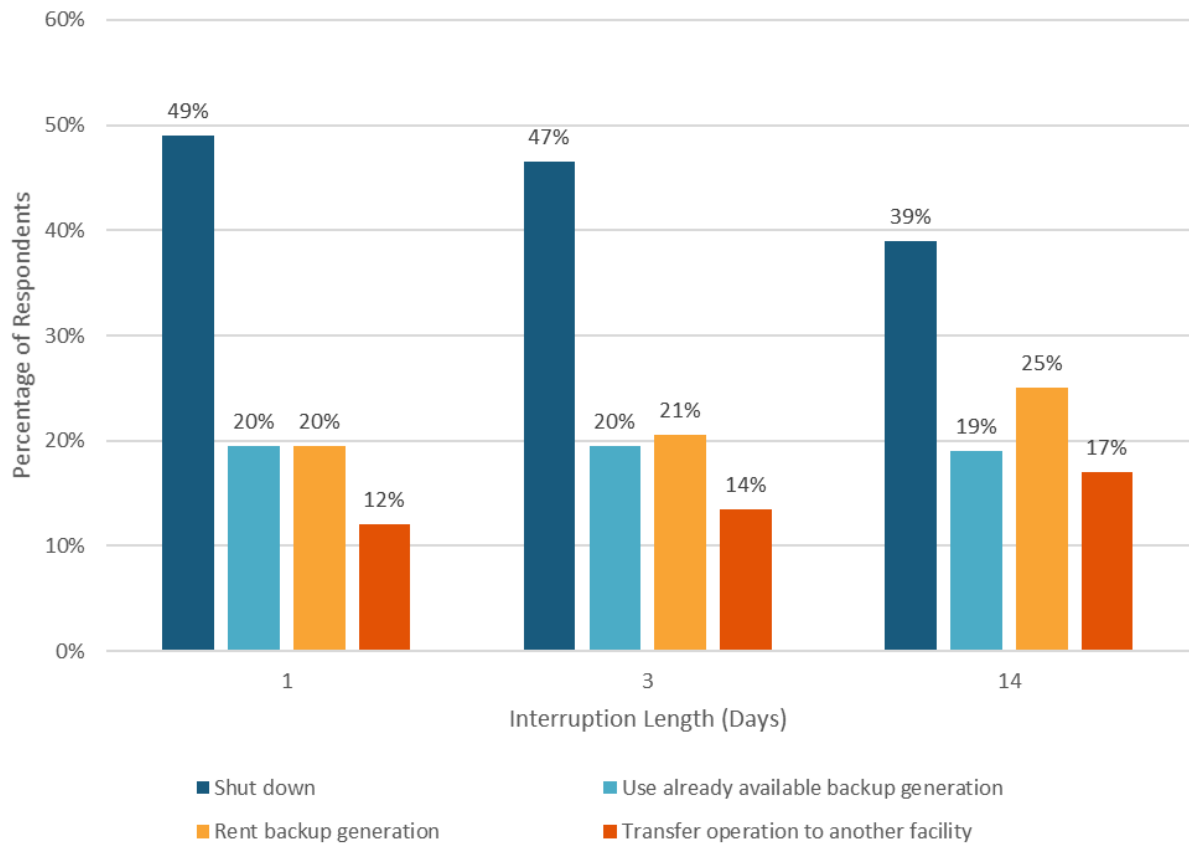


Figure 4-6. SMB resilience tactic by interruption duration

The resilience tactics selected by LCI respondents show a similar pattern to SMB respondents. Namely, shutting down the facility is the most common tactic, but respondents select it less frequently when presented with longer durations. The percentage of respondents who indicated they would shut down the facility drops from 54% for a one-day interruption to 31% for a 14-day interruption. While the percentage of respondents who rent backup generation increases from 10% for a one-day interruption to 26% for a 14-day interruption. Interestingly, there are a handful of respondents who indicated that they would transfer operations for a three-day interruption, but rent backup generation for a 14-day interruption. As shown in the figure below, the percentage of respondents who indicated they would transfer operations falls from 16% for a three-day interruption to 11% for a 14-day interruption.

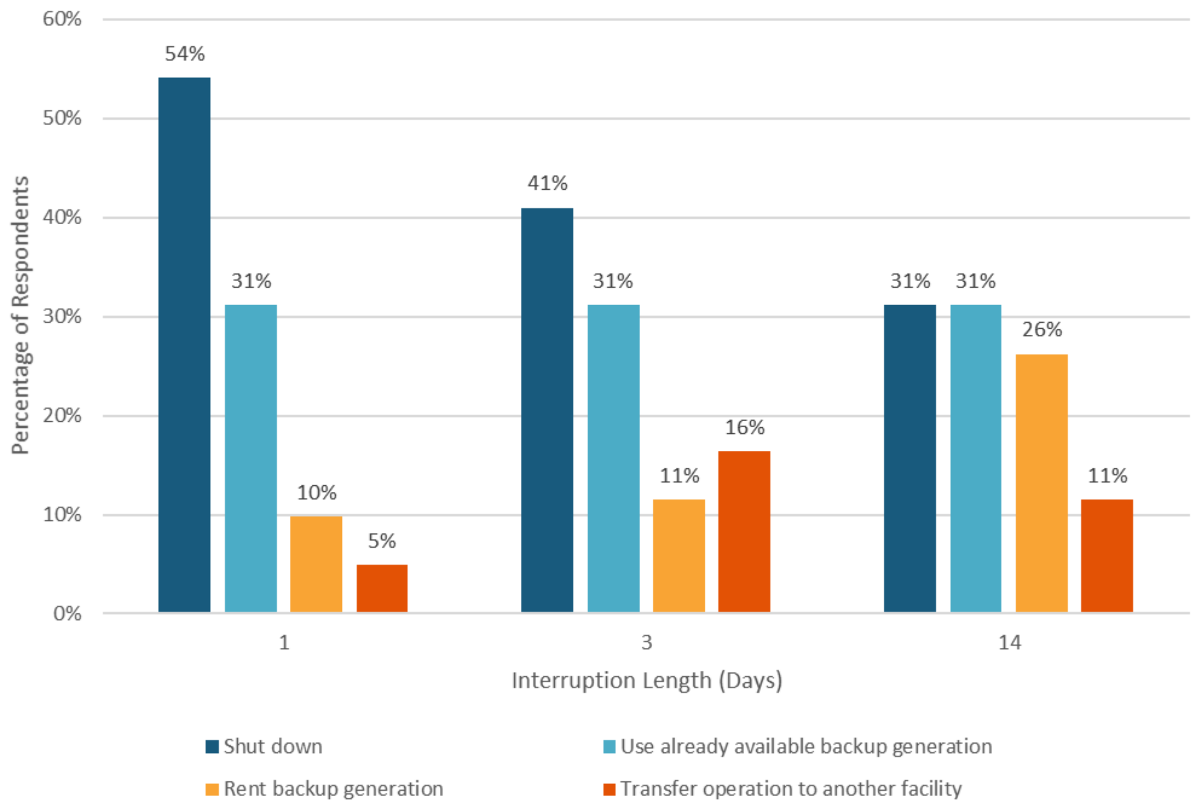


Figure 4-7. LCI resilience tactic by interruption duration

5. Introduction to POET and Calibration

5.1 POET computable general equilibrium model

This section summarizes the CGE simulation model of the Upper Midwest tri-state (Illinois-Indiana-Wisconsin) macro-regional economy. For this study, the model simulates the regional economy and its constituent groups of counties before the interruption occurs (i.e., business as usual) and at the end of a three-month period from the onset of an electricity disruption.

A CGE model is a stylized computational representation of the circular flow of the economy (see Figure 5-1 below). Households are endowed with factors of production, such as labor and capital, which they own and rent them out to firms in various industry sectors. Firms use these factors, along with purchases of goods and services that are produced by other firms, to produce output, which they in turn sell to household and firm customers. Households' purchases of commodities produced by firms are financed by income received from firms' payments for their factors inputs.

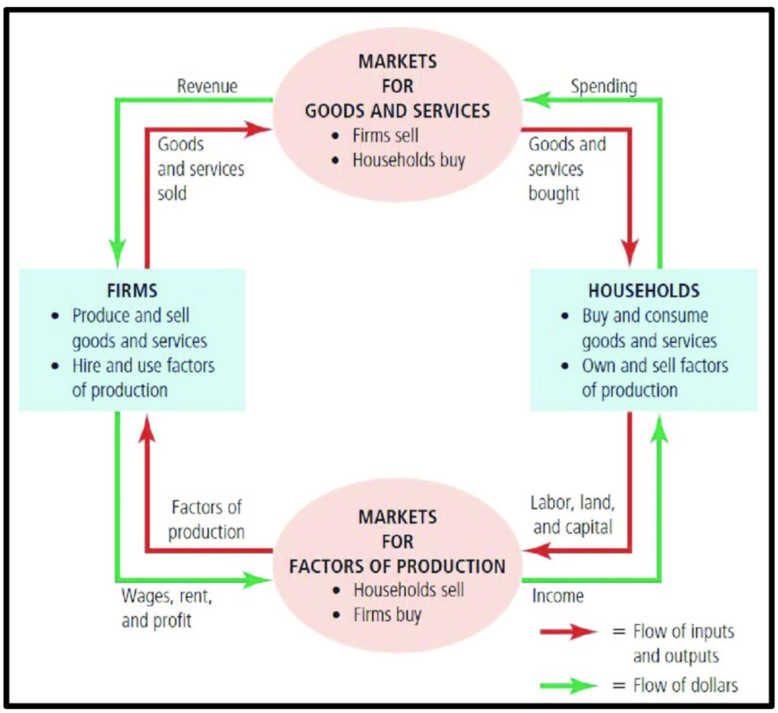


Figure 5-1. Basic circular flow diagram of a market economy (Mankiw 2021)

The CGE model simulates the equilibrium states of an economy. Three sets of balancing conditions are obtained when an economy is in equilibrium. First, the quantity of each factor demanded by firms is equal to the quantity of that factor supplied by households, and the quantities of a specific commodity demanded by all firms and households equals the quantity of that commodity supplied by the firms that produce it. This condition is known as *market clearance*. Second, the value of any firm's output (i.e., the product of the ruling price of the output good and the quantity of that good produced) is equal to the sum of the values of all commodity and factor inputs necessary to produce that output. Moreover, every firm allocates its inputs according to a production plan that brings the cost of each unit of its output into line with the ruling market price of the output commodity. This condition is known as *zero profit*, which allows for a normal rate of return on investment. Finally, the value of every household's total expenditures on commodities (i.e., the ruling price of each good multiplied by the quantity consumed, summed over all goods) is equal to the value of income, namely, remuneration received from supply of the household's factor endowment (i.e., the price of each factor multiplied by the quantity of the factor with which the household is endowed, summed over all factors). This condition is known as *income balance*.

These conditions are coupled with foundational assumptions about the behavior of consumers and producers. It is assumed that every consumer in the economy attempts to maximize their individual economic well-being ("utility") by allocating their consumption of different goods and services, subject to the constraint of their budget, which is circumscribed by the income they are able to obtain from supply of their factor endowment. The solution to this utility-maximization problem is a set of household demand functions that delineate the relationship between the quantity of commodities purchased, their corresponding market prices, and the household's income. It is further assumed that every firm attempts to maximize its profit by allocating their inputs of different factors, as well as inputs of commodities produced by other firms (so-called "intermediate inputs"), to the production process.

The solution to this profit-maximization problem is a set of factor and commodity demand functions that delineate the relationship between the quantities of factor and intermediate goods purchased, their corresponding market prices, and the level and market price of the firm's output. The general equilibrium of an economy can be expressed as a system of nonlinear equations. To solve this system numerically, it is parameterized or calibrated using economic accounts, and then solved to determine the prices of commodities and factors, as well as the levels of activity for households (i.e., utility or income) and firms across different industry sectors (i.e., output). Therefore, the CGE model characterizes the economy as a set of interrelated supply chains.

CGE models are numerically calibrated to simulate economies based on social accounting matrices (SAMs). SAMs are summary numerical representations of all market transactions in an economy during a specific period in time, usually one year. Supplies of the goods and services traded in the economy are disaggregated by the industries that produce them. Uses of goods and services are recorded by the entities that demand them, including intermediate consumption of each industry's output by the other industries in the economy, as well as final uses by household types broken out by income brackets. In addition, government sales and purchases are included, as are imports and exports, and investment. By construction, a SAM represents an economy in equilibrium, satisfying the zero profit, market clearance and income balance conditions. The calibration procedure computes numerical values for the parameters of the model's simultaneous equations, such that when the model is solved, it immediately replicates the equilibrium transactions recorded in the SAM without having to iterate over prices.

For this study, SAM data for the ComEd regional economy and surrounding areas (see below) for the year 2019 were purchased from IMPLAN, Inc., the primary source for data of this type in the United States. IMPLAN creates SAMs using U. S. government and other data at national and state levels, and for many types of economic accounts downscaled to geographic locations such as counties.

The POET model solves for the set of commodity and factor prices and activity levels of firms' outputs and households' incomes that equalize supply and demand across all markets in the Upper Midwest tri-state economy. Geographically, the model divides the economy into 15 micro-regions[9] (see Table 5-1 below):

- nine interruption-impacted ComEd micro-regions—Cook, DuPage, Kane, Lake, McHenry, and Will counties and three ComEd county aggregates (Dekalb-Kendall, Grundy-Kankakee, and 15 rural counties in the ComEd service area)
- three state-specific aggregates of counties adjacent to ComEd's service area (10 in Illinois, four in Indiana, and one in Wisconsin);
- aggregates of the remaining, non-adjacent counties in Indiana (88 counties), Wisconsin (71 counties), and Illinois (67 counties); and,
- all counties inside and outside of ComEd's service territory in Illinois, Indiana, and Wisconsin.

Table 5-1. Micro-regions impacted within POET model

Micro-region Impacted	Micro region: County or counties
1	Cook
2	Dekalb and Kendall
3	Dupage
4	Grundy and Kankakee
5	Kane
6	Lake
7	McHenry
8	Will
9	Rural ComEd: Winnebago, Boone, Ford, LaSalle, Lee, Stephenson, Jo Daviess, Carroll, Whiteside, Marshall, Ogle, Woodford, Bureau, Henry, and Livingston
10	Illinois counties adjacent to ComEd: Iroquois, McLean, Tazewell, Peoria, Stark, Putnam, Rock Island, Mercer, Knox, and Champaign

[9] Throughout this analysis, we use the term micro-region to describe a county or groups of counties within Illinois, Indiana, and Wisconsin.

Micro-region Impacted	Micro region: County or counties
11	Remainder of Illinois counties
12	Indiana counties adjacent to ComEd: Porter, Newton, Lake, and Jasper
13	Remainder of Indiana counties
14	Wisconsin counties adjacent to ComEd: Kenosha
15	Remainder of Wisconsin counties
16	All of ComEd
17	All counties in Illinois, Indiana, and Wisconsin

Within each micro-region the model divides the economy into 38 industry groupings (Table 5-2), each of which is modeled as a single representative firm that produces a single good or service[10]. Table 5-2 also shows the relationship between the industry groupings used in the POET model and the sectors used in the non-residential surveys of ComEd's customers. In each region, the model groups households into nine income classes, each of which is modeled by a representative consuming agent that saves a fixed fraction of their income. The government is also represented in a simplified fashion–its role in the circular flow of the economy is passive–collecting taxes from industries and passing some of the resulting revenue to the households as lump-sum transfers, in addition to purchasing commodities to create a composite government good consumed by the households. Two factors of production are represented within the model: labor and capital, both of which are owned by the representative agent and rented out (supplied) to the firms in exchange for factor income. In line with prior disaster-related studies that simulate the equilibrium of the economy on comparatively short timescales, each sector in each micro-region is assumed to utilize its own specific type of capital.

Table 5-2. Sectors used in surveys mapped to sectors used in POET model

Sectors used in customer surveys	Sectors evaluated in POET model
Agricultural, construction, and mining	Agriculture, forestry, fishing and hunting Construction Mining
Electric distribution, natural gas, and water	Electric power generation Electric power transmission and distribution

[10] The table presents 37 sectors, but there is technically an additional sector that is not used ("Rest of the economy"). The rest of the economy consists of sectors that are balancing line items in the IMPLAN SAM that do not directly map to any of the sectors used in the customer surveys.

Sectors used in customer surveys	Sectors evaluated in POET model
	Natural gas Water and sewer
Manufacturing	Food, beverage and tobacco products Manufacturing Motor and generator manufacturing Refined petroleum products
Wholesale trade, transportation	Transportation Warehousing and storage Wholesale trade
Retail	Retail (food and beverage stores) Other retail trade
Telecommunications, finance, data processing	Data processing, hosting, and related services Finance and insurance Internet publishing and broadcasting Telecommunications Other information services Real estate
Education	Educational services
Hospitals	Hospitals
Restaurants, entertainment, other services	Administrative and waste services Arts, entertainment and recreation Hotels and motels (including casino hotels) Management of companies Restaurants Other accommodation and food services Other health and social services Other services Private dwellings Professional, scientific, and technical services Rental and leasing services Repair
Government	Governments

Each micro-region is modeled as an open economy that engages in trade with other micro-regions listed in Table 5.1, as well as with the rest of the United States and the rest of the world. Micro-regions export commodities into a common pool of supply at the macro-regional level, which satisfies demands for intra-regional imports, as well as exports to the rest of the U.S. and the rest of the world. It is assumed that goods produced in a particular micro-region are imperfect substitutes for commodities imported from elsewhere—i.e., all else being equal, consumers in that region will prefer goods that are locally produced even if they are otherwise the same as imports. The model computes the prices and quantities of goods and factors that equalize supply and demand in all markets in the macro-regional economy, subject to constraints on the external balance of payments that bring the value of imports and exports into line with one another.

Electricity interruptions exert two effects on the economy, impacts on market equilibrium and disequilibrium impacts. Market equilibrium impacts are modeled as a curtailment in the use of the electricity distribution service commodity by industries, households and government entities, which has the effect of increasing the cost of distributing the residual supply of electricity that remains over the timeframe on which equilibrium is computed. That is, the curtailment of electric power supply below the level that would be demanded under baseline economic conditions induces firms and households to substitute other inputs for electricity to the extent possible. These actions in turn stimulate price and quantity adjustments across the economy. The overall effect of these adjustments is to generally increase firms' costs of production and the prices of associated commodities, reduce factor hiring and remuneration to households, and, as households simultaneously face rising prices and declining incomes, reduce consumers' aggregate purchases, and hence economic well-being.

Disequilibrium impacts refer to types of shocks to producers and consumers that are not associated with the functioning of markets under normal economic conditions. In particular, these shocks occur precisely because the ability of markets to function in ways that would restore equilibrium is temporarily disrupted. One way to think about this is that electricity interruptions are driving a wedge between the supplies of, and demands for, a range of goods and services, in ways that the particular price and quantity adjustments outlined above are not able to close (that is, they are unable to adjust to a new equilibrium state). The upshot is that, in the face of these disequilibrium impacts, restoration of equilibrium requires a *different* set of price and quantity adjustments, which are the sources of the macroeconomic impacts that we report later in this document (e.g., gross domestic product, gross output). Firms' and households' strategies to cope with this breakdown over the period of the interruption are incorporated within our modeling framework as exogenous secular increases in economic agents'' demands for various types of commodities. The information to parameterize these secular shocks is calculated based on the responses to the survey. Importantly, because these shocks are superimposed on top of the market impacts of electric power shortages, they exert additional distortionary effects on demand, prices and income, which further perturbs the equilibrium that is eventually attained by the economy relative to its initial baseline state.

5.2 Inputs to CGE Modeling

This section summarizes the translation of the survey results into input data in terms of direct costs or savings stemming from power interruptions for individual micro-regions that can be used in the CGE simulations. This process includes identifying relevant survey questions for respondents choosing different strategies, calculating the average costs (or savings) by income group for residential customers and by industry sector for non-residential customers for each interruption duration scenario, and scaling up the estimates from the sample level to the entire population of the micro-regions to estimate the total direct costs/savings. Therefore, the results presented throughout this section serve as intermediate inputs or information used to calibrate the POET model.

Residential customers

For each cost category that is relevant to a specific coping tactic, the average cost or saving is calculated for each income group for each of the three interruption duration scenarios, based on all valid responses obtained from the survey. To ensure a sufficient sample size, the 10 income brackets used in the survey are aggregated into 3 income groups:

- Income Group 1: Less than $50,000 (survey income bracket 1-2; IMPLAN households HH1 to HH4) (n=174)
- Income Group 2: $50,000 to $100,000 (survey income bracket 3-4; IMPLAN households HH5 to HH6) (n=214)
- Income Group 3: Greater than $100,000 (survey income bracket 5-10; IMPLAN HH7 to HH9) (n=256)

Table 5-3 presents the counts and the percentages of residential customers that choose different coping strategies by income group and interruption duration in the base case scenario (i.e., the proportion of customers choosing different coping strategies as reported by survey respondents).

Table 5-3. Counts and percentages of residential responses by income group and interruption duration (base case Scenario)

	Count			Percentage		
Tactic 1: Stay home and do activities that do not require electricity	**One day**	**Three day**	**14-day**	**One day**	**Three day**	**14-day**
Income less than $50,000	85	44	23	49%	25%	13%
Income $50,000 to $100,000	127	60	19	59%	28%	8.9%
Income greater than $100,000	144	58	11	56%	23%	4.3%
Refused to answer	88	40	12	48%	22%	6.5%
Tactic 2: Run backup generator or battery storage	**One day**	**Three day**	**14-day**	**One day**	**Three day**	**14-day**
Income less than $50,000	10	10	7	5.7%	5.7%	4.0%
Income $50,000 to $100,000	23	24	22	11%	11%	10%

Income greater than $100,000	43	42	26	17%	16%	10%
Refused to answer	29	24	18	16%	13%	9.7%
Tactic 3: Temporarily move	**One day**	**Three day**	**14-day**	**One day**	**Three day**	**14-day**
Income less than $50,000	78	119	144	45%	68%	83%
Income $50,000 to $100,000	64	128	172	30%	60%	80%
Income greater than $100,000	67	154	217	26%	60%	85%
Refused to answer	66	119	149	36%	64%	81%
Respondent did not select any resilience tactic	**One day**	**Three day**	**14-day**	**One day**	**Three day**	**14-day**
Income less than $50,000	1	1	0	0.6%	0.6%	0.0%
Income $50,000 to $100,000	0	2	1	0.0%	0.9%	0.5%
Income greater than $100,000	2	2	2	0.8%	0.8%	0.8%
Refused to answer	2	2	6	1.1%	1.1%	3.2%
Total	**One day**	**Three day**	**14-day**	**One day**	**Three day**	**14-day**
Income less than $50,000	174	174	174	100%	100%	100%
Income $50,000 to $100,000	214	214	214	100%	100%	100%
Income greater than $100,000	256	256	256	100%	100%	100%
Refused to answer	185	185	185	100%	100%	100%
Grand total	**829**	**829**	**829**			

After we calculate the average cost/saving at the sample level, the total number of households by income group are obtained from IMPLAN (see Appendix C, Table C - 1) costs incurred and total savings realized at the population level for the entire micro-region. For a given cost category pertaining to a specific tactic, the total cost/saving for each micro-region is calculated using Equation 1:

$$TC_{i,r,d} = AC_{i,d} \cdot THH_{i,r} \cdot P_{i,d} \quad (1)$$

where

$TC_{i,r,d}$: Total cost (saving) of a given cost category for income group *i* in micro-region *r* for interruption duration *d*

$AC_{i,d}$: Average cost (saving) of a given cost category for income group *i* and interruption duration *d* calculated based on survey responses

$THH_{i,r}$: Total number of households of income group *i* in micro-region *r*

$P_{i,d}$: Percentage of residential survey respondents in income group *i* that choose a specific tactic for interruption duration *d*

i: Aggregate income group (i=1,2,3)

d: Interruption duration (d=1,3,14)

r: Micro-region (r=1, 2, … 10)

Key assumptions for residential sector model calibration

In order to calibrate the CGE model, we made a set of detailed assumptions about the residential sector, which are summarized in Table 5-4 below.

Table 5-4. Key assumptions for residential sector model calibration

Category	Assumption
Average cost/savings by income group	The average costs/savings by income group are calculated from respondents that have selected one of the three residential customer coping strategies and have identified which income category they belong to.
Cost of meals for customers that remain at home	There are two sets of estimates associated with the cost of meals for customers that remain at home without backup generators. The first set is the cost of meals delivered, of which we use the total cost to increase the demand for the *Restaurants* sector within the CGE modeling framework factoring in the displacement effects of regular food purchases. The second set of costs includes both the cost of the meals and the transportation cost people incurred to pick up the food or drive to the restaurant to dine in. Since we do not have information on the split between meal cost and transportation cost, we assume that 10% of the cost is associated with transportation. Moreover, many people that remain at home without backup generators indicated that they would "eat cold foods, BBQ, camp stove and other home cooking." For these people, we assume the cost of meals remains the same as the baseline level.
Transportation cost of relocating	A number of respondents appeared to misinterpret the question asking for the transportation cost of relocation (see earlier discussion). Therefore, we estimated the transportation cost based on some simple, but reasonable assumptions rather than using the survey responses. The scenarios assume that the power interruption extends across a 20-mile radius of someone's home. If we assume the family relocates to somewhere 20 miles away, the round trip would cost about $8 for gasoline (assuming 20 mpg and $4/gal). However, we also recognize that there may be additional transportation-related costs to consider. For longer interruption durations, people may need to make multiple round trips between their homes and the temporary location. Therefore, we assume that the average per-household relocation transportation cost is $20, $24, and $40 for the one-day, three-day, and 14-day

Category	Assumption
	disruption scenarios, respectively.
Incremental costs of meals when relocating	We estimated the incremental cost of meals for people relocating by subtracting the business-as-usual expenditures on food and beverages to account for the fact that people would not incur these business-as-usual costs when they relocate. To estimate the normal expenditures on food and beverages, we use Bureau of Labor Statistics (BLS) data on consumer expenditures in the Chicago Metropolitan Area (BLS 2022). Average annual household expenditures on food and beverages were about $9,299 in 2020-21 or about $25/day. Therefore, the business-as-usual meal costs are subtracted from the average meal costs reported for each interruption duration scenario.
Transportation fuel expenditures	We use the default data provided in IMPLAN to distribute total expenditures on gasoline/diesel among the CGE modeling framework *Petroleum Refineries, Transportation, Retail Trade,* and *Wholesale Trade* sectors (see Table 5.5 below[11]). This includes Refined Petroleum product costs and the Transportation and Wholesale and Retail Trade costs associated with them (the latter are referred to as "margins" in IMPLAN because they represent the cost of doing business in the transportation and trade sectors and do not include the value of the products transported or sold, which is covered by the Petroleum Refining cost entry).

Table 5-5. Expenditures on petroleum products and associated transportation and trade margins (IMPLAN 2022)

Sector	% of total expenditures distributed
Transportation	1.6%
Wholesale	16%
Retail	15%
Petroleum refineries	68%
Total	**100%**

Table 5-6 presents the total costs incurred by residential customers in Cook County for the base case scenario. This information is then used in the calibration of the POET model. These costs are calculated by using Equation 1 based on the survey results and IMPLAN data on the total number of households by income bracket for each micro-region. Because of the limit in space, we present the results for Cook County as an example in Table 5.6. Similar results for other study regions and for each aggregate income group are used as inputs in the CGE simulations. Appendix B summarizes the methods used in simulating the impacts of these electricity disruption-associated costs in the CGE model, including

[11] Table 5-5 presents how the expenditures on transportation fuels are divided between the producing sector (Petroleum Refineries) and the various "margin" sectors associated with the transportation and trade services to deliver and sell petroleum products.

model equations used, parameters in the equations being shocked, and the commodities or sectors being affected.

The results for Cook County in Table 5-6 indicate that the total costs increase as the duration of power disruptions increases, from $418 million for a one-day interruption, to $1.1 billion and $4.7 billion for a three-day and 14-day interruption, respectively. The largest cost components for the one-day disruption are the cost of spoiled food for people choosing to stay but without a backup generator and the cost of relocating families for those who choose to move out of the interruption area. As the length of interruption increases, the costs associated with running backup generators for those who choose to stay and the food, and lodging costs for people who relocate increase rapidly, especially the relocation costs. Similar patterns in the relative magnitude of various types of costs and their changes across the three interruption duration scenarios are found in the results for other micro-regions as well.

Table 5-6. Total costs incurred by residential customers in Cook County by cost category and interruption duration (base case scenario) ($ millions)

Cost category	One day	Three day	14-day
Value of spoiled food	$154.7	$150.2	$55.9
Estimated cost of meal delivery	$3.4	$14.7	$7.9
Estimated cost of meals + transportation	$12.1	$14.3	$15.3
Operation cost of backup generators (fuel costs)	$1.1	$2.8	$9.3
Operation cost of backup generators (rental costs)	$1.4	$3.5	$13.3
Cost of backup generators (rental opportunity cost of BUG owners)	$3.6	$7.6	$29.1
Cost to move family members to another location and transport them back after the interruption is over	$14.0	$30.5	$66.2
Avoided transportation expense for commuting for people who relocate	-$2.9	-$15.7	-$95.3
Total cost of meals and lodging for people who relocate	$127.6	$740.6	$4,292.5
Avoided regular expenses on food and beverage for people who relocate	-$17.8	-$97.1	-$590.6
Net loss of income	$116.9	$285.5	$905.2
Total	**$414.1**	**$1,137.0**	**$4,708.9**

Non-residential customers

Since the magnitude of the costs/savings reported by the individual non-residential respondents vary significantly depending on the size of the business/enterprise, we decided to first normalize the responses using an indicator that can serve as a proxy of the size of the entity. Two potential indicators are the total number of employees and the total revenues for businesses (or the total budget for non-profit enterprises). However, since more respondents answered the question on employment (226 respondents) than the question on revenues (133 respondents), we ultimately decided to normalize the reported costs/savings by the number of employees. For the 38 entities that did not provide employment data, we used the average number of employees for their specific sector and business class type (SMB or LCI) as presented in Table 5-7.

Table 5-7. Average number of employees by industry sector and business class

Industry sector	SMB	LCI
Agricultural, construction, and mining	8	120
Electric distribution, natural gas, and water	7	100
Manufacturing	19	232
Wholesale trade, transportation	11	336
Retail	16	35
Telecommunications, finance, data processing	11	136
Education	44	447
Hospitals	30	2,705
Restaurants, entertainment, other services	14	254
Government	12	1,346

For each cost category that is relevant to a specific tactic, the average cost is calculated for each of the 10 aggregate industry sectors for the three interruption duration scenarios, respectively, based on all valid responses obtained from the survey. Table 5-8 presents the counts (and percentages) of responses (in terms of number of employees) of non-residential customers that choose alternative coping strategies by industry and interruption duration in the base case scenario.

Table 5-8. Counts and percentage of responses (in terms of number of employees) by industry and interruption duration (base case scenario)

		Count total			Percentage total		
Tactic 1: Shut down their facility except for safety and security staff		**One day**	**Three day**	**14-day**	**One day**	**Three day**	**14-day**
1	Agricultural, construction, and mining	169	116	129	15%	10%	11%
2	Electric distribution, natural gas, and water	0	0	0	0%	0%	0%
3	Manufacturing	1,376	756	241	75%	41%	13%
4	Wholesale trade, transportation	2,066	1,346	1,269	92%	60%	56%
5	Retail	277	257	162	68%	63%	40%
6	Telecommunications, finance, data processing	793	876	663	45%	49%	37%
7	Education	3,025	2,388	2,568	86%	68%	73%
8	Hospitals	5,496	5,496	5,496	34%	34%	34%
9	Restaurants, entertainment, other services	1,706	1,691	1,114	91%	90%	59%
10	Government	12,050	182	97	98%	1%	1%
Subtotal		*26,957*	*13,107*	*11,739*	*65%*	*31%*	*28%*
Tactic 2: Continue to perform tasks that do not require electricity or operate on backup power systems		**One day**	**Three day**	**14-day**	**One day**	**Three day**	**14-day**
1	Agricultural, construction, and mining	111	118	102	10%	10%	9%
2	Electric distribution, natural gas, and water	14	14	14	12%	12%	12%
3	Manufacturing	42	241	401	2%	13%	22%
4	Wholesale trade, transportation	107	149	124	5%	7%	5%
5	Retail	44	56	56	11%	14%	14%
6	Telecommunications, finance, data processing	772	319	192	43%	18%	11%

7	Education	0	1	447	0%	0.03%	13%
8	Hospitals	10,850	10,850	10,850	66%	66%	66%
9	Restaurants, entertainment, other services	100	83	93	5%	4%	5%
10	Government	269	229	193	2%	2%	2%
Subtotal		*12,309*	*12,061*	*12,472*	*30%*	*29%*	*30%*
Tactic 3: Temporarily shut down the facility until backup power systems can be rented		**One day**	**Three day**	**14-day**	**One day**	**Three day**	**14-day**
1	Agricultural, construction, and mining	34	45	66	3%	4%	6%
2	Electric distribution, natural gas, and water	100	100	100	88%	88%	88%
3	Manufacturing	402	670	889	22%	37%	49%
4	Wholesale trade, transportation	23	12	614	1%	1%	27%
5	Retail	76	91	186	18%	22%	45%
6	Telecommunications, finance, data processing	94	95	451	5%	5%	25%
7	Education	468	663	431	13%	19%	12%
8	Hospitals	12	0	0	0%	0%	0%
9	Restaurants, entertainment, other services	63	94	382	3%	5%	20%
10	Government	24	432	497	0%	4%	4%
Subtotal		*1,296*	*2,201*	*3,616*	*3%*	*5%*	*9%*
Tactic 4: Transfer operations to locations outside the area affected by the interruption		**One day**	**Three day**	**14-day**	**One day**	**Three day**	**14-day**
1	Agricultural, construction, and mining	850	885	867	73%	76%	74%
2	Electric distribution, natural gas, and water	0	0	0	0%	0%	0%
3	Manufacturing	11	164	300	1%	9%	16%
4	Wholesale trade, transportation	58	747	247	3%	33%	11%

5	Retail	12	5	5	3%	1%	1%
6	Telecommunications, finance, data processing	122	491	474	7%	28%	27%
7	Education	20	462	68	1%	13%	2%
8	Hospitals	23	35	35	0%	0%	0%
9	Restaurants, entertainment, other services	6	6	285	0%	0%	15%
10	Government	0	11,500	11,556	0%	93%	94%
Subtotal		*1,102*	*14,295*	*13,837*	*3%*	*34%*	*33%*
Total: All tactics		**One day**	**Three day**	**14-day**	**One day**	**Three day**	**14-day**
1	Agricultural, construction, and mining	1,164	1,164	1,164	100%	100%	100%
2	Electric distribution, natural gas, and water	114	114	114	100%	100%	100%
3	Manufacturing	1,831	1,831	1,831	100%	100%	100%
4	Wholesale trade, transportation	2,254	2,254	2,254	100%	100%	100%
5	Retail	409	409	409	100%	100%	100%
6	Telecommunications, finance, data processing	1,781	1,781	1,781	100%	100%	100%
7	Education	3,513	3,513	3,513	100%	100%	100%
8	Hospitals	16,381	16,381	16,381	100%	100%	100%
9	Restaurants, entertainment, other services	1,874	1,874	1,874	100%	100%	100%
10	Government	12,343	12,343	12,343	100%	100%	100%
Grand Total		41,664	41,664	41,664	100%	100%	100%

As in the case of the residential sector, the sample level average cost/saving estimates are used to calculate the total costs/savings at the population level for each micro-region represented in the model. Data on the total employment by industry are again obtained from IMPLAN (see Appendix C, Table C - 2). For a given cost category pertaining to a specific strategy, the total cost for a micro-region is calculated using Equation 2:

$$TC_{i,r,d} = ANC_{i,d} \cdot EMP_{i,r} \cdot P_{i,d} \quad (2)$$

Where

$TC_{i,r,d}$: Total cost (saving) of a given cost category for industry *i* in micro-region *r* for interruption duration *d*

$ANC_{i,d}$: Average normalized cost of a given cost category (calculated based on employment normalized cost) for industry *i* and interruption duration *d*

$EMP_{i,r}$: Total employment of industry *i* in micro-region *r*

$P_{i,d}$: Percentage of non-residential survey respondents in industry *i* that choose a specific tactic for interruption duration *d*

i: Aggregate industry sector (i=1,2, … 10)

d: Interruption duration (d=1,3,14)

r: Micro-region (r=1, 2, … 10)

Key assumptions for non-residential sector model calibration

Table 5-9 details the following assumptions about the non-residential sector that were used in the calibration of the CGE model.

Table 5-9. Key assumptions for non-residential sector model calibration

Category	Assumption
Fuel sources for backup generation	Based on survey responses to the question on fuel sources of the backup generation, we assume that 60% of backup generator fuel costs are from diesel and 40% from natural gas.
Fuel substitution	In the absence of data, we assume that the substitute fuels that businesses use for equipment or other tasks that typically require electricity are 50% diesel and 50% natural gas.
Additional removal of outliers	Two firms in the Wholesale Trade and Transportation sector were identified as statistical outliers based on their responses to the additional safety and security cost and value of damage to inventory questions within the 14-day interruption scenario. As a result, we exclude the responses from these two firms when calculating the respective average cost for this industry.

Table 5.10 presents the total costs incurred by the non-residential customers in Cook County for the

base case scenario. These costs are calculated by using Equation 2 based on the survey results and IMPLAN data on employment by industry for each individual micro-region. We again use Cook County as an example. Similar results by cost category for other micro-regions and by industry sector are used as inputs in the CGE simulations. We refer the readers to Appendix B again for the methods used in simulating these non-residential power interruption-related costs in the CGE model.

Table 5-10 also indicates that the total costs increase as the duration of power disruptions increases, from $1.5 billion for a one-day interruption, to $3.5 billion and $13.5 billion for a three-day and 14-day interruption, respectively, for Cook County. The largest incurred costs other than loss of revenues are the value of damaged inventories and the cost to restore production for the 1-day disruption and inventory loss and additional safety and security costs for the 14-day disruption.

Table 5-10. Total costs incurred by non-residential customers in Cook County by cost category and interruption duration (base case scenario) ($ millions)

Cost category	One day	Three day	14-day
Overtime pay or extra shifts cost for production recapture	$70.4	$300.5	$607.8
Net loss of revenue (before resilience)	$415.2	$1,473.1	$8,650.3
Electricity bill (savings)	-$47.9	-$124.6	-$464.2
Diesel fuel cost of backup generation (including fuels for on-site generation, rental generators and for substitute fuels)	$16.6	$49.5	$322.0
Natural gas fuel cost of backup generation (including fuels for on-site generation and for substitute fuels)	$8.3	$17.8	$106.6
Rental cost of backup generators	$9.0	$35.6	$247.2
Cost of transferring production to alternative locations	$25.2	$226.0	$198.2
Additional costs for production recapture	$15.0	$80.8	$162.6
Cost to restore operation	$207.1	$388.9	$537.8
Cost of additional safety and security	$66.8	$195.5	$449.0
Value of damage to inventory or feedstocks	$677.6	$855.9	$2,641.8
Cost of backup generators (rental opportunity cost of BUG owners)	$9.5	$27.3	$138.1
Total	**$1,472.7**	**$3,526.4**	**$13,597.2**

Note two considerations that will be addressed below. Not all of the costs or savings mentioned above are entered into the CGE model. For example, the cost of food spoilage is not entered because the food has already been purchased, and thus has no subsequent multiplier general equilibrium effect. Also, the above estimates refer to gross expenditures, and in some cases must be offset by expenditures that no longer need to be incurred. For example, household expenditures for fuel for ordinary commuting to work, shopping, family visits, etc. are no longer pertinent for those who have evacuated, and therefore must be subtracted from the fuel and transit costs, so that only the "increment" is included in the CGE analysis.

5.3 CGE impact methodology

Here we summarize the data, assumptions, and modeling steps to simulate the multi-regional economic impacts of electricity interruptions in a CGE model (see Table 5-11). The summary provides both a general characterization of the various steps involved and a pragmatic approach to reconciling unavoidable inconsistencies between extrapolated impacts based on “bottom-up” survey responses and the top-down regional economic accounts used to numerically calibrate the CGE model.

Table 5-11. Inputs to POET simulations

Category	Assumption
Residential Spending Stimuli	Expenditures for non-evacuee households that do not own a backup utility generator (BUG) are rental and fuel costs. For those who do own a BUG, we include fuel costs and an imputed rental/depreciation cost in the stimulus based on the rental cost responses from the survey. Expenses for evacuees incurred for lodging, food, and transportation are not included in their entirety, but factor in offsetting, or displaced, expenditures that would have otherwise been incurred during normal times. Therefore, only *increments* (gross values from the survey, net of ordinary expenditures for non-outage periods) are entered in the model as “shocks.” The following expenditure and displacement effects are incorporated: ● Hotels: Positive stimulus stems from hotel expenditures outside of the home incurred by evacuees. There is no Negative (Displacement) effect (households still need to pay rent on their apartments or rented houses or factor in the imputed value of their dwellings). ● Food: Positive stimulus stems from households eating at restaurants (including fast food and take-out) and negative (displacement) effect stems from the absence of the need to purchase food for home use. Negative (Displacement) effect stems from reduction in household purchase from 2 sectors in SAM accounts: Processed food (Food and Kindred Products) is assumed to be 90% of the total, and raw agricultural commodities (mainly Crops), are assumed to be 10% of the total. ● Transportation: Positive stimulus stems from the use of public transportation (bus and light rail) and is assumed to be 100% for the lowest income bracket. Use of private automobiles is assumed to be 100% for the other 2 income brackets. Negative (Displacement) effect stems from reduction in ordinary travel expenses (e.g., for a 14-day interruption, assume gasoline expenditures for 10 workdays of commuting (but could also add 2 workdays back to cover shopping trips, family visits, etc.). The CGE model allows for some substitution (displacement) of expenses incurred during outages for other consumer purchases on goods and services. Otherwise, we assume that people dip into savings to cover additional expenditures; however, replenishment of savings

	at a later date is not factored into the analysis. Residential loss of income is modeled as secular declines in the labor endowments of different household income classes within each affected micro-region.
Non-Residential Spending Stimuli	The following expenditure and displacement effects are incorporated: ● Expenditures for BUGs: For businesses, non-profits, and government agencies that do not own a BUG a positive stimulus stems from rental and fuel costs. For those who do own a BUG, we include fuel costs and an imputed rental/depreciation cost in the stimulus based on the rental cost responses from the survey. ● Expenditures on other resilience tactics were modeled as reductions in output. These shocks include the additional costs of production recapture, restoring operations, and damage to inventory and feedstocks, which we express in units of sectors' own output. ● Expenditures on additional safety and security and shifting production activity to alternative locations were modeled as increased sectoral demands for intermediate inputs of services and transportation, respectively. The CGE model allows for substitution among inputs within sectors, and for increases in the costs of sectors' production incurred by the power outage to be passed on to customers in the form of price increases in output markets. In most sectors, the residual impact is a decline in production activity and output.

Procedures to construct household shocks

We employed a two-step procedure to generate shocks to consumers' demands during the outage. In the first step, scaled-up results from the survey on induced additional household purchases were matched to overlapping groups of commodities in the IMPLAN economic accounts, and induced purchases were expressed as fractions of IMPLAN's benchmark 3-month expenditures on those sets of commodities by households in different income classes (see Table 5-12 below). The result is a vector of expenditure coefficients by additional impact category, household income group and affected micro-region. In the second step, benchmark 3-month expenditure on each individual commodity is multiplied by the expenditure coefficients for impact categories where the commodity belongs to the affected group of goods (see Table 5-13 below). The result is a vector of exogenous demands by commodity, household income group and affected micro-region.

Table 5-12. Summary of IMPLAN impact categories matched with survey responses

Category	Impact category	Survey output (numerator)	Matched commodity group of IMPLAN household expenditures (denominator)
Non-Evacuees	Spoiled food	Food purchases to replace spoilage	Agriculture Food products
	Delivered meals	Meal delivery expenditures	Food & beverage stores Restaurants
	Meals/transportation	Expenditures on meals and transportation	weighted sum: Restaurants (90%) Petroleum (10%)

Category	Impact category	Survey output (numerator)	Matched commodity group of IMPLAN household expenditures (denominator)
	Fuel for generators	Expenditures on fuel to operate generators	Petroleum Natural Gas
	Generator capital	Expenditures on generator rental/purchase costs	weighted sum: Motor & generator manufacturing (100%) Retail (1%–margins of equipment rental/purchase establishments)
Evacuees	Meals/lodging	Meal and lodging expenditures	Food & beverage stores Restaurants Accommodation & food services Hotels
	Transportation	Expenditures to evacuate and repatriate family members	Transportation Petroleum
	Avoided food consumption	Average household expenditures on Agriculture, Food products, Food & beverage stores, Restaurants over the outage periods	Agriculture Food products Food & beverage stores Restaurants
	Avoided transportation	Average household expenditures on Transportation, Petroleum over the outage periods	Transportation Petroleum

Table 5-13. Demand shocks generated by expenditure coefficients

Commodity for IMPLAN household expenditures	Expenditure coefficients of encompassing impact categories
Agriculture	Spoiled food - Avoided food consumption
Food products	Spoiled food - Avoided food consumption
Food & beverage stores	Delivered meals + Meals/lodging (Avoided food consumption)
Restaurants	Delivered meals + Meals/lodging + 90% of Meals/transportation - Avoided food consumption
Accommodation & food services	Meals/lodging
Hotels	Meals/lodging

Commodity for IMPLAN household expenditures	Expenditure coefficients of encompassing impact categories
Transportation	Transportation - Avoided transportation
Petroleum	10% of Meals/transportation + Transport + Fuel for generators - Avoided transportation
Natural gas	Fuel for generators
Motor & generator manufacturing	Generator capital
Retail	1% of Generator capital

6. Modeled Scenarios, Impact Metrics, and Post-Processing of Results

The POET modeling framework is data- and computationally-intensive, which necessitates the selection of a limited number of focused scenarios for further analysis. This section describes the logic used to produce these scenarios. These modeled scenarios include producing results by geographic extent of interruption, duration of interruption, and penetration levels of backup generation.

6.1 Modeled scenarios

Geographic extent of interruption

The POET model generates results for up to 10 interruption extent geographic micro-regions (see Table 6-1, below). Each of these micro-regions are interrupted independent of one another with the most extreme case being when the entire service territory is without electricity. Having the ability to interrupt one micro-region at a time allows us to measure the economic impacts within that micro-region and any spillover effects in other micro-regions and neighboring states. Unless otherwise denoted, the majority of the results presented in the next section assume that the entire service territory is without power. We selected this specific geographic extent scenario because it allows us to explore the sectors and micro-regions that are the most economically-sensitive to power disruptions of varying durations.

Table 6-1. Scenarios denoting regional extent of power interruption

Region	Micro-regions: County or counties (without power)
1	Cook
2	Dekalb and Kendall
3	Dupage
4	Grundy and Kankakee
5	Kane
6	Lake
7	McHenry
8	Will
9	Rural ComEd: Winnebago, Boone, Ford, La Salle, Lee, Stephenson, Jo Daviess, Carroll, Whiteside, Marshall, Ogle, Woodford, Bureau, and Henry Livingston
10	Entire ComEd service territory

Interruption duration

As discussed earlier, we presented survey respondents with three electricity interruption duration scenarios: (1) a one-day interruption; (2) a three-day interruption; and (3) a 14-day interruption. Consequently, the POET model produces measures of economic activity during a business as usual baseline and the three interruption scenarios.

Increased penetration of backup generation

Finally, we developed a scenario to evaluate the economic impacts (or avoided losses) of a strategy that entails significantly increasing the amount of backup generation across ComEd's service territory. This scenario assumes that a large share of customers could rent backup generation. In our modeling approach, the services sector of the economy is the party responsible for providing access to rental backup generation. For these reasons, we did not assume that the utility was responsible for installing the backup generation and diverting labor away from actual power restoration activities. Table 6-2 shows that the high backup generation scenario assumes double the penetration of backup generation relative to what was reported by ComEd's customers via the surveys.

Table 6-2. Backup generation penetration scenarios

Penetration of backup generation	Assumptions
Status quo (as reported by survey respondents)	Backup generation ownership and rental is allocated to residential, commercial, and industrial customers based on their survey responses.
High penetration of backup generation	This scenario assumes double penetration of backup generation compared to the status quo. In practice, we double the share of customers that adopt a backup generator-operating tactic (Tactic #2 for residential customers and Tactics #2 and #3 for non-residential customers) and proportionally reduce the share of customers adopting Tactics #1 and #3 or #4 (residential or non-residential).

6.2 Economic impact metrics

The POET model produces a range of economic impact metrics including gross output, gross domestic product, value-added, and household welfare (see Table 6.3) and relative to business as usual[12]. Gross output is reported as the percentage change against the business as usual or dollars disaggregated by industry sector, geographic extent of interruption, impacted region, and interruption duration. Gross output is approximately equal to business revenue. Gross domestic product (GDP) is the total value of final goods and services generated by the economy. GDP is reported as the percentage change against the business as usual or dollars disaggregated by geographic extent of interruption, impacted region, and interruption duration. Finally, the change in household consumption–or equivalent variation–represents the percentage and dollar change in household consumption attributed to a power

[12] Business as usual represents the total economic activity that would occur over a three-month period for each of the counties and sets-of-counties that we list in Table 5-1 *had the power interruption(s) never occurred.*

disruption. In dollar terms, it represents the amount of a subsidy given to a household to make them indifferent to the power interruption. Change in household consumption is disaggregated by geographic extent of the power disruption, impacted region, interruption duration, and one of three aggregate, population-weighted household income categories.

Table 6-3. Key economic impact metrics produced in this analysis[13]

Category	Description of economic impact metric	Interpretation
Gross output	% change and dollars of gross output by industry sector, geographic extent of interruption, impacted region, and interruption duration	% and dollar change in business revenue
Gross (regional) domestic product	% and dollar change in gross domestic product by geographic extent of interruption, impacted region, and interruption duration	% and dollar change of the total value of final goods and services generated by the economy
Change in household consumption	% and dollar change in consumption by geographic extent of power disruption, impacted region, nine household income categories, and interruption duration	Average lost consumption attributed to power disruption (alternatively, this is the amount of a subsidy to households to make them indifferent to the power disruption)

6.3 Post-processing of model results

We anticipate that one of the main uses of these results, from ComEd's perspective, will be to identify sensitive or essential industrial sectors whose resilience enhancement may have an outsized local and economy-wide impact. The dollar values of the sectoral output reported by the model cannot be readily used to compare across sectors because there are sector-level price deflators that are complex to develop. However, it is possible to develop a single appropriately deflated value for the entire economy.

For this reason, we developed a simple scaling process based on adjusting each sector's dollar output by the ratio between the above-mentioned economy-wide deflated value and the direct sum of all sectoral output without adjustment. This adjustment essentially applies a single deflated value to all sectors and allows for adequate comparisons across sectoral dollar output values.

[13] The POET model also produces a number of other metrics which are not reported in this manuscript, including industry sector-level "value-added". Value-added is expressed in both % and dollar change and is equivalent to sector-level gross output minus the costs of intermediate inputs. Value-added is reported via the visualization tool, but not in this report.

7. Results from POET

This section is organized around responses to several key questions detailing impacts to sectors, micro-regions, sector-micro region combinations, and households. In the analysis that follows, we focus on impacts to gross output (business revenue), gross domestic product, and household consumption.

7.1 What are the overall changes to industry activity from power interruptions of varying geographic extent and duration?

The results presented throughout this section reflect the changes that may occur following a three-month period for the economy to return to equilibrium after a power disruption of one, three, or 14-days. Modeling results suggest that service territory-wide losses to gross output (i.e. business revenue) will occur if an interruption impacted all of ComEd’s service territory or if Cook, Dupage, Lake, Will, or the rural portions of ComEd’s service territory are without power independently of each other. As expected, lost business revenue increases as the power interruption duration increases from one to 14-days. Figure 7-1 and Table 7-1 show that a scenario in which the entire service territory is without power would lead to $2.7 (or -0.9% relative to business as usual), $4.2 (-1.3%), and $8.5 billion (-2.7%) in output losses for the one day, three day, and 14-day interruptions, respectively. However, if Grundy and Kankakee, Dekalb and Kendall, McHenry, or Kane counties are without power, then businesses across the service territory may observe increased revenue. *This is likely due to the fact that (1) neighboring regions step in to provide the lost goods and services that, for example Grundy and Kankakee would have provided; and (2) there is a reallocation of lower wage laborers from interrupted industries to labor-intensive industries located in unaffected areas*[14]*.* We acknowledge that it is possible that, in reality, the labor-intensive industries that benefit from lower wage labor availability may not be able to absorb all of the labor suggested by these model results. For this reason, the net gains reported by the model require additional research and possibly adjustments to the underlying model structure to account for this constraint.

[14] Text reported in italics throughout this section reflect hypotheses or speculative statements that may require additional research to confirm.

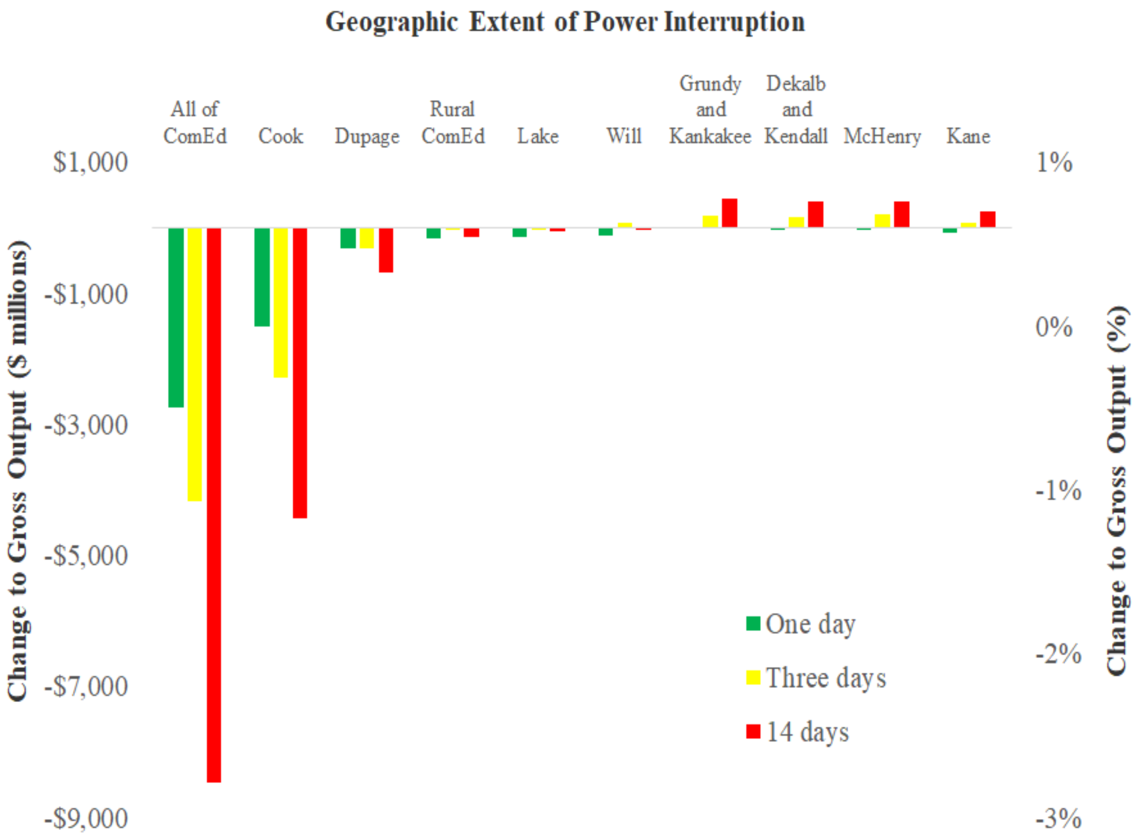


Figure 7-1. Change in overall gross output for all of ComEd's service territory

Table 7-1. Change in overall gross output for all of ComEd's service territory relative to business as usual ($ millions and % change)

Duration	Geographic extent of power interruption									
	Cook	Dekalb and Kendall	Dupage	Grundy and Kankakee	Kane	Lake	McHenry	Will	Rural ComEd	All of ComEd
Business as Usual	$315,272.4									
One day	-$1,500.5 (-0.5%)	-$5.4 (0.0%)	-$309.8 (-0.1%)	$8.4 (0.0%)	-$69.7 (0.0%)	-$129.7 (0.0%)	-$2.3 (0.0%)	-$113.1 (0.0%)	-$157.1 (0.0%)	-$2,735.4 (-0.9%)
Three days	-$2,275.6 (-0.7%)	$160.2 (0.1%)	-$306.8 (-0.1%)	$197.8 (0.1%)	$74.2 (0.0%)	-$22.7 (0.0%)	$214.4 (0.1%)	$89.0 (0.0%)	-$23.6 (0.0%)	-$4,165.0 (-1.3%)
14-days	-$4,435.2 (-1.4%)	$412.0 (0.1%)	-$674.7 (-0.2%)	$443.0 (0.1%)	$257.1 (0.1%)	-$50.1 (0.0%)	$400.7 (0.1%)	-$34.3 (0.0%)	-$141.2 (0.0%)	-$8,451.0 (-2.7%)

We project that there will be significant losses to service territory-wide gross domestic product if an interruption impacted all of ComEd's service territory or if Cook, Dupage, Lake, Will, Kane, or the rural portions of ComEd's service territory are without power independently of each other. Figure 7-2 and Table 7-2 show that a scenario in which the entire service territory is without power would lead to $2.2 (or -1.3% relative to business as usual), $4.3 (-2.6%), and $17.1 billion (-10.4%) in GDP losses for the one day, three day, and 14-day interruptions, respectively. Changes to GDP would be relatively modest if the interruptions occur across McHenry, Grundy and Kankakee, or Dekalb and Kendall counties.

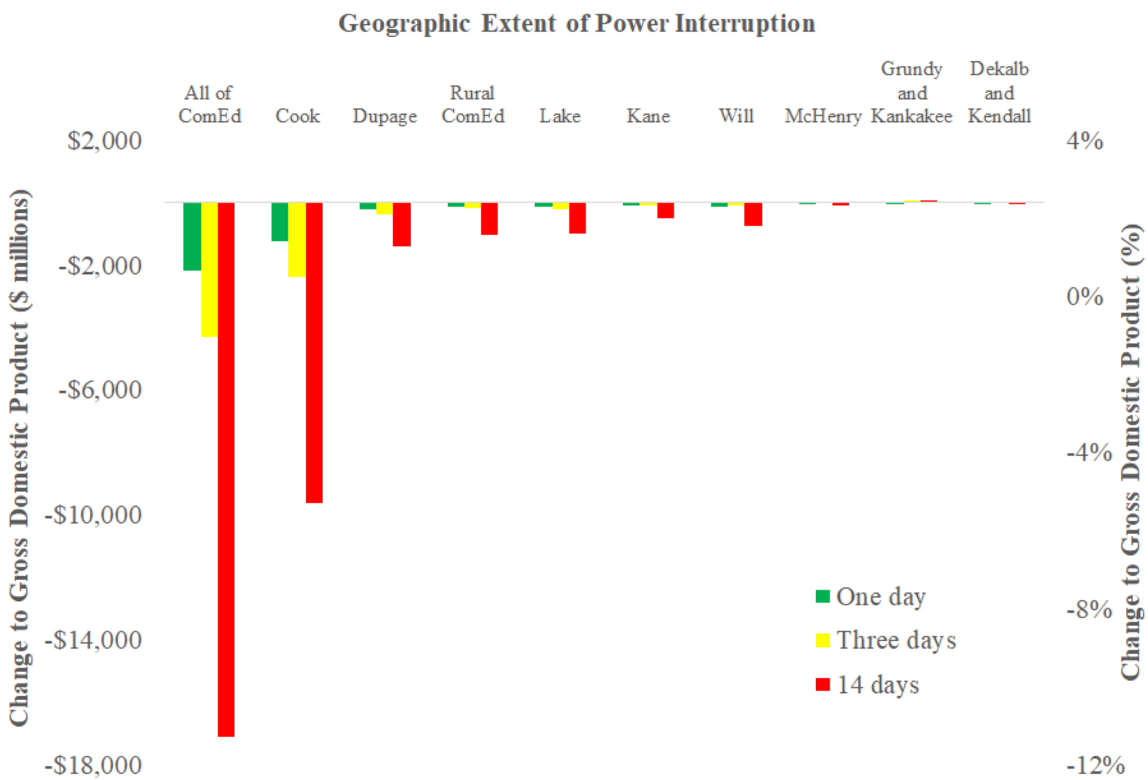


Figure 7-2. Change in overall gross domestic product for all of ComEd's service territory

Table 7-2. Change in overall gross domestic product for all of ComEd's service territory relative to business as usual ($ millions and % change)

Duration	Geographic extent of power interruption									
	Cook	Dekalb and Kendall	Dupage	Grundy and Kankakee	Kane	Lake	McHenry	Will	Rural ComEd	All of ComEd
Business as Usual	$165,159.5									
One day	-$1,213.8 (-0.7%)	-$17.4 (0.0%)	-$223.7 (-0.1%)	-$2.5 (0.0%)	-$71.8 (0.0%)	-$126.0 (-0.1%)	-$23.2 (-0.0%)	-$104.8 (-0.1%)	-$134.4 (-0.1%)	-$2,164.3 (-1.3%)
Three days	-$2,389.2 (-1.4%)	$31.2 (0.0%)	-$351.2 (-0.2%)	$71.9 (0.0%)	-$70.1 (0.0%)	-$188.6 (-0.1%)	$43.2 (-0.0%)	-$97.8 (-0.1%)	-$180.7 (-0.1%)	-$4,280.4 (-2.6%)
14-days	-$9,621.9 (-5.8%)	-$24.4 (0.0%)	-$1,391.9 (-0.8%)	$80.6 (0.0%)	-$496.9 (-0.3%)	-$965.6 (-0.6%)	-$91.8 (-0.1%)	-$726.7 (-0.4%)	-$1,014.0 (-0.6%)	-$17,094.5 (-10.4%)

7.2 What are the industry sectors most affected by service territory-wide interruptions? What industry sectors are the most economically-resilient to service-territory wide interruptions?

There are two relevant metrics to gauge what sectors are most sensitive to interruptions. First, we use the dollar value of sectoral output loss to identify sectors that have the highest influence on the overall economy. Second, we use the percent of sector output lost to identify sectors that are particularly sensitive to interruptions. In other words, these are sectors that have a high percent loss related to its own baseline regardless of the dollar volume of its economic loss. These two metrics recognize that a sensitive sector may not impact the economy as much, and a sector with a small loss with respect to its own baseline may still have an outsized impact on the economy if it is a large volume sector. Both metrics can help inform ComEd and regulatory decisions about where to target resilience investments. Interventions in sectors with the highest absolute dollar value impact will enhance economy-wide resilience. Targeted interventions within sectors that are particularly sensitive to interruptions may be relevant for the long-term resilience of those sectors.

The main focus of this analysis is on service territory-wide outcomes for a service territory-wide interruption. In general, this scenario produces the highest absolute levels of economic losses and hence it is worthwhile to examine in detail (see Figure 7-3 to Figure 7-5). The same analysis can be performed for interruptions occurring in specific regions, or for sectors within specific micro-regions. We feature a few specific examples to highlight sector-region combinations that appear to be particularly sensitive to interruptions.

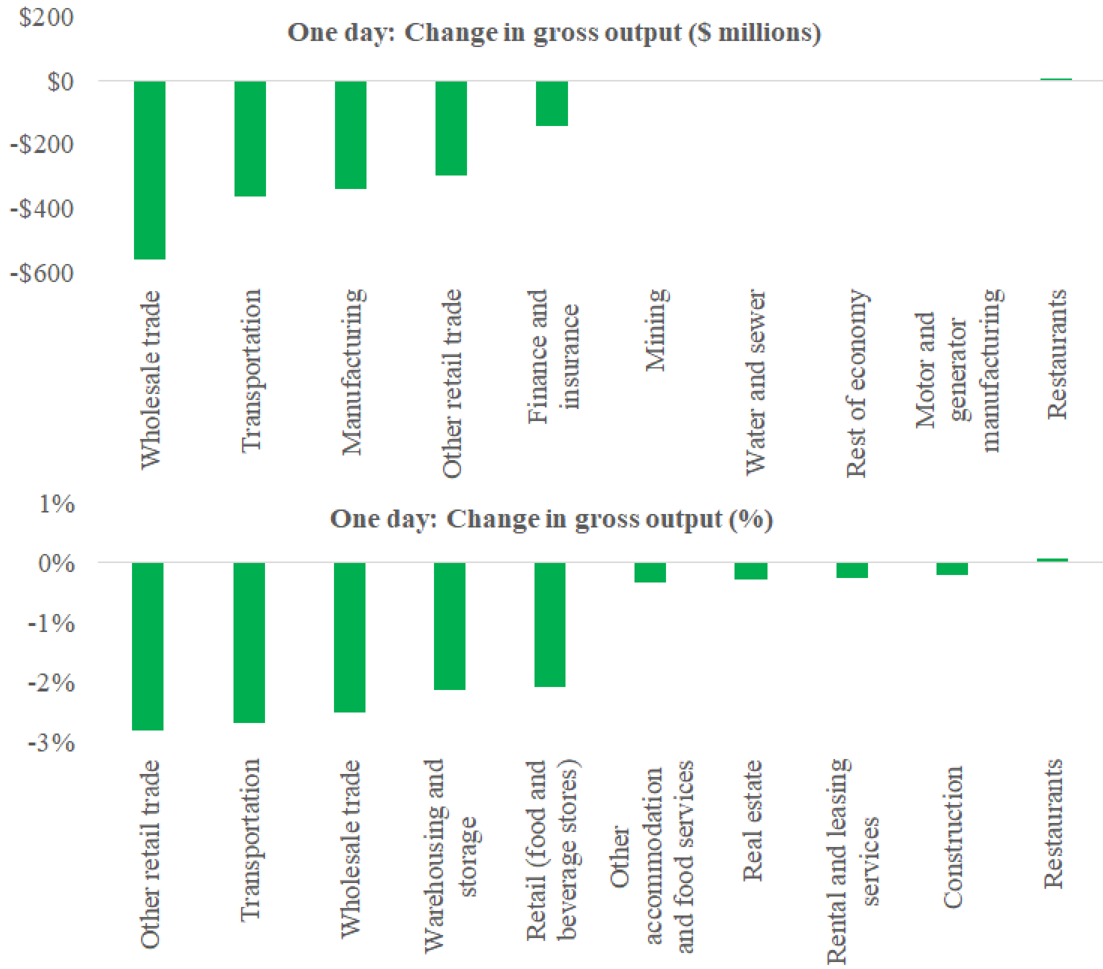
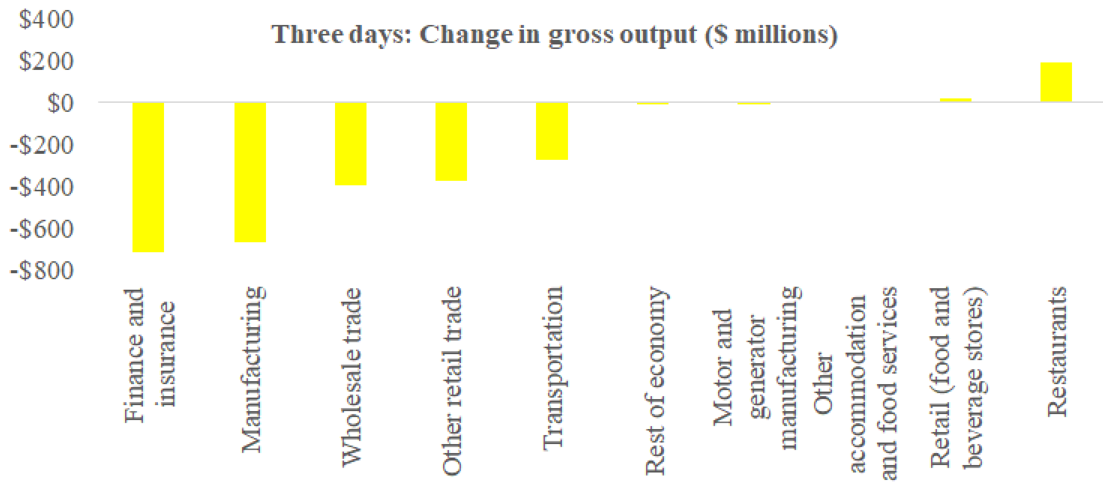


Figure 7-3. Changes to gross output attributed to a *one-day* service territory-wide power interruption ($ millions and %)



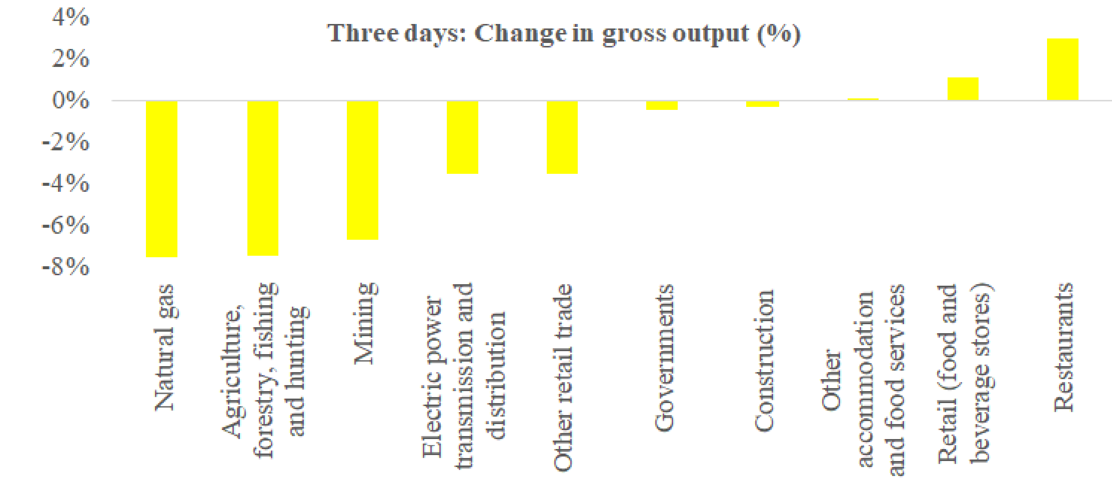


Figure 7-4. Changes to gross output attributed to a *three-day* service territory-wide power interruption ($ millions and %)

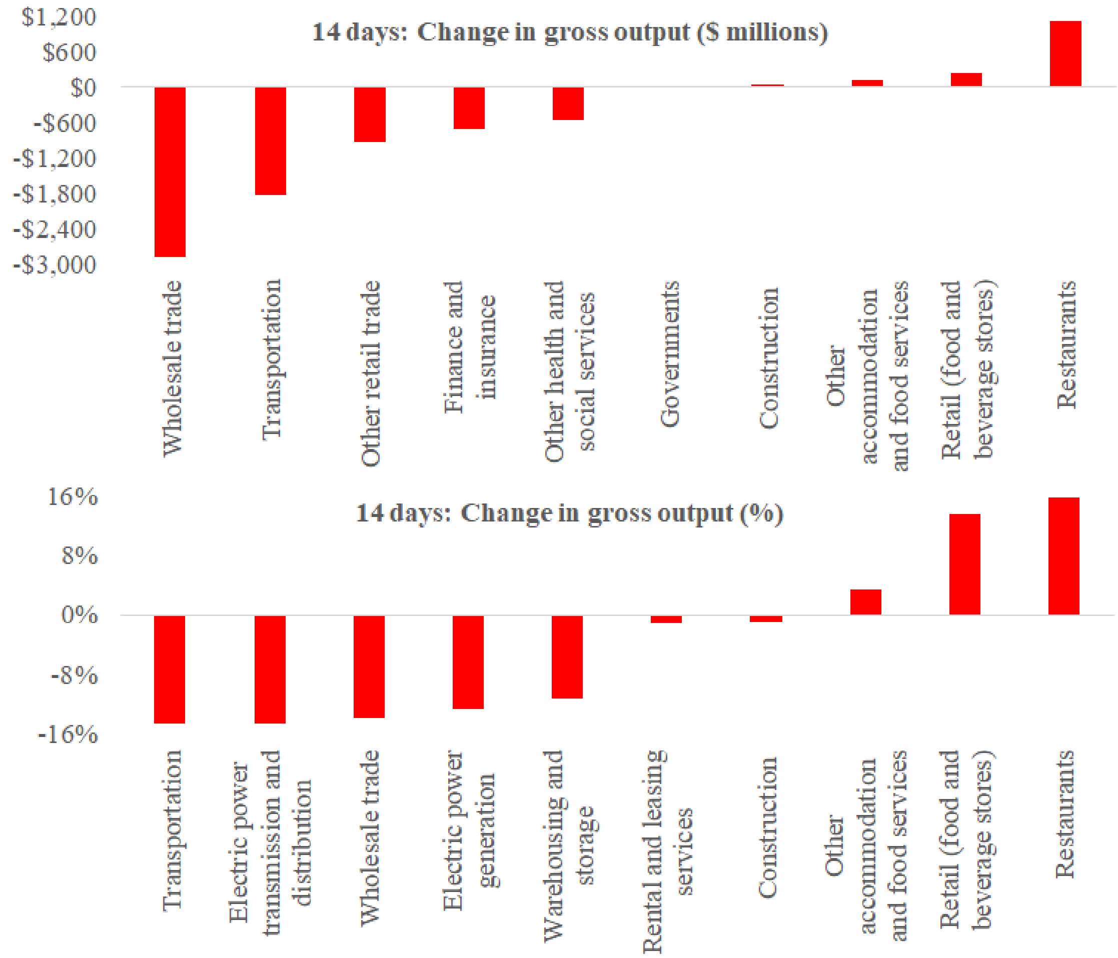


Figure 7-5. Changes to gross output attributed to a *14-day* service territory-wide power interruption ($ millions and %)

Sectors with high losses relative to total economy

We find that five sectors consistently represent between 60% to 80% of the total service territory-wide output loss regardless of interruption duration:

- wholesale trade
- transportation
- manufacturing
- retail trade
- financial and insurance services

These sectors have decreased output by about $1.7 billion in a 1-day interruption (Figure 7.3, top) to $6.8 billion in a 14-day interruption (Figure 7.5, top). Some of these sectors are among the most productive sectors in ComEd's service territory. However, other high output sectors, including professional/technical services, government, and construction, are not among the sectors that are expected to experience significant losses. *This finding suggests that these other sectors have an inherent resilience to power interruptions (Eyer and Rose 2019). Alternatively, the economic activity in the sectors identified above is more sensitive to WLD interruptions than other sectors.*

Sectors with high percentages of sector output lost

During a 1-day interruption, sectors that are most sensitive include (see Figure 7.3, bottom):

- wholesale trade
- other retail trade
- warehousing/storage
- transportation
- retail (food and beverage stores)

The aforementioned sectors lose 2% to 3% of their total gross output. However, the sectors with the highest percentage of losses during a 14-day interruption include (see Figure 7.5, bottom):

- transportation
- electric power transmission and distribution
- wholesale trade
- electric power generation
- warehousing and storage

These more sensitive sectors lose between 10% and 15% of their output during a 14-day interruption, even though these sectors are among the highest users of backup generation.

Sectors with high losses relative to total economy and high percentages of sector output lost

A particularly important set of sectors for resilience interventions are those that have high absolute economic impact in dollars as well as being highly sensitive to interruptions. The highly sensitive and influential sectors include:

- wholesale trade

- transportation

Interestingly, the model highlights the interdependence between these two sectors due to the important role of freight in providing a critical service to the wholesale trade industry.

Sectors with increasing output

A small number of sectors increase their output during long-duration interruptions given the change of demand patterns from customers. Across all three durations, the restaurant sector consistently shows the highest increase in output from 0.1% in one day duration (Figure 7.3, bottom) to 16% in a 14-day duration interruption (Figure 7.5, bottom). Two related sectors that increase their output during three day and 14-day interruptions are retail (food and beverage stores) and lodging, showing a 14% and 4% increase during the two-week interruption, respectively. This outcome is largely expected given that a large fraction of customers will turn to ordering food, eating out, and relocating as coping strategies.

Sector-region combinations that are sensitive to power interruptions

Finally, we identify sector-region combinations that are very sensitive to interruptions (see Table 7-3).

Table 7-3. Sector-region combinations with largest output losses during 14-day interruption occurring within micro-region

Industry sector	Geographic extent of power interruption								
	Cook	Dekalb and Kendall	Dupage	Grundy and Kankakee	Kane	Lake	McHenry	Will	Rural ComEd
Electric power transmission and distribution		✓		✓	✓		✓		
Electric power generation							✓		
Water and sewer							✓		
Agriculture	✓					✓			
Transportation	✓	✓					✓		✓
Wholesale trade		✓					✓		
Warehousing and storage		✓		✓				✓	✓
Mining						✓			

There are a number of sector-region combinations that are estimated to experience significant losses including:

- The **electric power transmission and distribution** sector shows high region-specific losses. The sector has a 47% loss in DeKalb and Kendall counties, a 40% loss in Grundy and Kankakee counties, and a 50% loss in Kane county when a 14-day power interruption occurs in those regions, as well as when it occurs across the entire service territory. *This finding may be related to the specific location of power infrastructure within ComEd's territory and its outsized role in the economic output in those counties.*
- The **electric power (generation, transmission, distribution)** and **water/sewer** sectors in McHenry county lose 20%-22% output for 14-day interruption in that county, but not for territory-wide interruptions.
- Other sensitive sector-region combinations include **agriculture** in Cook and Lake counties, **transportation** in Cook, Dekalb and Kendall, McHenry, and rural counties, **wholesale trade** in Dekalb and Kendall, and McHenry counties, **warehousing and storage** in Dekalb and Kendall, Grundy and Kankakee, Will and rural counties; and **mining** in Lake county.

7.3 What regions are more sensitive to service territory-wide interruptions, and which ones are more inherently economically-resilient?

We use GDP results to compare regional responses to interruptions. In general, there is a relatively consistent pattern in which the region affected by an interruption observe a GDP loss while the remaining regions in ComEd's territory indirectly benefit with increases in GDP. However, the net territory-wide GDP outcome is generally negative, with a few exceptions that we explore later in this section (see Table 7-2).

We first examine regions that are inherently more or less sensitive by comparing their GDP loss when the interruption occurs only in that same region. Cook county and the rural portions of ComEd's territory are the most sensitive to interruptions occurring in these micro-regions. This is reflected in the highest percent change in GDP. For example, a 14-day interruption occurring within Cook county results in an 11% loss in that county. By contrast, the least sensitive region is McHenry county with a 7.9% loss during a 14-day interruption occurring within this particular county (Table 7-4). *These patterns are generally consistent across interruption durations and may reflect the specific mix of industrial sectors that characterize each region.*

Table 7-4. Change in micro-region gross domestic product for an interruption in that same region relative to business as usual (%)

Duration	Geographic extent of power interruption *and* impacts to individual micro-regions									
	Cook	Dekalb and Kendall	Dupage	Grundy and Kankakee	Kane	Lake	McHenry	Will	Rural ComEd	All of ComEd
One day	-1.4%	-1.0%	-1.3%	-1.2%	-1.1%	-1.1%	-1.1%	-1.2%	-1.3%	-1.3%
Three days	-2.7%	-2.2%	-2.4%	-2.4%	-2.3%	-2.3%	-2.1%	-2.3%	-2.6%	-2.6%
14-days	-11.0%	-8.4%	-8.8%	-9.3%	-9.1%	-8.9%	-7.9%	-9.3%	-10.2%	-10.4%

Next, we identify locations that are particularly sensitive to interruptions occurring in other micro-regions. Here, we focus on two groups:

- Some micro-regions have GDP losses during interruptions occurring outside their area–a positive correlation–although these losses are generally very small. For example, DuPage, Grundy, Kankakee, and Lake counties have losses when a disruption occurs in Cook county. While these reductions are significantly lower than in Cook county itself, the correlation attests to the outsized influence of Cook county being without power.

- Some micro-regions exhibit GDP gains during interruptions occurring outside their area. For example, a 14-day interruption occurring in DeKalb and Kendall counties leads to a $315 million loss in this micro-region. At the same time, however, GDP increases in Cook county by $207 million and a number of other micro-regions. In this case, the net effect of the power interruption occurring in Dekalb and Kendall is negligible. Alternatively, a 14-day interruption in Grundy and Kankakee counties results in a $230 million loss that is almost entirely compensated by an increase in output in Cook county of $208 million.

We compare the GDP dollar loss from a region against the territory-wide loss and find that interruptions in the regions of DeKalb-Kendall, Grundy-Kankakee, and McHenry are more easily offset by increases in other regions compared to other areas in ComEd's territory. In other words, the economy in ComEd's territory is more resilient to interruptions in these three areas, as the net impact is mitigated to a large extent by increases in other regions. In contrast, GDP loss due to interruptions in other regions is barely compensated by increases outside the region interrupted. The compensation for economic losses due to interruptions in DeKalb-Kendall, Grundy-Kankakee, and McHenry may largely be due to the small size of these micro-regional economies, which are an order of magnitude smaller than the remaining regions in ComEd's territory.

In general, results support the idea that most micro-regions within ComEd–with the exception of Cook county–are relatively well economically isolated from each other. The economic losses of interruptions in one micro-region rarely propagate to other regions. In the case of interruptions in the smaller economic regions in ComEd's territory, the remaining areas are able to largely compensate for the loss. However, this is not possible for larger economic-output regions such as Cook, DuPage, and Lake, among others.

7.4 How do sectoral and regional economic output impacts compare across interruption durations? Are there sector-region combinations that respond differently to increasing durations compared to other sector-region combinations?

As a general rule, model results follow the intuition that longer duration interruptions have a higher economic impact, either in loss of sectoral output, GDP, or sectoral value-added. When we simulate the economy without any resilience tactic or response, we find that economic losses grow relatively proportional to the duration of the interruption. A three-day GDP loss is about three times that of the one-day loss, and the 14-day loss is about 15-17 times that of the one-day loss.

When we introduce the resilience tactic response based on the survey results, the immediate outcome is that the increase in economic loss does not scale proportional to interruption duration. The increase in GDP loss between a one-day and a three-day interruption ranges 1.9 to 2.1 times (compared to a potentially expected three-fold increase) across regions, whereas the increase in loss from three-day to 14-day interruptions ranges 3.6 to 4.0 times (compared to a potentially expected five-fold increase) across regions (Table 7-5). The one-day to 14-day economic loss multiplier ranges from a low 6.9 times for interruptions in DuPage county to a high 8.3 times for interruptions in Dekalb-Kendall, Kane, and Lake counties (compared to a potentially expected fourteen-fold increase). *These results reflect that the introduction of resilience response to interruption events has a strong impact in reducing the economic loss growth across durations for any given region.*

Table 7-5. Service territory-wide increase in economic output loss between one- and three-day interruptions and three and 14-day interruptions

Duration	Geographic extent of power interruption								
	Cook	Dekalb and Kendall	Dupage	Grundy and Kankakee	Kane	Lake	McHenry	Will	Rural ComEd
One- to three-day loss multiplier	2.0	2.1	1.9	2.1	2.1	2.1	2.0	1.9	2.0
Three to 14-day loss multiplier	4.1	3.9	3.6	3.8	4.0	3.9	3.7	4.1	3.9

We have established that a resilience tactic response reduces the economic loss multiplier across durations for each region. When comparing across regions, the differences in economic loss multiplier seem to depend more on underlying factors that characterize the economy of the region, rather than the particular resilience response. We compare the economic loss multipliers for a scenario with no resilience tactics (disruption only) reported at the beginning of this section against the scenarios with resilience response. The differences that we find across regions are already present in the no-resilience scenario, which suggests that the resilience response does not particularly affect the way duration informs economic loss.

7.5 How are different household income groups impacted by power interruptions of varying extent and duration? Are household income groups in certain regions more sensitive to interruptions than in other regions?

We start by using the equivalent variation metric described earlier in this document (see footnote that precedes Figure E.7) as a proxy for consumption loss to households. As expected, average losses to household consumption increase as the duration of power interruptions increases (see Figure 7-6).

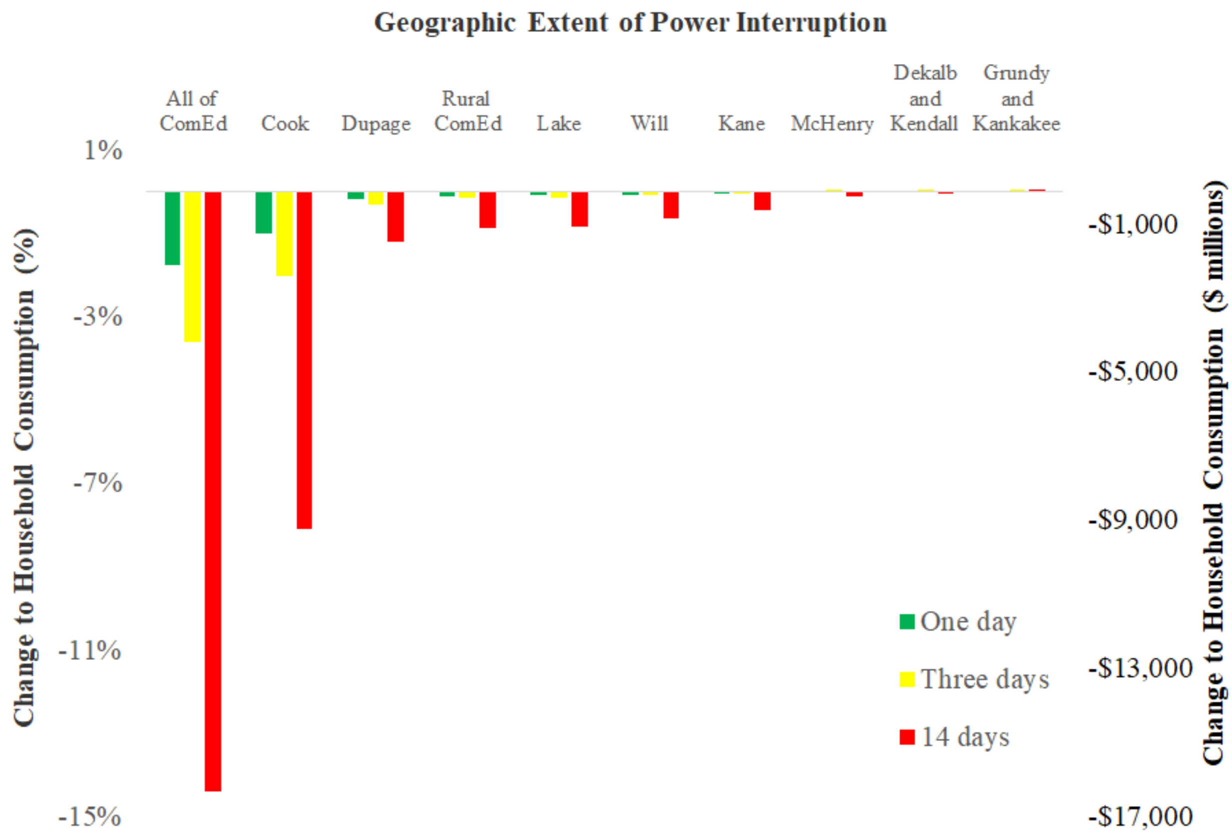


Figure 7-6. Average change to annual household consumption for all of ComEd's service territory[15]

For example, a 14-day, system-wide interruption results in nearly 15% of average lost annual consumption across all income groupings or nearly $17 billion in consumption losses (see Table 7-6).

[15] This is equivalent variation, which represents a subsidy of income to make all households indifferent to the power disruption. For example, -1.0% implies that an average household would need to receive a payment of 1% of their household income to be indifferent to the power interruption.

Table 7-6. Average change to annual household consumption for all of ComEd's service territory relative to business as usual ($ millions and % change)

Duration	Geographic extent of power interruption									
	Cook	Dekalb and Kendall	Dupage	Grundy and Kankakee	Kane	Lake	McHenry	Will	Rural ComEd	All of ComEd
Business as Usual	$115,957.8									
One day	-$1,153.2 (-1.0%)	-$16.7 (0.0%)	-$219.9 (-0.2%)	-$3.8 (0.0%)	-$68.8 (-0.1%)	-$119.4 (-0.1%)	-$23.8 (0.0%)	-$102.1 (-0.1%)	-$129.4 (-0.1%)	-$2,058.6 (-1.8%)
Three days	-$2,343.3 (-2.0%)	$27.3 (0.0%)	-$351.5 (-0.3%)	$67.1 (0.1%)	-$71.6 (-0.1%)	-$188.1 (-0.2%)	$38.8 (0.0%)	-$99.6 (-0.1%)	-$181.1 (-0.2%)	-$4,202.9 (-3.6%)
14-days	-$9,394.9 (-8.1%)	-$44.7 (0.0%)	-$1,392.7 (-1.2%)	$53.8 (0.0%)	-$508.7 (-0.4%)	-$970.7 (-0.8%)	-$121.0 (-0.1%)	-$745.2 (-0.6%)	-$1,022.1 (-0.9%)	-$16,706.8 (-14.4%)

Next, we examine consumption loss patterns across different household income groups and geographic extents of the interruption. For this analysis, we group all households into three income groups:

1. annual income below $50,000 ("low income")
2. annual income between $50,000 and $100,000 ("medium income")
3. annual income above $100,000 ("high income")

With the exception of a power interruption occurring in rural ComEd, the highest income group is expected to have the largest losses to consumption during a one-day interruption (see Figure 7-7).

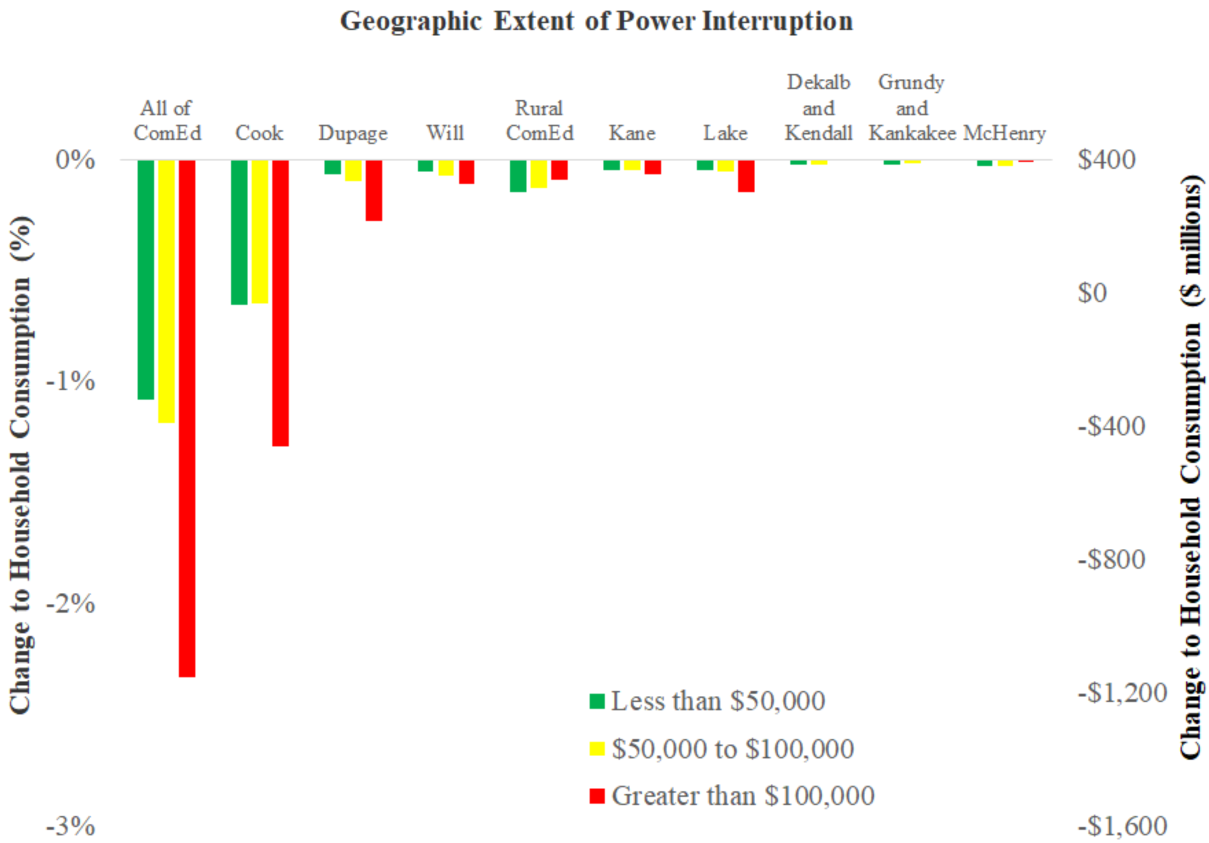


Figure 7-7. Losses to annual household consumption during a *one-day* power interruption by income grouping

However, as interruptions durations increase, consumption losses for lower income households increase to a point in which they exceed high income households during the 14-day interruption (see Figure 7-8). *It is not immediately clear why income groups have different consumption losses for each interruption duration, but it may be related to the choice of resilience tactics reported by survey respondents. As we learned from the survey responses, most respondents did not leave the affected area during a one-day power interruption. However, survey responses imply that high income households are more likely to relocate during longer duration power interruptions and consume goods and services in micro-regions not impacted by the power interruption. Conversely, low income earners may be less able to relocate and are therefore able to consume less during longer duration power interruptions.*

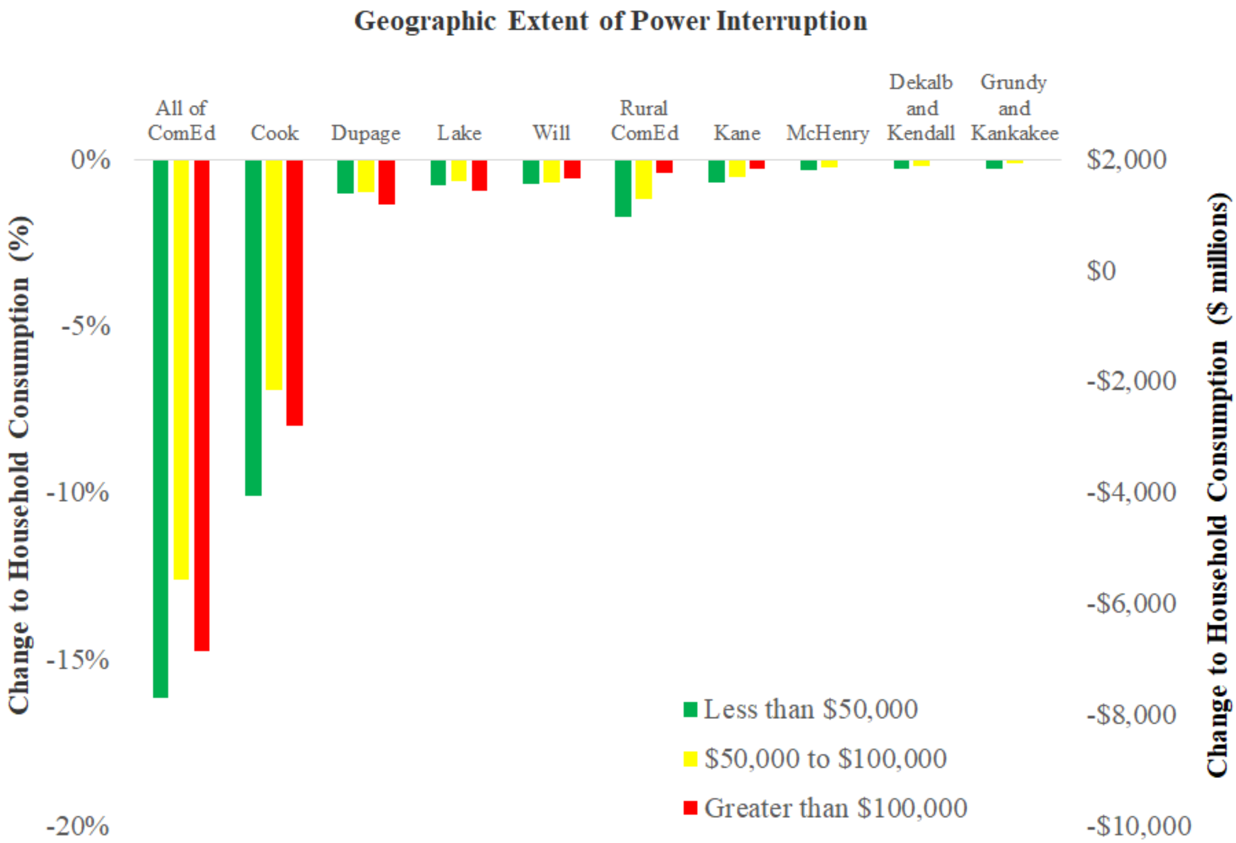


Figure 7-8. Losses to annual household consumption during a *14-day* power interruption by income grouping

We find that the higher income group consistently shows a significant difference in consumption loss across regions regardless of interruption duration. For example, high income households without power in Dekalb and Kendall and McHenry counties have consumption losses that are significantly smaller than the consumption losses in Cook and the rural ComEd counties. We cannot immediately explain why high-income households in places like McHenry and Dekalb and Kendall counties have a lower sensitivity to interruptions compared to high income households in other micro-regions.

7.6 What are the avoided economic losses (i.e., economic benefits) from a higher adoption of backup generation?

As discussed earlier, we account for the operational costs of backup generation and run a scenario that doubles the penetration of backup generation. We are able to evaluate how higher levels of backup generation lead to changes in gross output, gross domestic product, and household consumption. These avoided losses are essentially net benefits relative to no-backup scenarios –the benefits of higher levels of backup generation minus the operational costs–of doubling the amount of backup generation above existing levels. For example, avoided losses to gross output of $305 million, $606 million, and

$1.2 billion are possible for a one day, three day, and 14-day service territory-wide interruption–these values represent net benefits of 11 to 15% of overall gross output (see Table 7-7). It should be noted that there are cases of intra-region interruptions in which the costs of deploying more backup generation exceed the avoided losses to gross output in the region. The net benefits of deploying additional backup generation are negative for three and 14-day interruptions occurring within Dekalb and Kendall, Grundy and Kankakee, and McHenry counties. In these cases, the additional costs of procuring and operating increased levels of backup generation exceed the benefits that these additional levels of backup generation would provide to these counties.

Table 7-7. *Avoided* service territory-wide losses to gross output due to higher levels of backup generation ($ millions and % loss avoided)

Duration	Geographic extent of power interruption									
	Cook	Dekalb and Kendall	Dupage	Grundy and Kankakee	Kane	Lake	McHenry	Will	Rural ComEd	All of ComEd
One day	$177.3 (12%)	$0.2 (3%)	$32.8 (11%)	$0.3 (4%)	$7.5 (11%)	$15.9 (12%)	$0.3 (13%)	$9.2 (8%)	$15.7 (10%)	$305.2 (11%)
Three days	$329.4 (14%)	-$2.6 (-2%)	$61.4 (20%)	-$5.0 (-3%)	$16.0 (22%)	$28.3 (125%)	-$5.7 (-3%)	$11.0 (12%)	$30.3 (128%)	$606.2 (15%)
14-days	$580.1 (13%)	-$5.4 (-1%)	$49.6 (7%)	-$5.4 (-1%)	$57.4 (22%)	$66.7 (133%)	-$18.4 (-5%)	$36.7 (107%)	$104.0 (74%)	$1,182.7 (14%)

However, increasing the amount of backup generation deployed across ComEd's service territory leads to net increases in system-wide gross domestic product for all interruption extents and durations (see Table 7.8). Avoided system-wide losses to gross domestic product range from $291 million (one day) to $614 million (three day) to $1.9 billion (14-day)–or 11 to 14% of overall gross domestic product. Interestingly, avoided losses to gross domestic product are extremely high relative to total GDP in some places (e.g., a 14-day power interruption originating in Dekalb and Kendall counties).

Table 7-8. ***Avoided*** **service territory-wide losses to gross domestic product due to higher levels of backup generation ($ millions and % loss avoided)**

Duration	Geographic extent of power interruption									
	Cook	Dekalb and Kendall	Dupage	Grundy and Kankakee	Kane	Lake	McHenry	Will	Rural ComEd	All of ComEd
One day	$170.9 (14%)	$2.5 (14%)	$29.0 (13%)	$1.4 (55%)	$11.4 (16%)	$17.5 (14%)	$3.7 (16%)	$12.1 (12%)	$15.4 (11%)	$290.5 (13%)
Three days	$337.4 (14%)	$6.0 (19%)	$58.8 (17%)	$0.5 (1%)	$27.4 (39%)	$37.1 (20%)	$4.7 (11%)	$23.5 (24%)	$36.5 (20%)	$614.0 (14%)
14-days	$1,028.1 (11%)	$24.5 (101%)	$110.7 (8%)	$12.5 (16%)	$122.0 (25%)	$140.4 (15%)	$13.2 (14%)	$98.8 (14%)	$137.3 (14%)	$1,873.4 (11%)

Furthermore, installing higher amounts of backup generation will likely result in *avoided* losses to household consumption. Table 7-9 shows that a service territory-wide interruption that has been partially mitigated by backup generation will lead to average avoided losses to consumption–across all income categories–of 0.3% (one day) to 0.5% (three day) to 1.6% (14-days). In dollar terms, these avoided losses (i.e., net economic benefits) of higher penetration of backup generation range from $287 million (one day) to $1.8 billion (14-days).

Table 7-9. ***Avoided*** **losses to consumption for average household attributed to power interruptions ($ millions and % loss avoided)**

Duration	Geographic extent of power interruption									
	Cook	Dekalb and Kendall	Dupage	Grundy and Kankakee	Kane	Lake	McHenry	Will	Rural ComEd	All of ComEd
One day	$169.3 (0.2%)	$2.4 (0.0%)	$28.8 (0.0%)	$1.2 (0.0%)	$11.1 (0.1%)	$17.1 (0.0%)	$3.6 (0.0%)	$11.9 (0.0%)	$15.0 (0.0%)	$287.4 (0.3%)
Three days	$334.7 (0.3%)	$5.7 (0.0%)	$58.7 (0.0%)	$0.5 (0.0%)	$26.7 (0.1%)	$36.7 (0.1%)	$4.6 (0.0%)	$23.2 (0.0%)	$36.0 (0.1%)	$609.0 (0.5%)
14-days	$1,000.7 (0.9%)	$23.4 (0.0%)	$108.1 (0.1%)	$12.5 (0.1%)	$117.7 (0.1%)	$137.7 (0.1%)	$13.4 (0.0%)	$97.3 (0.0%)	$134.5 (0.1%)	$1,824.3 (1.6%)

7.7 What do the results imply for improving resilience in the ComEd service territory?

Sectoral-level interventions

It should be noted that micro-regions which experience net gains in economic activity do not necessarily imply that ComEd should focus exclusively on making investments in micro-regions with significant losses. Some customers, especially low-income households, may be disproportionately impacted by power disruptions within micro-regions that experience net gains to economic activity.

Five sectors consistently represent the largest share of total economic losses regardless of interruption duration: (1) wholesale trade; (2) transportation; (3) manufacturing; (4) retail trade; and (5) financial and insurance services. Sectors that are most sensitive to a one-day interruption include (1) wholesale trade (2) retail trade, and (3) warehousing/storage. However, the sectors that are the most sensitive to a 14-day interruption are (1) transportation, (2) electric power, (3) wholesale trade, (4) retail trade, and (5) healthcare. Wholesale trade and the transportation sector have both high absolute economic impact in dollars as well as being highly sensitive to interruptions.

Regulators and planners may want to design post-event interventions to help these sectors recover, especially critical public services including the transportation, electric power, and the healthcare sectors. Targeted interventions for the wholesale and retail trade sectors - perhaps with higher degrees of backup generation - could also mitigate the relatively high impact of long duration interruptions in these sectors.

A small number of sectors *increase* their output during long-duration interruptions given the change of demand patterns from customers. The restaurant sector consistently shows the highest increase in output. And two related sectors, food/beverage retail and lodging, also increase their output during the three-day and 14-day interruptions. These specific sectors are also candidates for resilience interventions because they provide essential services during power interruptions–customers rely on these sectors to cope with long duration interruptions and it is important to ensure that they remain operational.

Household-level interventions

The differences in household consumption loss across regions and durations may help inform targeted interventions for certain income groups. For example, lower income households in Cook county may benefit more from resilience interventions compared to lower income households in Lake or Dupage. Furthermore, resilience interventions for higher income households may generally be harder to justify in front of regulators, but in certain regions including Cook county and rural ComEd, high income households have consumption losses that are similar to those of low-income households.

Increasing amount of backup generation as one possible intervention

Increasing the amount of backup generation deployed across ComEd's service territory leads to net increases in system-wide gross domestic product for all interruption extents and durations. This finding suggests that designing incentive programs to encourage the installation of backup generation–or other technologies–may be an important strategy to cost-effectively mitigate the economic impacts of longer duration power interruptions. Furthermore, avoided losses to gross domestic product are extremely high relative to total GDP in some places (e.g., a 14-day power interruption originating in Dekalb and Kendall counties). This finding suggests that prioritizing the installation of backup technologies in specific locations may be preferred to a widespread strategy of increasing backup generation across the entire service territory.

7.8 How could the results from this study be incorporated into a traditional cost-benefit framework to evaluate investments in resilience?

The results from this study could be used to inform future integrated planning and cost-benefit analyses undertaken by regulatory staff, utility staff, or other policymakers. One step in the overall valuation proposition of resilience investments and/or tactics involves calculating the benefits of tactics to enhance power system or customer resilience. One important type of benefit is an avoided economic loss to residential and non-residential customers due to reductions in the frequency and/or duration of one or more power interruptions. Proper accounting of the benefits provided by a resilience investment requires a number of assumptions that will need to be made by policymakers including, but not limited to the:

- likelihood of future power interruptions of varying durations and geographic extents;
- reduction in interruption risk due to the investment;
- economic impacts of power interruptions before and after the investment;
- lifespan of the investment, and;
- discount rate.

Using economic impact metrics in a cost-benefit framework

Although gross output, gross domestic product (or industry value-added), and household consumption are all useful metrics to evaluate the benefits of resilience investments, one metric–*household consumption (i.e., equivalent variation)*–is our preferred metric for estimating one of the key benefits of investments in resilience. Consumption captures both impacts to households and firms simultaneously and is most closely aligned with the concept of overall welfare of the economy. For example, assume that there is a service territory-wide, 14-day power interruption. In this case, households across ComEd would need to be compensated $16.7 billion to make them indifferent to that same power interruption ($116 billion under business as usual minus $99.3 billion for 14-day interruption; see Figure E.8). It follows that a decision-maker should not consider a service territory-wide investment of more than $16.7 billion to mitigate the impacts of a 14-day interruption.

Nonetheless, we recommend that decision-makers consider running cost-benefit analyses using each of the economic metrics presented in this report independent of one another to evaluate the robustness of the insights that each of these estimates may provide. For example, positive and significant benefits regardless of economic metric used would indicate that resilience investments targeting a particular micro-region, industry sector, and/or household income group may be particularly beneficial.

Important considerations when evaluating the benefits of resilience tactics

Two issues that this work does not address are (1) the frequency, duration, and the geographic extent of *future* interruptions and (2) what level of mitigation a given resilience investment—beyond the doubling of backup generation—provides to mitigate the impacts of power interruptions. The stream of benefits that accrues from the sum of all mitigated interruptions that occur within the lifetime of a resilience investment is the total economic benefit of that resilience project. In the example above, it is socially beneficial to spend up to $16.7 billion to mitigate the impacts of a single 14-day interruption that occurs within the lifetime of the investment. However, it may also be socially beneficial to spend more than $16.7 billion considering that interruptions that last fewer than 14-days may also occur, and even more frequently, and these may also be partially or fully mitigated. In contrast, it may also be beneficial to spend less than $16.7 billion for a resilience investment that partially mitigates a 14-day interruption. It is important to note that capital investments that improve resilience for one type of hazard may not ensure resilience to all hazards. And no investments will completely eliminate the risk of power interruptions in the future–it is financially and technically infeasible to ensure that all customers at all times have perfectly reliable electricity service.

8. Caveats, Research Needs, and Conclusion

The findings from this research effort are meant to provide valuable insights to ComEd, policymakers in Illinois, and other stakeholders who have a vested interest in the future of the power system. Nonetheless, it is recognized that the complexities involved in estimating impacts from power interruptions, the methods, survey responses, and results presented can be difficult to communicate to a wide-ranging audience. In this regard, it is important to be upfront in acknowledging the limitations and ongoing research needs that should be addressed in the future.

8.1 Caveats and research needs

Survey respondents knew, in advance, the duration of the power interruptions

The onset of long duration interruptions can be predicted with some level of certainty given that most are linked to extreme weather events. It follows that, since these extreme weather events can be typically forecasted a few days in advance, customers can prepare their resilience response in anticipation of the event. However, a much more difficult thing to estimate are restoration times and their distribution across the ComEd service territory. The survey intentionally removes this uncertainty from customer decision-making by stipulating the anticipated duration of the interruption as part of the survey. Customers' survey responses are then based on perfect information about interruption duration.

In reality, customers rarely know the exact extent or duration of the interruption and may need to make multiple decisions as new information from the local utilities regarding the extent of the damage and restoration times becomes available. A single customer may employ a sequence of resilience tactics depending on how the interruption evolves. The survey and model cannot capture these sequences, but future work may focus on reviewing actual customer responses to long duration interruptions to gain a better understanding of the resilience response dynamics.

Low survey response rates for non-residential customers may mean some of the information we collected is not representative of population

Over the last ten years, the recruitment of non-residential customers for this type of long and detailed survey has become particularly difficult, which may be due to the increasing rate of scam phone calls, particularly those that involve fraudulent use of the utility name. This environment drastically increases the challenge of reaching the right person within a business and subsequently convincing him/her to provide a large amount of private information about their business through the survey. As a result, modifications to the non-residential phone recruitment strategy are being considered for future interruption cost surveys.

Extremely high relocation rates may not be possible given transportation bottlenecks

A large number of survey respondents indicated their desire to relocate to an area not affected by the power interruption, especially during the longer duration power interruptions. In fact, over 80% of residential customers surveyed indicated that they would temporarily relocate during a 14-day power interruption. It is likely that existing transportation infrastructure, especially in high population density areas like Cook county, would be unable to support the number of people who decide to relocate. The implication of this issue is that some share of customers who wished to relocate, but were unable to, would be forced to stay home and continue to be directly impacted by the power interruption. Accordingly, our estimates of the direct economic impacts of longer duration power interruption may be biased low.

Impacts to economies and households that extend beyond Illinois, Wisconsin, and Indiana were not estimated

Cook county is an important regional, national, and international trade hub. Due to budget and time constraints, we did not attempt to assess the economic impacts that would spill over to regions that extend beyond Illinois, Wisconsin, and Indiana. It is possible that other regions beyond this three-state area may step in to provide goods and services–and report increased economic activity–during times when part or all of ComEd's service territory are without power. Furthermore, many households beyond the three state region have an economic interest in businesses that operate within Illinois, Wisconsin, and Indiana (e.g., owners of mutual funds or stocks that derive value from economic activity).

Backup generation rentals may not be widely available during widespread, long duration interruptions

It is also important to acknowledge that the POET model assumes that rental backup generators will be available to all customers who need them. This assumption is probably not realistic, because there would not be enough rental generators to meet demand or the rental generators that are available may not be located in the areas hardest hit by the interruption. For these reasons, the losses attributed to power interruptions may be higher than what we estimate, especially under the high backup generation scenario. Further research surveying the stock and generator characteristics for existing firms that offer backup generator rental services in ComEd's territory could help refine the assumptions for backup generation in the model. A follow-on study could investigate the benefits and costs of the utility owning and operating a fleet of backup generators or other technologies (e.g., long duration storage) designed to mitigate the impacts of power interruptions.

Pollution-related costs of running backup generators were not included in the CGE model

There are many complexities when estimating the societal costs of pollution associated with increased amounts of backup generation. For example, to properly account for these additional costs, one would need to know the existing mix and location of where ComEd currently receives its power from and then subtract those pollution-related costs from the pollution costs associated with running a significant number of backup generators. Having said that, we calculated a stand-alone estimate of the additional pollution-related costs from doubling the backup generation without taking into account the emissions that would have occurred had ComEd continued to provide power to its customers using electricity from power facilities that are currently supplying the region (see below). In other words, the additional pollution-related costs from doubling the amount of backup generation, without taking into account the existing emissions from current sources, could serve as a proxy for the additional costs relative to a “clean energy future” (i.e., little/no air pollution due to widespread use of renewables and storage to mitigate the impacts of power interruptions). The range of emissions depends on generator efficiency, which applies to NO_X and PM_{10} emissions only.

We estimate that the current owned and rented backup generation stock in ComEd’s territory would generate 11, 33, and 147 GWh for one, three, and 14 day interruption events according to our survey data and scaling based on total ComEd retail sales. Doubling backup generation use would then generate 22, 67, and 293 GWh for the three interruption durations. Using publicly-available pollutant emission intensity values, we estimate a range of incremental emissions for four key pollutants from doubling backup generation use, as described in Table 8-1 below (all units in metric tons) (Miller and Lents 2005).

Table 8-1. *Incremental* emissions from doubling the use of backup generation for three interruption duration scenarios (metric tons)

Duration (days)	NO_X	CO_2	CH_4	PM_{10}
1	185-500	7,717	2	10-43
3	550-1,487	23,550	8	27-121
14	2,373-6,365	103,350	43	105-468

Next, we monetize these emissions based on publicly-available data for the net present value of the social cost of these pollutants (IWGSCGG 2021; Muller and Mendelsohn 2009). These monetary values vary significantly depending on assumptions about discount rate and whether they are averages or the 95th percentile. We select a set of average values to estimate the cost of typical emission levels, and a set of higher values to monetize the higher bound. We estimate total incremental social air pollution costs of $0.3-$11, $1.2-$33, and $5-$139 million dollars (in 2020) for one, three and 14 day interruption durations (see Table 8-2, below).

Table 8-2. *Incremental* air pollution-related costs from doubling the use of backup generation ($ millions)

Duration (days)	Social cost of air pollution
1	$0.3-$11
3	$1.2-$33
14	$5-$139

Conversely, these values also represent the avoided pollution costs that would accrue to society should non-polluting sources (e.g., renewable resources with storage capabilities) be used to provide higher levels of backup generation instead of traditional fossil fuel-based resources. It is important to note that this analysis does not account for the additional health and safety risks that often increase as a result of consumers running fossil fuel-based backup generators in areas that do not have proper ventilation (e.g., carbon monoxide poisoning).

Sectoral-level impacts must be evaluated in greater detail in order to develop specific resilience interventions

We identify several sectors that may have an outsized impact on resilience, either because their output volume is very high, their sensitivity to interruptions is higher than other sectors, or both. The survey outcomes illuminate how a subset of firms within each of these sectors would respond to interruptions. However, more detailed information that covers a larger population of firms in these essential sectors is needed to better understand their specific costs and identify proper interventions. For example, there may be a natural inclination to supply essential firms with backup generation or battery storage. However, survey results show that some key sectors such as hospitals and healthcare already show very high penetration of these resources and hence alternative strategies would be more effective.

Sector-specific surveys may help to understand other direct costs that can be mitigated, as well as validate the indirect costs and sectoral dependencies suggested by the model. To overcome the low response rate limitations described above, these surveys should take the form of sectoral focus groups or similar types of engaged data gathering processes.

Labor constraints in sectors and/or micro-regions with increased economic activity should also be investigated

The net economic gains reported by the model require additional research and possibly adjustments to the underlying model structure. Adjustments may be necessary to account for the constraint that labor-intensive industries that benefit from lower wage labor availability may not be able to absorb all of the labor suggested by the model.

Relationships between reported customer interruption costs and regional economic impacts should be explored in greater detail

In addition to the economic impacts generated from the POET model, we collected–via the survey responses–direct costs of interruptions by tactic, geographic area, duration, and industry. Some of this information is used to calibrate the POET model. However, the overall relationship between the aggregated costs that customers report and how this information is related to overall changes in gross output, GDP, and household consumption are quite complex and understanding them will require further research.

The rates at which individual micro-region losses increase as interruption durations increase should be investigated further

The model results follow the intuition that longer duration interruptions have a higher economic impact, either in loss of sectoral output, GDP, sectoral value-added, or household consumption. There are significant differences in the rate in which losses increase depending on the micro-region. The differences that we find across regions are already present in the no-resilience scenario, which suggests that the resilience response does not particularly affect the way duration informs economic loss. Additional research is needed to fully explain why an economic loss in one micro-region grows slower (faster) as the duration increases compared to other micro-regions.

High income household consumption losses should also be investigated further

We reported that high income households without power in Dekalb and Kendall and McHenry counties have consumption losses that are significantly smaller than the consumption losses in Cook and the rural ComEd counties. We cannot immediately explain why high-income households in places like McHenry and Dekalb and Kendall counties have a lower sensitivity to interruptions compared to high income households in other micro-regions. Follow-up research could explore why high-income households in some counties have significantly lower consumption loss compared to households in other regions.

With the exception of a power interruption occurring in rural ComEd, the highest income group is expected to have the largest losses to consumption during a one-day interruption. However, as interruptions durations increase, consumption losses for lower income households increase to a point in which they exceed high income households during the 14-day interruption. It is not immediately clear why income groups have different consumption losses for each interruption duration, but it may be related to the choice of resilience tactics reported by survey respondents. Additional research into the survey responses and modeling outcomes is needed to fully understand this issue and confirm this hypothesis.

Computational limitations prevented the assignment of resilience tactics to all 38 industry sectors

Instead, the POET model maps resilience tactics into three broadly-defined customer classes: residential, commercial, and industrial. Not surprisingly, the survey responses show that individual industrial sectors engage in disparate tactics. For example, sectors like hospitals, agriculture, and construction are much less likely to shut down their activities, either because they are an essential sector (hospitals) or they do not substantially depend on electricity (agriculture). In contrast, sectors including restaurants and education largely stop operating with short duration interruptions, deploying tactics for continued operation only in a 14-day event (see Table 5.8).

The current version of the model is unable to reflect these sector-specific tactic choices and hence the sectoral response follows the average of the aggregated commercial and industrial sectors, rather than the tactic choice that a sector is more likely to follow. This limitation means that sectors that reported high ability to remain operational during WLD interruptions (e.g., hospitals) have simulated sectoral output losses that are probably higher than they would be in reality. Conversely, sectors that reported a relatively low ability to remain operational (e.g., education, restaurants) have simulated sectoral output losses that are probably lower than they would be in reality. The model is calibrated so that these differences are netted out in aggregated analyses, but should be considered when interpreting sector-level results. Further model development–as well as higher sector-specific survey sample sizes–are needed to incorporate unique sectoral-level resilience tactic benefits and costs.

Not all societal impacts of power interruptions were captured in this type of analysis

There are a number of additional interruption cost categories that were not directly captured in this analysis including morbidity costs, mortality costs, and loss of school-based childcare on employment patterns. However, some of these costs may have been captured implicitly in the way that the customers responded to the value of lost load questions. For example, customers were asked if they would have lost income due to the power interruption--it is possible that these respondents were accounting for the fact that they would have to provide childcare during the interruption instead of working. Nonetheless, these issues would necessitate a more in-depth set of survey instruments to generate the information needed for CGE modeling and/or separate analyses to assess these additional costs to society (or the benefits of avoiding these costs in the future due to investments in resilience).

8.2 Conclusion

Society depends on electric power for many activities, making individual and collective vulnerability to power disruptions a key question for electric utility planning. Most electric power interruptions, which often originate at the distribution system-level, cause little disruption to daily life. However, widespread, long duration power interruptions, including those caused by extreme weather, can result in substantial economic impacts to society. It is essential to consider the costs of power interruptions when making decisions about power system reliability and resilience.

This project involved implementing a hybrid resilience valuation approach that combines: (1) advanced survey-based techniques to identify mitigating/adaptive behaviors that residential, commercial, and industrial customers may take to reduce risk before, during, or after a power interruption occurs; (2) techniques to elicit the direct interruption costs to non-residential customers; and (3) a regional economic model that has been calibrated to assess the full range of economic impacts from power interruptions occurring across the ComEd service territory and beyond. The project produced estimates of the full economic impacts of power interruptions of various geographic extents and durations. In addition, results were produced for nearly 40 industrial sectors, household income groups using a range of economic impact metrics. We hope that the information has been presented in a way that immediately benefits the utility and other stakeholders as they take steps to enhance the resilience of ComEd's power system.

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APPENDIX A. Survey instruments used to collect customer responses

Residential

Survey Overview (internal only - not visible to respondents)

The survey is split into six sections:

1. Welcome page
2. Intro questions
3. Scenario A: Cause #1 – 24 hours
4. Scenario B: Cause #1 – 3 days
5. Scenario C: Cause #1 – 2 weeks
6. Demographic questions

Scenario A starts by describing a power outage caused by either a severe thunderstorm (derecho) or an ice storm. This cause is randomly picked for each respondent. In the file provided to VuPoint, there will be a "cause" column that will be either "a severe thunderstorm" or "an ice storm". This value should be used for Scenarios A through C.

Each respondent then answers questions about that outage for three different lengths: 24 hours, three days, and two weeks. This covers Scenarios A–C.

There are coding provisions here for when the respondent skips past questions, there should be no options presented online that show "Refused" or "Skip" as a response option.

Notes to survey programmers are placed in *[square brackets and italicized]*. These notes are not displayed to survey participants. Question numbers are not displayed to respondents.

Start of Block: Welcome page

Commonwealth Edison – 2022 Power Outage Survey

Thank you for participating in this valuable study. ComEd is working with Lawrence Berkeley National Laboratory (LBNL), Resource Innovations Inc., and VuPoint Research to conduct this research survey to better understand how electricity outages affect customers. Completing this survey also provides you with an opportunity to plan your response should you experience an outage in the future.

This study is being conducted as a part of research and your participation is voluntary. To take part in the study, you must be at least 25 years old, have lived in the ComEd service territory for two years or more, and be aware of, or responsible for, your home's electricity bills.

In this study, we will ask you first for basic information about your household and the status of several items related to power outages, such as whether you own a back-up generator and what type of heating system you have. Next, we will ask questions about examples of power outages that last for different amounts of time and have different impacts. These questions include asking you to estimate how much money those power outages could cost you.

This survey will take approximately **10 minutes** to complete.

The research team will immediately remove sensitive information after initial processing and before any analysis is performed. This information includes your name, account number, email address, mailing address, and any other personally identifiable information. The answers you provide will be kept strictly confidential, anonymized, and stored on private, password-protected servers. There is always a small risk that your data may be compromised, or you could be identified as a participant, however, the study team is taking as many steps as possible to prevent this.

If you have any concerns, please contact ComEd's Customer Care Center at 1-800-EDISON-1 (1-800-334-7661). For specific questions about the survey, please contact Jeremy Smith by email at jsmith@resource-innovations.com. If you have questions about your legal rights as a participant in the survey, please contact the LBNL Human Subjects Committee at harc@lbl.gov.

Start of Block: Intro questions

In answering the questions on the survey assume a power outage involves a complete interruption of electricity service so that none of the appliances or other devices in your home that depend on electricity will work, unless they can be powered by batteries or a backup generator.

If you share a building with other owners or tenants, please answer the questions only about your residence.

[ASK ALL]
[OPEN-ENDED RESPONSE]
Q2. Including yourself, how many people live in your household?

1. _________ persons

[ASK ALL]
[SINGLE RESPONSE]
Q4_1. Do you currently work to earn an income?

1. Yes
2. No

[ASK ALL]
[OPEN-ENDED RESPONSE, ALLOW ENTRIES 0 - 9]

Q4_2. Including yourself, how many people living in your household are currently working to earn an income?

1. _________ persons

[ASK IF (Q4_1 = 1 & Q4_2 > 1) OR (Q4_1 = 2 & Q4_2 > 0]
[OPEN-ENDED RESPONSE, ALLOW ENTRIES 0 - 9]

Q4_3. Besides yourself, how many people living in your household are paid on an hourly basis?

1. _________ persons

[ASK IF Q4_2 > 0]
[THE NUMBER OF ROWS SHOULD BE EQUAL TO THE ANSWER IN Q4_2]

Q5. For each working person, please indicate whether they are currently working from home or outside the home, how the person is paid, whether the person is working at home because of the COVID-19 pandemic and, if so, whether the person will return to working outside of home after COVID-19 has been contained and restrictions have been relaxed.

[Insert table that collects information for each working person using drop down menus for Q5_2 – Q5_5 and open-ended response for Q5_6]

Q5_1 **Person**	**Q5_2** **Work Location**	**Q5_3** **Wage Payment Type**	**Q5_4** **Currently working from home because of COVID pandemic?**	**Q5_5** **Working from home after COVID pandemic?**	**Q5_6** **Monthly Earnings**
Person 1	1. Outside 2. Home	1. Salaried 2. Hourly 3. Own 4. Business 5. Other	1. Yes 2. No	1. Yes 2. No	1. [OPEN-ENDED]
Person 2					
Person n					

[ASK IF Q4_3 > 0]
[THE NUMBER OF ROWS SHOULD BE EQUAL TO THE ANSWER IN Q4_3]
[Insert table that collects information for each working person using drop down menus for Q6_2 – Q6_3]

Q6. You indicated that besides you, (one or more) of the persons in your household (is/are) paid on an hourly basis. In the table provided below, please indicate whether they would be paid if they were unable to work because the electricity was out at their work or at home.

Q6_1 **Person**	**Q6_2** **Would this person still be paid if a power**	**Q6_3** **Would this person still be paid if a power**

	outage prevented them from working at their place of employment (outside of the home)?	outage prevented them from working at home?
Insert hourly person1	1. Yes 2. No -98. Don't know -99. Refused	1. Yes 2. No -98. Don't know -99. Refused
Insert hourly person2		
Insert hourly person3		

[ASK IF Q4_2 > 0]
[SINGLE RESPONSE]

Q7. Is it possible for people in your household to work from home when the power is out for an extended period of time?

1. Yes – for all people who work
2. Yes – for some people who work
3. No – not for anyone
-98. Not sure

[ASK ALL]
[SINGLE RESPONSE]

Q8. Does anyone in your household have any health conditions that could be worsened by a long power outage? (For example, someone might need an oxygen machine powered by electricity or take medication that requires refrigeration.)

1. Yes - Please explain: ____
2. No
-98. I'd rather not answer

[ASK ALL]
[OPEN-ENDED RESPONSE]

Q9. What is the approximate value of the contents of your refrigerator(s)?

1. $__________

[ASK ALL]
[OPEN-ENDED RESPONSE]
[Q9 and Q10 should display on the same page]

Q10. What is the approximate value of the contents of your freezer(s)? (If you have one)

1. $_________

[ASK ALL]

[OPEN-ENDED RESPONSE]

Q11. How much does your household spend on food per week?

1. $_________

[ASK ALL]

[OPEN-ENDED RESPONSE]

Q12. How many days' worth of food and water do you currently have on hand in your home?

1. _______ days

[ASK ALL]

[SINGLE RESPONSE]

Q13. Does your household have a solar PV system connected to a battery storage device?

1. Yes
2. No
-98. Don't know

[ASK Q13 = 1]

[OPEN-ENDED RESPONSE]

Q13_1. What was the cost to purchase and install the solar PV and battery storage system after rebates and tax incentives?

1. $_________
-98. Don't know

[ASK ALL]

[SINGLE RESPONSE]

Q14. Does your household have a backup generator?

1. Yes
2. No
-98. Don't know

[ASK IF Q14 = 1]

[SINGLE RESPONSE]

Q14_1 What is the backup generator's fuel source?

1. Diesel or gasoline
2. Natural Gas
3. Propane gas

4. Other: ____

-98. Don't know

[ASK IF Q14_1 = 1]

[SINGLE RESPONSE]

Q14_2 How much fuel does your backup generator consume while operating?

1. Less than 0.5 gallon per hour
2. 0.5 – 1 gallon per hour
3. 1 – 2 gallons per hour
4. 2 – 3 gallons per hour
5. More than 3 gallons per hour

98. Don't know

[ASK IF Q14_1 = 2, 3 OR IF Q14_2 = 98]

[OPEN-ENDED RESPONSE]

Q14_3 What is the output wattage of your backup generator?

1. Less than 1,000 W
2. 1,000 W – 2,499 W
3. 2,500 W – 4,999 W
4. 5,000 W – 7,999 W
5. 8,000 W or more

98. Don't know

[ASK Q14 = 1]

[OPEN-ENDED RESPONSE]

Q14_4 What was the cost to purchase and install the backup generator after rebates and tax incentives?

1. $_________

-98. Don't know

[ASK IF Q14 = 1]

[SINGLE RESPONSE]

Q15. On a scale of 0 to 100 percent, how certain are you that your backup generator will start when you try to turn it on?

0% 10 20 30 40 50 60 70 80 90 100%

Percent Certain

[ASK IF Q14 = 1]

[SINGLE RESPONSE]

Q16. On a scale of 0 to 100 percent, how familiar are you with how to operate your generator?

0%	10	20	30	40	50	60	70	80	90	100%
Not At All Familiar					Somewhat Familiar					Very Familiar

[ASK IF Q14 = 1]
[SINGLE RESPONSE]
Q17. Have you tested the backup generator in the past 12 months?

1. Yes – How long did you run it? hours_____ minutes _____
2. No
-98. Don't know

[ASK IF Q14_1 = 1, 3]
[OPEN-ENDED RESPONSE]
Q18. How long can your generator run given the fuel that is normally stored on-site?

______ Days and

______ hours
-98. Don't know

[ASK Q4_2 > 0]
[SINGLE RESPONSE]
[DISPLAY THE "NOTE" BASED ON PREVIOUS ANSWERS AND THE REST OF THE Q TO EVERYONE]

(*Person taking survey works*)
[DISPLAY IF Q4_1 = 1]
Note: Answer the following questions about work as they relate to your income, regardless of who else in the household also has an income.

(*Household works except the person taking the survey*)
[DISPLAY IF Q4_1 = 2 & Q4_2 > 0]
Note: If more than one other person in your household works, answer the following questions about work as they pertain to the one person who is the main source of income for your household. In the following questions "you" refers to the person who provides main source of income.

[DISPLAY ALL]
Q19 Are you currently working from home most of the time?

1. Yes
2. No

Start of Block: Scenario A

[DISPLAY IF CAUSE = "SEVERE THUNDERSTORM"]
In this section, please imagine the following situation: It is a normal summer weekday in July. In the early afternoon, a series of thunderstorms form in the area, bringing rain and destructive winds as strong as a tornado.

In the middle of the wind and rain, the power goes out. Assume the power outage extends across a 20-mile radius surrounding your home. The wind did not cause extensive damage to nearby buildings and roads, but did cause widespread damage to trees and power lines that will take some time to repair.

Weather is expected to be "typical" summer weather throughout the duration of the outage. Meteorologists do not expect any heatwaves or large storms.

[DISPLAY IF CAUSE = "ICE STORM"]
Scenario Description: In this section, please imagine the following situation: It is a normal weekday in January. In the morning, freezing rain begins, with ice building up on the ground, roads, trees, and power lines.

In the middle of the storm, the power goes out. Assume the outage extends across a 20-mile region surrounding your home. The storm did not cause extensive damage to nearby buildings, but did leave a layer of ice on roads and caused widespread damage to trees and power lines that will take some time to repair.

Weather is expected to be "typical" winter weather throughout the duration of the outage. Meteorologists do not expect any other snow or ice storms.

[DISPLAY ALL]
After a few hours, your utility announces that the outage will last for **24 hours**.

A number of appliances at your home and services in your community will not work during this time period. The following appliances will not work at your home (If centralized electricity services are disrupted):

- Electrical appliances that are not supplied by backup generation or battery power (refrigerator, freezer, television, desktop computers, washing machine, dryer, vehicle charger, garage door opener, etc.)
- Land-line telephones that plug into a power outlet
- Cell phones, once the batteries run out
- Cable
- Internet
- Solar PV panels
- Electric heating devices, such as space heaters and heat pumps

- Air conditioning and other electric cooling appliances
- Interior lighting

The following services will not work in the area affected by the outage:

- Traffic signals
- Street lights
- Banks and ATMs
- Most gas stations
- Most grocery stores
- Most restaurants and retail stores
- Airports (major delays)
- Cellular phone service may work occasionally throughout the outage but will not be consistent or reliable.

[DISPLAY IF CAUSE = "SEVERE THUNDERSTORM"]
Please select the strategy that is closest to the one that you would use to adapt to a **24-hour** outage caused by **summer thunderstorms**. You should assume that you cannot purchase a backup generator during the outage.

[DISPLAY IF CAUSE = "ICE STORM"]
Please select the strategy that is closest to the one that you would use to adapt to a **24-hour** outage caused by a **winter ice storm**. You should assume that you cannot purchase a backup generator during the outage.

[DISPLAY ALL]
1. Stay home and do activities that do not require electricity
2. Stay home running your own backup generator or battery storage unit to power critical appliances and devices
3. Temporarily move some or all family members to places that have electric power (i.e., houses of family or friends outside the affected area, hotels or emergency shelters outside the affected area)

[ASK ALL]
[SINGLE RESPONSE]
Q20_1_1 Do you think the contents of your refrigerator or freezer would spoil during this <u>24-hour</u> outage?

1. Yes – Some or all off the contents would spoil
2. No
-98. Don't know

[ASK IF Q20_1_1 = 1]
[OPEN-ENDED RESPONSE]

Q20_1_2 What would be the approximate value of the spoiled food?

1. $_______

(Ask if they answered that they or other household members work from home)
[ASK IF Q20 = 1 & Q19 = 1]
[SINGLE RESPONSE]
Q20_1_3 Would you be able to work at your home during the time when the power is out?

1. Yes
2. No
-98. Don't know

[ASK IF 20_1_3 = 2]
[SINGLE RESPONSE]
Q20_1_4 Would your employer pay if you were unable to work during the outage?

1. Yes
2. No
-98. Don't know

[ASK IF 20_1_4 = 2]
[OPEN-ENDED RESPONSE]
Q20_1_5 How much income would you lose because your employer(s) would not pay you during this <u>24-hour</u> outage?

1. $_____

[ASK IF 20_1_4 = 2]
[SINGLE RESPONSE]
Q20_1_6 Would you be able to make up any of the lost income by working more when the power returns?

1. Yes
2. No
-98. Don't know

[ASK IF 20_1_6 = 1]
[OPEN-ENDED RESPONSE]
Q20_1_7 How much of the lost income would you be able to recoup?

1. $_____

(Ask if they answer that they work outside the home)
[ASK IF Q20 = 1 & Q19 = 2]
[SINGLE RESPONSE]
Q20_1_8 Is your workplace more than 20 miles away from your home?

1. Yes
2. No
-98. Don't know

[ASK IF Q20_1_8 = 2]
[SINGLE RESPONSE]
Q20_1_9 If you could not work during this outage because your employer's facilities were closed, would you be paid?

1. Yes
2. No
-98. Don't know

[ASK IF Q20_1_9 = 2]
[OPEN-ENDED REPONSE]
Q20_1_10 How much income would your household lose because you could not work during this 24-hour outage?

1. $________

[ASK IF Q20_1_9 = 2]
[SINGLE REPONSE]
Q20_1_11 Would you be able to make up any of the lost income by working more when the power returns?

1. Yes
2. No
-98. Don't know

[ASK IF Q20_1_11 = 1]
[OPEN-ENDED REPONSE]
Q20_1_12 How much of the lost income would you be able to recoup?

1. $_____

[ASK IF Q20 = 1]
[SINGLE REPONSE]
Q20_1_13 How would you provide meals to your household during this 24-hour outage? (select one)

1. Eat cold foods, BBQ, camp stove and other home cooking
2. Order food delivered (remember the closest restaurant is 20 miles away)
3. Travel to restaurant located 20 or more miles away

[ASK IF Q20_1_13 = 2]
[SINGLE REPONSE]
Q20_1_14 What are the estimated cost of meals and delivery each day?

1. _______$/day

[ASK IF Q20_1_13 = 3]
[SINGLE REPONSE]
Q20_1_15 What are the estimated cost of meals and transportation each day?

1. _______$/day

[ASK IF Q20 = 2]
[MULTIPLE RESPONSE]
Q20_2_1 Given the size of your generator and available fuel, or battery storage capacity, what appliances would be powered during this period? (select all that apply)

1. All of them
2. Refrigerator
3. Freezer
4. Lights
5. Air conditioning system
6. Heating system
7. Stove
8. Cooktop
9. Electronic devices (e.g., cell phone, computer)
10. Home entertainment systems
11. Automobile charging station
12. Swimming pool/spa
13. Water pumps
14. Other (specify) ___________________________

[ASK IF Q14 = 1 AND Q20 = 2]
[OPEN-ENDED RESPONSE]
Q20_2_2 Approximately how many hours per day would you be running your generator?

1. Hours _____

[ASK IF Q20 = 3]
[OPEN-ENDED RESPONSE]
Q20_3_1 How much do you think it would cost to move your family members to another location and transport them back after the 24-hour outage is over?
1. $________

[ASK IF Q20 = 3]
[OPEN-ENDED RESPONSE]
Q20_3_2 How much do you think meals and lodging would cost on a daily basis?
1. $________/Day

(Ask if they answered that they or other household members work from home)
[ASK IF Q20 = 3 & Q19 = 1]
[SINGLE RESPONSE]
Q20_3_3 Would you be able to work at the new temporary location during the time when you are located there?

1. Yes
2. No
-98. Don't know

[ASK IF Q20_3_3 = 2]
[SINGLE RESPONSE]
Q20_3_4 Would your employer pay you if you were unable to work during the outage?

1. Yes
2. No
-98. Don't know

[ASK IF Q20_3_4 = 2]
[OPEN-ENDED RESPONSE]
Q20_3_5 How much income would your household lose because your employer would not pay you during this 24-hour outage?
1. $_____

[ASK IF Q20_3_4 = 2]
[SINGLE RESPONSE]
Q20_3_6 Would you be able to make up any of the lost income by working more when the power returns?

1. Yes
2. No
-98. Don't know

[ASK IF Q20_3_6 = 1]
[OPEN-ENDED RESPONSE]
Q20_3_7 How much of the lost income would you be able to recoup?
1. $_____

(Ask if they answer that they work outside the home)
[ASK IF Q20 = 3 & Q19 = 2]
[SINGLE RESPONSE]
Q20_3_8 Is your workplace more than 20 miles away from your home?
1. Yes
2. No
-98. Don't know

[ASK IF Q20_3_8 = 1]
[SINGLE RESPONSE]
Q20_3_9 Would you be able to travel to your workplace from your temporary location?
1. Yes
2. No
-98. Don't know

[ASK IF Q20_3_9 = 2]
[SINGLE RESPONSE]
Q20_3_10 Would your employer pay you if you could not come to work during this outage?
1. Yes
2. No
-98. Don't know

[ASK IF Q20_3_10 = 2]
[OPEN-ENDED RESPONSE]
Q20_3_11 How much income would your household lose because your employer(s) would not pay you during the <u>24-hour</u> outage?
1. $________

[ASK IF Q20_3_10 = 2]
[SINGLE RESPONSE]
Q20_3_12 Would you be able to make up any of the lost income by working more when the power returns?

1. Yes
2. No
-98. Don't know

[ASK IF Q20_3_12 = 1]
[OPEN-ENDED RESPONSE]
Q20_3_13 How much of the lost income would you be able to recoup?
1. $_____

[ASK IF Q20_3_8 = 2]
[SINGLE RESPONSE]
Q20_3_14 If you could not work during this outage because your employer's facilities were closed, would you be paid?
1. Yes
2. No
-98. Don't know

[ASK IF Q20_3_14 = 2]
[OPEN-ENDED RESPONSE]
Q20_3_15 How much income would your household lose because you could not work during this <u>24-hour</u> outage?
1. $________

[ASK IF Q20_3_14 = 2]
[SINGLE RESPONSE]
Q20_3_16 Would you be able to make up any of the lost income by working more when the power returns?

1. Yes
2. No
-98. Don't know

[ASK IF Q20_3_16 = 1]
[OPEN-ENDED RESPONSE]
Q20_3_17 How much of the lost income would you be able to recoup?
1. $_____

Start of Block: Scenario B

[DISPLAY IF CAUSE = "SEVERE THUNDERSTORM"]
Scenario B

This scenario is similar to the previous scenario, but the outage lasts for **3 days**.

A severe thunderstorm with high winds in July causes widespread damage to the region, including severe damage to electricity generation and power lines. Your utility announces that the outage will last for **3 days** and affect an area covering a **20-mile radius from your residence.**

Weather is expected to be "typical" summer weather throughout the duration of the outage. Meteorologists do not expect any heatwaves or large storms during the rest of the power outage.

[DISPLAY IF CAUSE = "ICE STORM"]
Scenario B

This scenario is similar to the previous scenario, but the outage lasts for **3 days**.

An ice storm in January causes widespread damage to the region, including severe damage to electricity generation and power lines. Your utility announces that the outage will last for **3 days** and affect an area covering a **20-mile radius from your residence.**

Weather is expected to be "typical" winter weather throughout the duration of the outage. Meteorologists do not expect any other snow or ice storms.

[DISPLAY IF CAUSE = "SEVERE THUNDERSTORM"]
Please select the strategy that is closest to the one that you would use to adapt to a **3-day** outage caused by **summer thunderstorms**. You should assume that you cannot purchase a backup generator during the outage.

[DISPLAY IF CAUSE = "ICE STORM"]
Please select the strategy that is closest to the one that you would use to adapt to a **3-day** outage caused by a **winter ice storm**. You should assume that you cannot purchase a backup generator during the outage.

[DISPLAY ALL]

1. Stay home and do activities that do not require electricity
2. Stay home running your own backup generator or battery storage unit to power critical appliances and devices
3. Temporarily move some or all family members to places that have electric power (i.e., houses of family or friends outside the affected area, hotels or emergency shelters outside the affected area)

[ASK ALL]
[SINGLE RESPONSE]
Q21_1_1 Do you think the contents of your refrigerator or freezer would spoil during this <u>3-day</u> outage?
1. Yes – Some or all off the contents would spoil
2. No
-98. Don't know
-99. Refused

[ASK IF Q21_1_1 = 1]
[OPEN-ENDED RESPONSE]
Q21_1_2 What would be the approximate value of the spoiled food?
1. $_______

(Ask if they answered that they or other household members work from home)
[ASK IF Q21 = 1 & Q19 = 1]
[SINGLE RESPONSE]
Q21_1_3 Would you be able to work at your home during the time when the power is out?

1. Yes
2. No
-98. Don't know

[ASK IF Q21_1_3 = 2]
[SINGLE RESPONSE]
Q21_1_4 Would your employer pay if you were unable to work during the outage?

1. Yes
2. No
-98. Don't know

[ASK IF Q21_1_4 = 2]
[OPEN-ENDED RESPONSE]
Q21_1_5 How much income would you lose because your employer(s) would not pay you during this <u>3-day</u> outage?
1. $_____

[ASK IF Q21_1_4 = 2]
[SINGLE RESPONSE]
Q21_1_6 Would you be able to make up any of the lost income by working more when the power

returns?

1. Yes
2. No
-98. Don't know

[ASK IF Q21_1_6 = 1]
[OPEN-ENDED RESPONSE]
Q21_1_7 How much of the lost income would you be able to recoup?
1. $_____

(Ask if they answer that they work outside the home)
[ASK IF Q21 = 1 & Q19 = 2]
[SINGLE RESPONSE]
Q21_1_8 Is your workplace more than 20 miles away from your home?
1. Yes
2. No
-98. Don't know

[ASK IF Q21_1_8 = 2]
[SINGLE RESPONSE]
Q21_1_9 If you could not work during this outage because your employer's facilities were closed, would you be paid?

1. Yes
2. No
-98. Don't know

[ASK IF Q21_1_9 = 2]
[OPEN-ENDED REPONSE]
Q21_1_10 How much income would your household lose because you could not work during this <u>3-day</u> outage?
1. $________

[ASK IF Q21_1_9 = 2]
[SINGLE REPONSE]
Q21_1_11 Would you be able to make up any of the lost income by working more when the power returns?

1. Yes
2. No
-98. Don't know

[ASK IF Q21_1_11 = 1]
[OPEN-ENDED REPONSE]
Q21_1_12 How much of the lost income would you be able to recoup?
1. $_____

[ASK IF Q21 = 1]
[SINGLE REPONSE]
Q21_1_13 How would you provide meals to your household during this <u>3-day</u> outage? (select one)
1. Eat cold foods, BBQ, camp stove and other home cooking
2. Order food delivered (remember the closest restaurant is 20 miles away)
3. Travel to restaurant located 20 or more miles away

[ASK IF Q21_1_13 = 2]
[SINGLE REPONSE]
Q21_1_14 What are the estimated cost of meals and delivery each day?
1. _______$/day

[ASK IF Q21_1_13 = 3]
[SINGLE REPONSE]
Q21_1_15 What are the estimated cost of meals and transportation each day?
1. _______$/day

[ASK IF Q21 = 2]
[MULTIPLE RESPONSE]
Q21_2_1 Given the size of your generator and available fuel, or battery storage capacity, what appliances would be powered during this period? (select all that apply)

1. All of them
2. Refrigerator
3. Freezer
4. Lights
5. Air conditioning system
6. Heating system
7. Stove
8. Cooktop
9. Electronic devices (e.g., cell phone, computer)
10. Home entertainment systems
11. Automobile charging station
12. Swimming pool/spa
13. Water pumps
14. Other (specify) ___________________________

[ASK IF Q14 = 1 AND Q21 = 2]
[OPEN-ENDED RESPONSE]
Q21_2_2 Approximately how many hours per day would you be running your generator?
1. Hours _____

[ASK IF Q21 = 3]
[OPEN-ENDED RESPONSE]
Q21_3_1 How much do you think it would cost to move your family members to another location and transport them back after the <u>3-day</u> outage is over?
1. $________

[ASK IF Q21 = 3]
[OPEN-ENDED RESPONSE]
Q21_3_2 How much do you think meals and lodging would cost on a daily basis?
1. $________/Day

(Ask if they answered that they or other household members work from home)
[ASK IF Q21 = 3 & Q19 = 1]
[SINGLE RESPONSE]
Q21_3_3 Would you be able to work at the new temporary location during the time when you are located there?

1. Yes
2. No
-98. Don't know

[ASK IF Q21_3_3 = 2]
[SINGLE RESPONSE]
Q21_3_4 Would your employer pay you if you were unable to work during the outage?

1. Yes
2. No
-98. Don't know

[ASK IF Q21_3_4 = 2]
[OPEN-ENDED RESPONSE]
Q21_3_5 How much income would your household lose because your employer would not pay you during this <u>3-day</u> outage?
1. $_____

[ASK IF Q21_3_4 = 2]
[SINGLE RESPONSE]

Q21_3_6 Would you be able to make up any of the lost income by working more when the power returns?

1. Yes
2. No
-98. Don't know

[ASK IF Q21_3_6 = 1]
[OPEN-ENDED RESPONSE]
Q21_3_7 How much of the lost income would you be able to recoup?
1. $_____

(Ask if they answer that they work outside the home)
[ASK IF Q21 = 3 & Q19 = 2]
[SINGLE RESPONSE]
Q21_3_8 Is your workplace more than 20 miles away from your home?
1. Yes
2. No
-98. Don't know

[ASK IF Q21_3_8 = 1]
[SINGLE RESPONSE]
Q21_3_9 Would you be able to travel to your workplace from your temporary location?
1. Yes
2. No
-98. Don't know

[ASK IF Q21_3_9 = 2]
[SINGLE RESPONSE]
Q21_3_10 Would your employer pay you if you could not come to work during this outage?
1. Yes
2. No
-98. Don't know

[ASK IF Q21_3_10 = 2]
[OPEN-ENDED RESPONSE]
Q21_3_11 How much income would your household lose because your employer(s) would not pay you during the <u>3-day</u> outage?
1. $________

[ASK IF Q21_3_10 = 2]
[SINGLE RESPONSE]

Q21_3_12 Would you be able to make up any of the lost income by working more when the power returns?

1. Yes
2. No
-98. Don't know

[ASK IF Q21_3_12 = 1]
[OPEN-ENDED RESPONSE]
Q21_3_13 How much of the lost income would you be able to recoup?
1. $_____

[ASK IF Q21_3_8 = 2]
[SINGLE RESPONSE]
Q21_3_14 If you could not work during this outage because your employer's facilities were closed, would you be paid?
1. Yes
2. No
-98. Don't know

[ASK IF Q21_3_14 = 2]
[OPEN-ENDED RESPONSE]
Q21_3_15 How much income would your household lose because you could not work during this <u>3-day</u> outage?
1. $________

[ASK IF Q21_3_14 = 2]
[SINGLE RESPONSE]
Q21_3_16 Would you be able to make up any of the lost income by working more when the power returns?

1. Yes
2. No
-98. Don't know

[ASK IF Q21_3_16 = 1]
[OPEN-ENDED RESPONSE]
Q21_3_17 How much of the lost income would you be able to recoup?
1. $_____

Start of Block: Scenario C

[DISPLAY IF CAUSE = “SEVERE THUNDERSTORM”]
Scenario C

This scenario is similar to the previous two scenarios, but the outage lasts for **2 weeks**.

A severe thunderstorm with high winds in the summer causes widespread damage to the region, including severe damage to electricity generation and power lines. Your utility announces that the outage will last for **2 weeks** and affect an area covering a **20-mile radius from your residence.**

Weather is expected to be “typical” summer weather throughout the duration of the outage. Meteorologists do not expect any heatwaves or large storms during the rest of the power outage.

[DISPLAY IF CAUSE = “ICE STORM”]
Scenario C

This scenario is similar to the previous scenario, but the outage lasts for **2 weeks**.

An ice storm in January causes widespread damage to the region, including severe damage to electricity generation and power lines. Your utility announces that the outage will last for **2 weeks** and affect an area covering a **20-mile radius from your residence.**

Weather is expected to be “typical” winter weather throughout the duration of the outage. Meteorologists do not expect any other snow or ice storms.

[DISPLAY IF CAUSE = “SEVERE THUNDERSTORM”]
Please select the strategy that is closest to the one that you would use to adapt to a **2-week** outage caused by **summer thunderstorms**. You should assume that you cannot purchase a backup generator during the outage.

[DISPLAY IF CAUSE = “ICE STORM”]
Please select the strategy that is closest to the one that you would use to adapt to a **2-week** outage caused by a **winter ice storm**. You should assume that you cannot purchase a backup generator during the outage.

[DISPLAY ALL]
1. Stay home and do activities that do not require electricity
2. Stay home running your own backup generator or battery storage unit to power critical appliances and devices
3. Temporarily move some or all family members to places that have electric power (i.e., houses of family or friends outside the affected area, hotels or emergency shelters outside the affected area)

[ASK ALL]
[SINGLE RESPONSE]
Q22_1_1 Do you think the contents of your refrigerator or freezer would spoil during this <u>2-week</u> outage?
1. Yes – Some or all off the contents would spoil
2. No
-98. Don't know

[ASK IF Q22_1_1 = 1]
[OPEN-ENDED RESPONSE]
Q22_1_2 What would be the approximate value of the spoiled food?
1. $_______

(Ask if they answered that they or other household members work from home)
[ASK IF Q22 = 1 & Q19 = 1]
[SINGLE RESPONSE]
Q22_1_3 Would you be able to work at your home during the time when the power is out?

1. Yes
2. No
-98. Don't know

[ASK IF Q22_1_3 = 2]
[SINGLE RESPONSE]
Q22_1_4 Would your employer pay if you were unable to work during the outage?

1. Yes
2. No
-98. Don't know

[ASK IF Q22_1_4 = 2]
[OPEN-ENDED RESPONSE]
Q22_1_5 How much income would you lose because your employer(s) would not pay you during this <u>2-week</u> outage?
1. $_____

[ASK IF Q22_1_4 = 2]
[SINGLE RESPONSE]
Q22_1_6 Would you be able to make up any of the lost income by working more when the power returns?

1. Yes

2. No
-98. Don't know

[ASK IF Q22_1_6 = 1]
[OPEN-ENDED RESPONSE]
Q22_1_7 How much of the lost income would you be able to recoup?
1. $_____

(Ask if they answer that they work outside the home)
[ASK IF Q22 = 1 & Q19 = 2]
[SINGLE RESPONSE]
Q22_1_8 Is your workplace more than 20 miles away from your home?
1. Yes
2. No
-98. Don't know

[ASK IF Q22_1_8 = 2]
[SINGLE RESPONSE]
Q22_1_9 If you could not work during this outage because your employer's facilities were closed, would you be paid?

1. Yes
2. No
-98. Don't know

[ASK IF Q22_1_9 = 2]
[OPEN-ENDED REPONSE]
Q22_1_10 How much income would your household lose because you could not work during this 2-week outage?
1. $________

[ASK IF Q22_1_9 = 2]
[SINGLE REPONSE]
Q22_1_11 Would you be able to make up any of the lost income by working more when the power returns?

1. Yes
2. No
-98. Don't know

[ASK IF Q22_1_11 = 1]
[OPEN-ENDED REPONSE]

Q22_1_12 How much of the lost income would you be able to recoup?
1. $_____

[ASK IF Q22 = 1]
[SINGLE REPONSE]
Q22_1_13 How would you provide meals to your household during this <u>2-week</u> outage? (select one)
1. Eat cold foods, BBQ, camp stove and other home cooking
2. Order food delivered (remember the closest restaurant is 20 miles away)
3. Travel to restaurant located 20 or more miles away

[ASK IF Q22_1_13 = 2]
[SINGLE REPONSE]
Q22_1_14 What are the estimated cost of meals and delivery each day?
1. _______$/day

[ASK IF Q22_1_13 = 3]
[SINGLE REPONSE]
Q22_1_15 What are the estimated cost of meals and transportation each day?
1. _______$/day

[ASK IF Q22 = 2]
[MULTIPLE RESPONSE]
Q22_2_1 Given the size of your generator and available fuel, or battery storage capacity, what appliances would be powered during this period? (select all that apply)

1. All of them
2. Refrigerator
3. Freezer
4. Lights
5. Air conditioning system
6. Heating system
7. Stove
8. Cooktop
9. Electronic devices (e.g., cell phone, computer)
10. Home entertainment systems
11. Automobile charging station
12. Swimming pool/spa
13. Water pumps
14. Other (specify) ___________________________

[ASK IF Q14 = 1 AND Q22 = 2]
[OPEN-ENDED RESPONSE]
Q22_2_2 Approximately how many hours per day would you be running your generator?

1. Hours _____

[ASK IF Q22 = 3]
[OPEN-ENDED RESPONSE]
Q22_3_1 How much do you think it would cost to move your family members to another location and transport them back after the 2-week outage is over?
1. $________

[ASK IF Q22 = 3]
[OPEN-ENDED RESPONSE]
Q22_3_2 How much do you think meals and lodging would cost on a daily basis?
1. $________/Day

(Ask if they answered that they or other household members work from home)
[ASK IF Q22 = 3 & Q19 = 1]
[SINGLE RESPONSE]
Q22_3_3 Would you be able to work at the new temporary location during the time when you are located there?

1. Yes
2. No
-98. Don't know

[ASK IF Q22_3_3 = 2]
[SINGLE RESPONSE]
Q22_3_4 Would your employer pay you if you were unable to work during the outage?

1. Yes
2. No
-98. Don't know

[ASK IF Q22_3_4 = 2]
[OPEN-ENDED RESPONSE]
Q22_3_5 How much income would your household lose because your employer would not pay you during this 2-week outage?
1. $_____

[ASK IF Q22_3_4 = 2]
[SINGLE RESPONSE]
Q22_3_6 Would you be able to make up any of the lost income by working more when the power returns?

1. Yes
2. No
-98. Don't know

[ASK IF Q22_3_6 = 1]
[OPEN-ENDED RESPONSE]
Q22_3_7 How much of the lost income would you be able to recoup?
1. $_____

(Ask if they answer that they work outside the home)
[ASK IF Q22 = 3 & Q19 = 2]
[SINGLE RESPONSE]
Q22_3_8 Is your workplace more than 20 miles away from your home?
1. Yes
2. No
-98. Don't know

[ASK IF Q22_3_8 = 1]
[SINGLE RESPONSE]
Q22_3_9 Would you be able to travel to your workplace from your temporary location?
1. Yes
2. No
-98. Don't know

[ASK IF Q22_3_9 = 2]
[SINGLE RESPONSE]
Q22_3_10 Would your employer pay you if you could not come to work during this outage?
1. Yes
2. No
-98. Don't know

[ASK IF Q22_3_10 = 2]
[OPEN-ENDED RESPONSE]
Q22_3_11 How much income would your household lose because your employer(s) would not pay you during the 2-week outage?
1. $________

[ASK IF Q22_3_10 = 2]
[SINGLE RESPONSE]
Q22_3_12 Would you be able to make up any of the lost income by working more when the power returns?

1. Yes
2. No
-98. Don’t know

[ASK IF Q22_3_12 = 1]
[OPEN-ENDED RESPONSE]
Q22_3_13 How much of the lost income would you be able to recoup?
1. $_____

[ASK IF Q22_3_8 = 2]
[SINGLE RESPONSE]
Q22_3_14 If you could not work during this outage because your employer’s facilities were closed, would you be paid?
1. Yes
2. No
-98. Don’t know

[ASK IF Q22_3_14 = 2]
[OPEN-ENDED RESPONSE]
Q22_3_15 How much income would your household lose because you could not work during this <u>2-week</u> outage?
1. $________

[ASK IF Q22_3_14 = 2]
[SINGLE RESPONSE]
Q22_3_16 Would you be able to make up any of the lost income by working more when the power returns?

1. Yes
2. No
-98. Don’t know

[ASK IF Q22_3_16 = 1]
[OPEN-ENDED RESPONSE]
Q22_3_17 How much of the lost income would you be able to recoup?
1. $_____

Start of Block: Demographic data

[DISPLAY ALL]
To better understand how electrical power outages affect your household, we would like to gather some information on your household characteristics. Please answer the following questions to the best of your ability. If you live in an apartment building or duplex, answer only for the part of the building you actually live in.

[ASK ALL]
[OPEN-ENDED RESPONSE]
Q23 What is the size of your residence?

1. Square feet ____

[ASK ALL]
[TABLE WITH DROP DOWN MENU]
Q20_0 Please indicate all the different kinds of heating systems you have in your home and whether those heating systems will work if the electricity is out.

System	Have or Don't Have	Will or Won't work if electricity is out
Q20_0_1 Gas fireplace(s)		
Q20_0_2 Gas wall heater(s)		
Q20_0_3 Fireplace(s)		
Q20_0_4 Wood burning stove(s)		
Q20_0_5 Gas central heating		

[ASK ALL]
[TABLE WITH DROP DOWN MENU]
[DISPLAY ONLY OPTIONS THAT ARE "HAVE" AND "WILL WORK WHEN ELECTRICITY IS OUT" FROM Q20_0]
Q20_0_6 Please indicate how much of your home each heating system can approximately supply?

System	Can provide heat for…
Q20_0_7 Gas fireplace(s)	1. 1 room 2. 2 rooms 3. 3 rooms 4. 4 or more rooms

	5. Entire home
Q20_0_8 Gas wall heater(s)	1. 1 room 2. 2 rooms 3. 3 rooms 4. 4 or more rooms 5. Entire home
Q20_0_9 Fireplace(s)	1. 1 room 2. 2 rooms 3. 3 rooms 4. 4 or more rooms 5. Entire home
Q20_0_10 Wood burning stove(s)	1. 1 room 2. 2 rooms 3. 3 rooms 4. 4 or more rooms 5. Entire home
Q20_0_11 Gas central heating	1. 1 room 2. 2 rooms 3. 3 rooms 4. 4 or more rooms 5. Entire home

[ASK ALL]
[SINGLE RESPONSE]
Q24 Do you rent or own your residence?

1. Rent
2. Own
3. Neither
-98. Don't know

[ASK ALL]
[SINGLE RESPONSE]
Q25 What type of home best describes your residence?

1. Single-family detached
2. Townhome/townhouse (Single-family attached to two or more houses)
3. Duplex (two-family building)
4. Condominium
5. Small apartment building (3 to 4 units)
6. Large apartment building (5+ units)

7. A mobile or manufactured home
8. Other: ____

[ASK ALL]
[SINGLE RESPONSE]
Q26 Which of the following categories best describes your total annual household income in 2021, before taxes and other deductions? Please, include all income to the household including social security, interest welfare payments, child support, etc.

1. Under $25,000
2. $25,000 - $49,999
3. $50,000 - $74,999
4. $75,000 - $99,999
5. $100,000 - $124,999
6. $125,000 - $149,999
7. $150,000 - $174,999
8. $175,000 - $199,999
9. $200,000 - $250,000
10. Above $250,000

-99. Refuse

Please share any additional comments:
____
____
____
____
____

End of Survey

Thank you for taking this survey. Your response has been recorded.

Non-Residential

Survey Overview (internal only - not visible to respondent)

The survey is split into 6 sections:

1. Welcome page
2. General intro questions (firmographics)
3. Long-duration outages intro
4. Scenario A: 24 hours
5. Scenario B: 3 days
    a. Questions identical to Scenario A

6. Scenario C: 2 weeks
    a. Questions identical to Scenarios A/B

Scenario A starts by describing a power outage caused by either a severe thunderstorm (derecho) or an ice storm. This cause is randomly picked for each respondent. In the file provided to VuPoint Research there will be a "cause" column that will be either "a severe thunderstorm" or "an ice storm". This value should be used for Scenarios A through C.

There are coding provisions here for when the respondent skips past questions, there should be no options presented online that show "Refused" or "Skip" as a response option.

Notes to survey programmers and/or interviewers are placed in *[square brackets and italicized]*. These notes are not displayed to survey participants. Question numbers are not displayed to respondents.

Start of Block: Welcome page

Thank you for agreeing to participate in this important study. We ask that you complete this survey thinking **only** about the facilities that your organization occupies **at this location**:

«SERV_STREET_ADDR», «SERV_CITY_NAME»

If your organization shares a building with other businesses or you're the property manager at the above address(es), please answer the questions only for the space **your organization** occupies at this location and the activities **your organization** undertakes.

This survey will take approximately **30 minutes** to complete. Upon completion of the survey, your company will be eligible to receive a *[DISPLAY IF SMB]* **$100** *[DISPLAY IF LCI]* **$150** *[DISPLAY ALL]* **check**.

Start of Block: General Intro Questions

When completing this survey, please note that a "power outage" refers to a <u>complete</u> loss of electric power to your facility.

While most power outages last between a few minutes and a few hours, it is possible for an outage to last multiple days or weeks. We would like to know about various aspects of your business that would be affected by these longer outages.

If a question is difficult for you to answer, please give us your best estimate.

[ASK ALL]
[OPEN-ENDED RESPONSE]
Q5 In general, how long can a power outage last before it significantly affects your operations (e.g.,

causes them to stop or slow down)? Please estimate in hours and minutes.

5_1. Hours _______ and

5_2. minutes _______

-98. Don't know

[ASK ALL]

[SINGLE RESPONSE]

Q6 If the electricity grid needs maintenance that will require a 24-hour power outage, how much advance warning would your organization need to significantly reduce the problems caused by the outage? *[ONLY READ LIST IF NEEDED]*

1. Advance notice would not reduce problem(s)
2. 1 hour or less
3. Between 1 to 4 hours
4. Between 4 to 8 hours
5. Between 8 to 24 hours
6. More than 24 hours

-98. Don't know

[ASK ALL]

[OPEN-ENDED RESPONSE]

Q7 What is the approximate square footage of this facility?

1. Square feet _________

-98. Don't know

[ASK ALL]

[SINGLE RESPONSE]

Q8 (Internal note: this is where the survey will split based on the type of business)

We have your business type as «Q8_BUSINESS_TYPE». Is that correct?

[IF NEEDED: In other words, what type of business is your organization? ONLY READ LIST IF NEEDED.]

1. Agriculture, Forestry, Fishing & Hunting	
2. Mining	
3. Utilities	
3.1 Electric Power Generation	
3.2 Electric Power Transmission and Distribution	
3.3 Natural Gas Distribution	
3.4 Water, Sewage, and Other Systems	
4. Construction	
5. Manufacturing	
5.1 Motor and Generator Manufacturing	
5.2 Other Manufacturing	
6. Wholesale Trade	
7. Retail Trade	
7.1 Food and Beverage Stores	

7.1 Other Retail Trade	
8. Transportation	
9. Warehousing and Storage	
10. Information / Data / Telecommunications	
10.1 Internet Publishing and Broadcasting	
10.2 Telecommunications	
10.3 Data Processing, Hosting, and Related Services	
10.4 Other Information Services	
11. Finance & Insurance	
12. Real Estate	
13. Rental & Leasing Services	
14. Professional, Scientific, & Tech Services	
15. Management of Companies	
16. Administrative & Support Services	
17. Waste Management & Remediation Services	
18. Educational Services	
19. Health Care & Social Assistance	
19.1 Hospitals	
19.2 Other Health & Social Services	
20. Arts, Entertainment & Recreation	
21. Accommodation & Food Services	
21.1 Hotels and Motels (including Casino Hotels)	
21.2 Restaurants	
21.3 Other Accommodation & Food Services	
22. Public Administration / Government	
23. Other Services	
99. None of the above	

[ASK ALL]

[OPEN-ENDED RESPONSE]

Q13 How many of each of the following types of employees currently report to this location, including remote workers that would normally be present? *[READ AND RECORD RESPONSE TO EACH]*

1. Salaried employees ________
2. Hourly employees __________
3. Contract employees ________

-98. Don't know

Start of Block: Longer Outages Intro (Long Duration - General)

[ASK ALL]

[SINGLE RESPONSE]

Q15 For an outage lasting days or weeks, are there any activities at your business that can take place without electricity?

1. No
2. Yes - What activities? ____

-98. Don't know

[ASK ALL]
[SINGLE RESPONSE]
Q16_1 Does your firm perform any processes using electricity that can utilize an alternative fuel source during an outage? (For example, using natural gas instead of electricity during a manufacturing process.)
1. No
2. Yes
-98. Don't know

[ASK IF 16_1 = 2]
[OPEN-ENDED RESPONSE]
Q16_2 What percent of your daily electricity consumption can you replace with another fuel?
1. ______%
-98. Don't know

[ASK ALL]
[SINGLE RESPONSE]
Q17_1 Does your firm have some form of emergency backup electrical power? For example, a generator powered by natural gas, diesel or gasoline.
1. No
2. Yes
-98. Don't know

[ASK IF 17_1 = 2]
[SINGLE RESPONSE]
Q17_2 What is the fuel source for the generation equipment?
1. Diesel or gasoline
2. Natural Gas
3. Propane gas
4. Other: ____
-98. Don't know

[ASK IF Q17_2 = 1]
[SINGLE RESPONSE]
Q17_5 How much fuel does your backup generator consume while operating? Please give your best estimate in gallons per hour. *[ONLY READ IF NECESSARY]*

6. Less than 1 gallon per hour
7. 1 – 4 gallons per hour
8. 5 – 10 gallons per hour
9. 11 – 30 gallons per hour
10. More than 30 gallons per hour
99. Don't know

[ASK IF Q17_2 = 2, 3 OR IF Q17_5 = 98]

[OPEN-ENDED RESPONSE]

Q17_6 What is the power output of your backup generator? Please give your best estimate in kilowatts. *[ONLY READ IF NECESSARY. FYI for interviewer 1 kW = 1,000 W]*

1. Less than 10 kW
2. 10 kW – 39 kW
3. 40 kW – 149 kW
4. 150 kW – 399 kW
5. 400 kW or more

99. Don't know

[ASK IF Q17_2 = 1 or 3]

[OPEN-ENDED RESPONSE]

Q17_3 How long can the backup generation equipment operate with the fuel available on site?

1. _______ hours

-98. Don't know

[ASK Q17_1 = 2]

[OPEN-ENDED RESPONSE]

Q17_4 What was the cost to purchase and install your emergency backup electrical system after any rebates and tax incentives?

1. $_________

-98. Don't know

[ASK ALL]

[SINGLE RESPONSE]

Q18_1 Apart from emergency backup generation, does your firm generate any of its own electricity? (For example, a solar PV system or combined heat-power (CHP) gas turbine supplying power to your facility.)

1. No
2. Yes

-98. Don't know

[ASK IF Q18_1 = 2]

[OPEN-ENDED RESPONSE]

Q18_2 What percentage of your daily electricity consumption is supplied by your own generation equipment?

1. %_________________________________

-98. Don't know

[ASK ALL]

[SINGLE RESPONSE]

Q19_1 Does your firm have a battery storage system capable of supplying power for operations other than emergencies?

1. No
2. Yes

-98. Don't know

[ASK IF Q19_1 = 2]
[MULTIPLE RESPONSE]

Q19_2 What purpose does your battery storage system serve? (Select all that apply) *[READ LIST]*

1. Bill savings
2. Reducing demand during certain times of day
3. Backup power
4. Storing energy from onsite solar PV
5. Other (please specify) _________

-98. Don't know

[ASK IF Q19_1 = 2]
[OPEN-ENDED RESPONSE]

Q19_3 What percentage of your electricity needs can the battery storage system supply?

1. _____ %

-98. Don't know

[ASK Q19_1 = 2]
[OPEN-ENDED RESPONSE]

Q19_4 What was the cost to purchase and install your battery storage system after any rebates and tax incentives?

1. $_________

-98. Don't know

[ASK ALL]
[OPEN-ENDED RESPONSE]

Q20 What is the approximate economic value of your facility's annual operations? For businesses report revenue or sales and for non-profit enterprises report budget. *[IF NEEDED] As a reminder, this information will be kept confidential, anonymized, and used only to estimate your potential loss of revenue in the upcoming power outage scenarios.*

1. $_____________ per year

-98. Don't know

Start of Block: Scenario A (Long Duration)

Scenario A

Scenario Description:

[DISPLAY IF CAUSE = "SEVERE THUNDERSTORM"]
In this section, please imagine the following situation: it is a normal summer **weekday** in **July**. In the early afternoon, a series of thunderstorms form in the area, bringing rain and destructive tornado-level winds.

In the middle of the wind and rain, the power goes out. Assume the power outage extends across a **20-mile radius surrounding your facility**. The wind did not cause extensive damage to nearby buildings and roads but did cause widespread damage to trees and power lines that will take some time to repair.

Weather is expected to be "typical" summer weather throughout the duration of the outage. Meteorologists do not expect any heatwaves or other large storms.

[DISPLAY IF CAUSE = "ICE STORM"]
In this section, please imagine the following situation: it is a normal **weekday** in **January**. In the morning, freezing rain begins, with ice building up on the ground, roads, trees, and power lines.

In the middle of the storm, the power goes out. Assume the outage extends across a **20-mile region surrounding your facility**. The storm did not cause extensive damage to nearby buildings, but did leave a layer of ice on roads and caused widespread damage to trees and power lines that will take some time to repair.

Weather is expected to be "typical" winter weather throughout the duration of the outage. Meteorologists do not expect any other snow or ice storms.

[DISPLAY ALL]
After a few hours, your utility announces that the outage will last **24 hours**.

Most of the mechanical equipment and appliances at your facility and services in your community will not work during this time period. The following equipment will not work at your facility:

- Machines and appliances powered by electricity that cannot be run on backup power supply systems
- Land-line telephones that plug into a power outlet
- Cell phones, once the batteries run out
- Cable
- Internet
- Solar PV panels

- Electric heating devices, such as space heaters and heat pumps
- Air conditioning and refrigeration systems
- Lights, except for emergency lights
- Security systems that do not have battery backup

The following services will not work in the area affected by the outage:

- Traffic signals
- Street lights
- Banks and ATMs
- Gas stations
- Grocery stores
- Restaurants and retail stores
- Cellular phone service may work occasionally throughout the outage but will not be consistent or reliable.

[Start of outage related questions – to be asked for each scenario]

[ASK ALL]
[SINGLE RESPONSE]
Q21 Does your organization have a written plan for how to respond to such an outage?

1. No
2. Yes
-98. Don't know

[DISPLAY IF CAUSE = "SEVERE THUNDERSTORM"]
Q22 Which of the following sentences best describes how your facility would react to this <u>24-hour</u> outage caused by a severe thunderstorm.

[DISPLAY IF CAUSE = "ICE STORM"]
Q22 Which of the following sentences best describes how your facility would react to this <u>24-hour</u> outage caused by an ice storm.

[DISPLAY ALL]
[SINGLE RESPONSE]
[READ LIST]

1. Shut down the facility except for staff needed to support safety and security
2. Continue to operate the facility performing tasks that do not require electricity and, if present, use emergency backup systems, other generation systems, batteries, or other fuels
3. Temporarily shut down the facility until backup power supply systems can be rented
4. Transfer production or service delivery to locations outside the area affected by the outage.

This could include some of your workforce if they are able to work from home and live outside the outage area.

[ASK IF Q22 = 1]
[OPEN-ENDED RESPONSE]
Q22_1_1 After electricity service is restored, how long will it take for the facility to return to normal operation? Please estimate in days and hours.
1. ____ days and
2. ____ hours

[ASK IF Q22 = 1 AND (Q13_2 > 0 OR Q14_2 > 0)] [i.e., hourly employees > 0]
[SINGLE RESPONSE]
Q22_1_2 Would you pay hourly employees during this period of non-operation?
1. No
2. Yes
3. Not applicable
4. Other. Please explain_______________________________________
-98. Don't know

[ASK IF Q22_1_2 = 1 or 4]
[OPEN-ENDED RESPONSE]
Q22_1_3 Approximately how much would your company save in labor costs during the time it is not in operation?
1. $_________

[ASK IF Q22 = 1]
[SINGLE RESPONSE]
Q22_1_8 Would any employees be laid off or furloughed during the outage?
1. No
2. Yes
-98. Don't know

[ASK IF Q22_1_8 = 2]
[OPEN-ENDED RESPONSE]
Q22_1_9 About how many employees would be laid off or furloughed?
1. ______ employees

[ASK IF Q22 = 1]
[SINGLE RESPONSE]
Q22_1_6 Would there be any extra costs to ensure safety or security while the facility was shut down?
1. No

2. Yes
-98. Don't know

[ASK IF Q22_1_6 = 2]
[OPEN-ENDED RESPONSE]
Q22_1_7 Estimate extra cost of additional safety and security:
1. $________

[ASK IF Q22 = 1]
[SINGLE RESPONSE]
Q22_1_10 Would there be any damage to inventory or feedstocks as a result of the loss of electric power during the outage (e.g., spoilage of refrigerated products)?

1. No
2. Yes
-98. Don't know

[ASK IF Q22_1_10 = 2]
[OPEN-ENDED RESPONSE]
Q22_1_11 What is the approximate value of the damage?
1. $_______

[ASK IF Q22 = 1]
[SINGLE RESPONSE]
Q22_1_4 Would there be any other costs to restore operation to normal?
1. No
2. Yes
-98. Don't know

[ASK IF Q22_1_4 = 2]
[OPEN-ENDED RESPONSE]
Q22_1_5 Estimate the other costs to restore operation:
1. $________

[ASK IF Q22 = 1 & Q20 NOT = -98]
[SINGLE RESPONSE]
Q22_1_12 You previously stated your annual revenue or budget is $*[insert value from Q20]*. Based on this, we estimate that your lost revenue from this 24-hour outage would be $ *[insert revenue from Q20 * (1/300)]*. *[i.e., one day of revenue or budget]*
Does that seem about right?
1. No

2. Yes
-98. Don't know

[ASK IF Q22_1_12 = 1 OR Q20 = -98]
[OPEN-ENDED RESPONSE]
Q22_1_13 What would you estimate the lost revenue to be for this <u>24-hour</u> outage?
1. $ _______

[ASK IF Q22 = 1]
[OPEN-ENDED RESPONSE]
Q22_1_14 Approximately how much would you avoid on your electricity bill from this <u>24-hour</u> power outage?
1. $_____

[ASK IF Q22 = 1]
[SINGLE RESPONSE]
Q22_1_15 Do you think you would make up any of the lost output over the two months following the outage?
1. No
2. Yes
-98. Don't know

[ASK IF Q22_1_15 = 2]
[OPEN-ENDED RESPONSE]
Q22_1_16 What percent of lost production would you be able to make up?
1. ______%

[ASK IF Q22_1_15 = 2]
[SINGLE RESPONSE]
Q22_1_17 Would your hourly employees have to work overtime or extra shifts to make up the lost production? *[READ IF NEEDED] (For example, if your hourly employees normally work 5 shifts in a week and now had to work 6 shifts to make up for the lost production, this would be one extra shift and could result in overtime.)*
1. No
2. Yes
-98. Don't know

[ASK IF Q22_1_17 = 2]
[OPEN-ENDED RESPONSE]
Q22_1_18 How much would the overtime pay or extra shifts cost the company for this <u>24-hour</u> outage?
1. $______

[ASK IF Q22_1_15 = 2]
[SINGLE RESPONSE]
Q22_1_19 Besides labor costs, would there be any additional costs to make up for lost production? (For example, renting extra equipment.)
1. No
2. Yes
-98. Don't know

[ASK IF Q22_1_19 = 2]
[OPEN-ENDED RESPONSE]
Q22_1_20 Estimate the additional costs:
1. $_____

[ASK IF Q22 = 2]
[OPEN-ENDED RESPONSE]
Q22_2_1 About how many employees would be present at the facility during this time? *[READ AND RECORD RESPONSE TO EACH]*
1. Salaried: _________
2. Hourly: __________
3. Contract: _________

[ASK IF Q22 = 2 AND (Q13_2 > 0 OR 14_2 > 0)] [i.e., hourly employees > 0]
[SINGLE RESPONSE]
Q22_2_2 Would you pay hourly employees during any period of non-operation?
1. No
2. Yes
3. Not applicable
4. Other. Please explain_______________________________________
-98. Don't know

[ASK IF Q22_2_2 = 1 or 4]
[OPEN-ENDED RESPONSE]
Q22_2_3 Approximately how much would your company avoid in labor costs during the time it is not in operation?
1. $_________

[ASK IF Q22 = 2]
[SINGLE RESPONSE]
Q22_2_4 Which of the following best describes your expected level of operation/production during the outage?
1. 100% of normal (no change)
2. 99% - 75% of normal

3. 50% - 74% of normal
4. 25% - 49% of normal
5. 1% - 24% of normal
-98. Don't know

[ASK IF Q22 = 2]
[OPEN-ENDED RESPONSE]
Q22_2_5 What would be the daily cost to A) operate on-site power generation systems and B) supply any needed substitute fuels to your facility during the outage?
1. On-site generation: $__________/day
2. Substitute fuels: $__________/day
-98. Don't know

[ASK IF Q22_2_4 = 3, 4, 5 or 6 & Q20 NOT = -98]
[SINGLE RESPONSE]
Q22_2_6 You previously stated your annual revenue or budget is $*[insert revenue from Q20]*. Based on this, we estimate that your lost revenue from this <u>24-hour</u> outage would be $ *[insert revenue from Q20 * (1 - midpoint from Q22_2_4) * (1/300)]*. [*i.e., midpoint from 50% - 74% would be .62*]
Does that seem about right?
1. No
2. Yes
-98. Don't know

[ASK IF Q22_2_6 = 1 OR Q20 = -98]
[OPEN-ENDED RESPONSE]
Q22_2_7 What would you estimate the lost revenue to be for this <u>24-hour</u> outage?
1. $ _______
-98. Don't know

[ASK IF Q22 = 2]
[OPEN-ENDED RESPONSE]
Q22_2_8 Approximately how much would you avoid on your electricity bill from this <u>24-hour</u> power outage?
1. $_____
-98. Don't know

[ASK IF Q22 = 2]
[SINGLE RESPONSE]
Q22_2_9 Do you think you would make up any of the lost output over the two months following the outage?
1. No
2. Yes

-98. Don’t know

[ASK IF Q22_2_9 = 2]
[OPEN-ENDED RESPONSE]
Q22_2_10 What percent of lost production would you be able to make up?
1. ______%
-98. Don’t know

[ASK IF Q22_2_9 = 2]
[SINGLE RESPONSE]
Q22_2_11 Would your hourly employees have to work overtime or extra shifts to make up the lost production? *[READ IF NEEDED] (For example, if your hourly employees normally work 5 shifts in a week and now had to work 6 shifts to make up for the lost production, this would be one extra shift and could result in overtime.)*
1. No
2. Yes
-98. Don’t know

[ASK IF Q22_2_11 = 2]
[OPEN-ENDED RESPONSE]
Q22_2_12 How much would the overtime or extra shifts cost the company for this <u>24-hour</u> outage?
1. $______
-98. Don’t know

[ASK IF Q22_2_9 = 2]
[SINGLE RESPONSE]
Q22_2_13 Besides labor costs, would there be any additional costs to make up for lost production? (For example, renting extra equipment.)
1. No
2. Yes
-98. Don’t know

[ASK IF Q22_2_13 = 2]
[OPEN-ENDED RESPONSE]
Q22_2_14 Estimate the additional costs:
1. $____
-98. Don’t know

[ASK IF Q22 = 3]
[OPEN-ENDED RESPONSE]
Q22_3_1 How many employees would be present at the facility during the time between when the outage starts and the time the backup generation systems begin to operate? *[READ AND RECORD*

RESPONSE FOR EACH]

1. Salaried employees: ______
2. Hourly employees: ______
3. Contract employees: ______

[ASK IF Q22 = 3]
[OPEN-ENDED RESPONSE]
Q22_3_2 How many employees will be present at the facility once the backup generation systems begin to operate? *[READ AND RECORD RESPONSE FOR EACH]*

1. Salaried employees: ______
2. Hourly employees: ______
3. Contract employees: ______

[ASK IF Q22 = 3 AND (Q13_2 > 0 OR 14_2 > 0)] [i.e. hourly employees > 0]
[SINGLE RESPONSE]
Q22_3_3 Would you pay hourly employees during the period of non-operation?

1. No
2. Yes
3. Not applicable
4. Other. Please explain____

-98. Don't know

[ASK IF Q22_3_3 = 1 or 4]
[OPEN-ENDED RESPONSE]
Q22_3_4 Approximately how much would your company save in labor costs during the time it is not in operation?

1. $_________

-98. Don't know

[ASK IF Q22 = 3]
[SINGLE RESPONSE]
Q22_3_5 Do you have an existing arrangement with a generator supply company to supply standby generation in the event of a long duration outage?

1. No
2. Yes

-98. Don't know

[ASK IF Q22_3_5 = 2]
[OPEN-ENDED RESPONSE]
Q22_3_6 How long after the onset of an outage will the standby generation system be delivered? Please estimate in hours.

1. Hours _____

-98. Don’t know

[ASK IF Q22_3_5 = 2]
[SINGLE RESPONSE]
Q22_3_7 Is the output from the *standby* generator sufficient to support full scale operation of the facility?
1. No
2. Yes
-98. Don’t know

[ASK IF Q22_3_7 = 1]
[SINGLE RESPONSE]
Q22_3_23 What percentage of the facilities’ operation will the *standby* generator support? *(Only read if necessary)*
1. 99% - 75%
2. 50% - 74%
3. 25% - 49%
4. 1% - 24%
-98. Don’t know

[ASK IF Q22_3_5 = 1]
[OPEN-ENDED RESPONSE]
Q22_3_9 How long after onset of an outage do you think it would take before a rented standby generator could be delivered and begin operating? Please estimate in hours.
1. Hours (Per facility) _____
-98. Don’t know

[ASK IF Q22_3_5 = 1]
[SINGLE RESPONSE]
Q22_3_10 Would the output from the rented standby generator be sufficient to support full scale operation of the facility?
1. No
2. Yes
-98. Don’t know

[ASK IF Q22_3_10 = 1]
[SINGLE RESPONSE]
Q22_3_24 What percentage of the facilities’ operation will the *rented* standby generator support? *(Only read if necessary)*
1. 99% - 75%
2. 50% - 74%
3. 25% - 49%

4. 1% - 24%
-98. Don't know

[ASK IF Q22_3_10 = 1]
[OPEN-ENDED RESPONSE]
Q22_3_11 What facilities will the generator support?
1. ____

[ASK IF Q22 = 3]
[OPEN-ENDED RESPONSE]
Q22_3_12 What will be the daily cost of the standby generator (including rent and fuel)?
1. $_________
-98. Don't know

[ASK IF Q22 = 3]
[SINGLE RESPONSE]
Q22_3_13 Which of the following best describes your expected level of operation/production during the outage?
1. 100% of normal (no change)
2. 99% - 75% of normal
3. 50% - 74% of normal
4. 25% - 49% of normal
5. 1% - 24% of normal
-98. Don't know

[ASK IF Q22_2_13 = 2, 3, 4, 5 & Q20 NOT = -98]
[SINGLE RESPONSE]
Q22_3_14 You previously stated your annual revenue or budget is $*[insert revenue from Q20]*. Based on this, we estimate that your lost revenue from this 24-hour outage would be $*[insert revenue from Q20 * (1 - midpoint from Q22_3_13) * (1/300)]*. [*i.e. midpoint from 50% - 74% would be .62*]
Does that seem about right?
1. No
2. Yes
-98. Don't know

[ASK IF Q22_3_14 = 1 OR Q20 = -98]
[OPEN-ENDED RESPONSE]
Q22_3_15 What would you estimate the lost revenue to be for this 24-hour outage?
1. $ _______
-98. Don't know

[ASK IF Q22 = 3]
[OPEN-ENDED RESPONSE]
Q22_3_16 Approximately how much would you avoid on your electricity bill from this 24-hour power outage?
1. $_____
-98. Don't know

[ASK IF Q22 = 3]
[SINGLE RESPONSE]
Q22_3_17 Do you think you would make up any of the lost output over the two months following the outage?

1. No
2. Yes
-98. Don't know

[ASK IF Q22_3_17 = 2]
[OPEN-ENDED RESPONSE]
Q22_3_18 What percent of lost production would you be able to make up?
1. ______%
-98. Don't know

[ASK IF Q22_3_17 = 2]
[SINGLE RESPONSE]
Q22_3_19 Would your hourly employees have to work overtime or extra shifts to make up the lost production? *[READ IF NEEDED] (For example, if your hourly employees normally work 5 shifts in a week and now had to work 6 shifts to make up for the lost production, this would be one extra shift and could result in overtime.)*
1. No
2. Yes
-98. Don't know

[ASK IF Q22_3_19 = 2]
[OPEN-ENDED RESPONSE]
Q22_3_20 How much would the overtime or extra shifts cost the company for this 24-hour outage?
1. $______
-98. Don't know

[ASK IF Q22_3_17 = 2]
[SINGLE RESPONSE]
Q22_3_21 Besides labor costs, would there be any additional costs to make up for lost production? (For example, renting extra equipment.)

1. No
2. Yes
-98. Don't know

[ASK IF Q22_3_21 = 2]
[OPEN-ENDED RESPONSE]
Q22_3_22 Estimate the additional costs:
1. $____
-98. Don't know

[ASK IF Q22 = 4]
[SINGLE RESPONSE]
Q22_4_1 Are there other locations operated by your organization outside the 20 mile radius of the outage that are available for you to quickly transfer business or other activities once the outage has started? For offices, this could include employee homes outside of service territory.
1. No
2. Yes
-98. Don't know

[ASK IF Q22_4_1 = 2]
[OPEN-ENDED RESPONSE]
Q22_4_2 How long would it take you to transfer operations to those locations? Please estimate in days and hours.
1. Days ____
2. and hours ____

[ASK IF Q22 = 4]
[SINGLE RESPONSE]
Q22_4_3 What percent of your production do you expect to be able to carry out at these alternative locations? *(Only read if necessary)*
1. 100% of normal (no change)
2. 99% - 75% of normal
3. 50% - 74% of normal
4. 25% - 49% of normal
5. 1% - 24% of normal
-98. Don't know

[ASK IF Q22 = 4]
[OPEN-ENDED RESPONSE]
Q22_4_4 What do you think it would cost for you to transfer production to these alternative locations? (Please include the cost of returning production to your current location if you intend to do so.)

1. $________
-.98 Don't know

[ASK IF Q22_4_3 = 2, 3, 4, 5 & Q20 NOT = -98]
[SINGLE RESPONSE]
Q22_4_5 You previously stated your annual revenue or budget is $*[insert revenue from Q20]*. Based on this, we estimate that your lost revenue from this 24-hour outage would be $*[insert revenue from Q20 * (1 - midpoint from Q22_4_3) * (1/300)]*. [*i.e., midpoint from 50% - 74% would be .62*]
Does that seem about right?
1. No
2. Yes
-98. Don't know

[ASK IF Q22_4_5 = 1 OR Q20 = -98]
[OPEN-ENDED RESPONSE]
Q22_4_6 What would you estimate the lost revenue to be for this <u>24-hour</u> outage?
1. $ _______
-98. Don't know

[ASK IF Q22 = 4]
[OPEN-ENDED RESPONSE]
Q22_4_7 Approximately how much would you avoid on your electricity bill from this <u>24-hour</u> power outage?
1. $ _____
-98. Don't know

[ASK IF Q22 = 4]
[SINGLE RESPONSE]
Q22_4_8 Do you think you would make up any of the lost output over the two months following the outage?
1. No
2. Yes
-98. Don't know

[ASK IF Q22_4_8 = 2]
[OPEN-ENDED RESPONSE]
Q22_4_9 What percent of lost production would you be able to make up?
1. ______%
-98. Don't know

[ASK IF Q22_4_8 = 2]
[SINGLE RESPONSE]

Q22_4_10 Would your hourly employees have to work overtime or extra shifts to make up the lost production? *[READ IF NEEDED] (For example, if your hourly employees normally work 5 shifts in a week and now had to work 6 shifts to make up for the lost production, this would be one extra shift and could result in overtime.)*
1. No
2. Yes
-98. Don't know

[ASK IF Q22_4_10 = 2]
[OPEN-ENDED RESPONSE]
Q22_4_11 How much would the overtime pay or extra shifts cost the company for this 24-hour outage?
1. $______
-98. Don't know

[ASK IF Q22_4_8 = 2]
[SINGLE RESPONSE]
Q22_4_12 Besides labor costs, would there be any additional costs to make up for lost production? (For example, renting extra equipment.)
1. No
2. Yes
-98. Don't know

[ASK IF Q22_4_12 = 2]
[OPEN-ENDED RESPONSE]
Q22_4_13 Estimate the additional costs:
1. $____
-98. Don't know

Start of Block: Scenario B (Long Duration)

Scenario B

Scenario Description:

[DISPLAY ALL]
This scenario is similar to the previous scenario, but the outage lasts for **3 days**. The following questions will be similar to those you previously answered, but it is important to understand if your responses differ for longer outages.

[DISPLAY IF CAUSE = "SEVERE THUNDERSTORM"]
A severe thunderstorm with high winds in July causes widespread damage to the region. Your facility

does not experience any property damages from the storm, but the power goes out.

[DISPLAY IF CAUSE = "ICE STORM"]
An ice storm in January causes widespread damage to the region. Your facility does not experience any property damages from the storm, but the power goes out.

[DISPLAY ALL]
After a few hours, your utility announces that the outage will last for **3 days** and affect an area covering a **20-mile radius from your facility**.

[DISPLAY IF CAUSE = "SEVERE THUNDERSTORM"]
Weather is expected to be "typical" summer weather throughout the duration of the outage. Meteorologists do not expect any heatwaves or other large storms.

[DISPLAY IF CAUSE = "ICE STORM"]
Weather is expected to be "typical" winter weather throughout the duration of the outage. Meteorologists do not expect any other snow or ice storms.

[ASK ALL]
[SINGLE RESPONSE]
Q23 Does your organization have a written plan for how to respond to such an outage?
1. No
2. Yes
-98. Don't know

[DISPLAY IF CAUSE = "SEVERE THUNDERSTORM"]
Q24 Which of the following sentences best describes how your facility would react to this 3-day outage caused by a severe thunderstorm.

[DISPLAY IF CAUSE = "ICE STORM"]
Q24 Which of the following sentences best describes how your facility would react to this 3-day outage caused by an ice storm.

[DISPLAY ALL]
[SINGLE RESPONSE]
[READ LIST]

1. Shut down the facility except for staff needed to support safety and security
2. Continue to operate the facility performing tasks that do not require electricity and, if present, use emergency backup systems, other generation systems, batteries, or other fuels
3. Temporarily shut down the facility until backup power supply systems can be rented
4. Transfer production or service delivery to locations outside the area affected by the outage.

This could include some of your workforce if they are able to work from home and live outside the outage area.

[ASK IF Q24 = 1]
[OPEN-ENDED RESPONSE]
Q24_1_1 After electricity service is restored, how long will it take for the facility to return to normal operation? Please estimate in days and hours.
1. ____ days and
2. ____ hours

[ASK IF Q24 = 1 AND (Q13_2 > 0 OR 14_2 > 0)] [i.e. hourly employees > 0]
[SINGLE RESPONSE]
Q24_1_2 Would you pay hourly employees during this period of non-operation?
1. No
2. Yes
3. Not applicable
4. Other. Please explain_______________________________________
-98. Don't know

[ASK IF Q24_1_2 = 1 or 4]
[OPEN-ENDED RESPONSE]
Q24_1_3 Approximately how much would your company save in labor costs during the time it is not in operation?
1. $_________

[ASK IF Q24 = 1]
[SINGLE RESPONSE]
Q24_1_6 Would there be any extra costs to ensure safety or security while the facility was shut down?
1. No
2. Yes
-98. Don't know

[ASK IF Q24_1_6 = 2]
[OPEN-ENDED RESPONSE]
Q24_1_7 Estimate extra cost of additional safety and security:
1. $________

[ASK IF Q24 = 1]
[SINGLE RESPONSE]
Q24_1_8 Would any employees be laid off or furloughed during the outage?
1. No

2. Yes
-98. Don't know

[ASK IF Q24_1_8 = 2]
[OPEN-ENDED RESPONSE]
Q24_1_9 About how many employees would be laid off or furloughed?
1. ______ employees

[ASK IF Q24 = 1]
[SINGLE RESPONSE]
Q24_1_10 Would there be any damage to inventory or feedstocks as a result of the loss of electric power during the outage (e.g., spoilage of refrigerated products)?
1. No
2. Yes
-98. Don't know

[ASK IF Q24_1_10 = 2]
[OPEN-ENDED RESPONSE]
Q24_1_11 What is the approximate value of the damage?
1. $_______

[ASK IF Q24 = 1]
[SINGLE RESPONSE]
Q24_1_4 Would there be any other costs to restore operation to normal?
1. No
2. Yes
-98. Don't know

[ASK IF Q24_1_4 = 2]
[OPEN-ENDED RESPONSE]
Q24_1_5 Estimate the other costs to restore operation:
1. $________

[ASK IF Q24 = 1 & Q20 NOT = -98]
[SINGLE RESPONSE]
Q24_1_12 You previously stated your annual revenue or budget is $*[insert value from Q20]*. Based on this, we estimate that your lost revenue from this <u>3-day</u> outage would be $*[insert revenue from Q20 * (3/300)]*. [*i.e., three days of revenue or budget*]
Does that seem about right?
1. No
2. Yes
-98. Don't know

[ASK IF Q24_1_12 = 1 OR Q20 = -98]
[OPEN-ENDED RESPONSE]
Q24_1_13 What would you estimate the lost revenue to be for this <u>3-day</u> outage?
1. $ _______

[ASK IF Q24 = 1]
[OPEN-ENDED RESPONSE]
Q24_1_14 Approximately how much would you avoid on your electricity bill from this <u>3-day</u> power outage?
1. $_____

[ASK IF Q24 = 1]
[SINGLE RESPONSE]
Q24_1_15 Do you think you would make up any of the lost output over the two months following the outage?
1. No
2. Yes
-98. Don't know

[ASK IF Q24_1_15 = 2]
[OPEN-ENDED RESPONSE]
Q24_1_16 What percent of lost production would you be able to make up?
1. ______%

[ASK IF Q24_1_15 = 2]
[SINGLE RESPONSE]
Q24_1_17 Would your hourly employees have to work overtime or extra shifts to make up the lost production? *[READ IF NEEDED] (For example, if your hourly employees normally work 5 shifts in a week and now had to work 6 shifts to make up for the lost production, this would be one extra shift and could result in overtime.)*
1. No
2. Yes
-98. Don't know

[ASK IF Q24_1_17 = 2]
[OPEN-ENDED RESPONSE]
Q24_1_18 How much would the overtime or extra shifts cost the company for this <u>3-day</u> outage?
1. $______

[ASK IF Q24_1_15 = 2]
[SINGLE RESPONSE]
Q24_1_19 Besides labor costs, would there be any additional costs to make up for lost production?

(For example, renting extra equipment.)
1. No
2. Yes
-98. Don't know

[ASK IF Q24_1_19 = 2]
[OPEN-ENDED RESPONSE]
Q24_1_20 Estimate the additional costs:
1. $_____

[ASK IF Q24 = 2]
[OPEN-ENDED RESPONSE]
Q24_2_1 About how many employees would be present at the facility during this time? *[READ AND RECORD RESPONSE FOR EACH]*
1. Salaried employees: _________
2. Hourly employees: __________
3. Contract employees: _________

[ASK IF Q24 = 2 AND (Q13_2 > 0 OR 14_2 > 0)] [i.e., hourly employees > 0]
[SINGLE RESPONSE]
Q24_2_2 Would you pay hourly employees during any period of non-operation?
1. No
2. Yes
3. Not applicable
4. Other. Please explain_______________________________________
-98. Don't know

[ASK IF Q24_2_2 = 1 or 4]
[OPEN-ENDED RESPONSE]
Q24_2_3 Approximately how much would your company avoid in labor costs during the time it is not in operation?
1. $_________
-98. Don't know

[ASK IF Q24 = 2]
[SINGLE RESPONSE]
Q24_2_4 Which of the following best describes your expected level of operation/production during the outage?
1. 100% of normal (no change)
2. 99% - 75% of normal
3. 50% - 74% of normal
4. 25% - 49% of normal

5. 1% - 24% of normal
-98. Don't know

[ASK IF Q24 = 2]
[OPEN-ENDED RESPONSE]
Q24_2_5 What would be the daily cost to A) operate on-site power generation systems and B) supply any needed substitute fuels to your facility during the outage?
1). On-site power generation systems: $__________/day
2). Substitute fuels: $__________/day
-98. Don't know

[ASK IF Q24_2_4 = 3, 4, 5 or 6 & Q20 NOT = -98]
[SINGLE RESPONSE]
Q24_2_6 You previously stated your annual revenue or budget is *$[insert value from Q20]*. Based on this, we estimate that your lost revenue from this <u>3-day</u> outage would be *$[insert revenue from Q20 * (1 - midpoint from Q24_2_4) * (3/300)]*. [*i.e., midpoint from 50% - 74% would be .62*]
Does that seem about right?
1. No
2. Yes
-98. Don't know

[ASK IF Q24_2_6 = 1 OR Q20 = -98]
[OPEN-ENDED RESPONSE]
Q24_2_7 What would you estimate the lost revenue to be for this <u>3-day</u> outage?
1. $ _______
-98. Don't know

[ASK IF Q24 = 2]
[OPEN-ENDED RESPONSE]
Q24_2_8 Approximately how much would you avoid on your electricity bill from this <u>3-day</u> power outage?
1. $_____
-98. Don't know

[ASK IF Q24 = 2]
[SINGLE RESPONSE]
Q24_2_9 Do you think you would make up any of the lost output over the two months following the outage?
1. No
2. Yes
-98. Don't know

[ASK IF Q24_2_9 = 2]
[OPEN-ENDED RESPONSE]
Q24_2_10 What percent of lost production would you be able to make up?
1. ______%
-98. Don't know

[ASK IF Q24_2_9 = 2]
[SINGLE RESPONSE]
Q24_2_11 Would your hourly employees have to work overtime or extra shifts to make up the lost production? *[READ IF NEEDED] (For example, if your hourly employees normally work 5 shifts in a week and now had to work 6 shifts to make up for the lost production, this would be one extra shift and could result in overtime.)*
1. No
2. Yes
-98. Don't know

[ASK IF Q24_2_11 = 2]
[OPEN-ENDED RESPONSE]
Q24_2_12 How much would the overtime or extra shifts cost the company for this <u>3-day</u> outage?
1. $______
-98. Don't know

[ASK IF Q24_2_9 = 2]
[SINGLE RESPONSE]
Q24_2_13 Besides labor costs, would there be any additional costs to make up for lost production? (For example, renting extra equipment.)
1. No
2. Yes
-98. Don't know

[ASK IF Q24_2_13 = 2]
[OPEN-ENDED RESPONSE]
Q24_2_14 Estimate the additional costs:
1. $____
-98. Don't know

[ASK IF Q24 = 3]
[OPEN-ENDED RESPONSE]
Q24_3_1 How many employees would be present at the facility during the time between when the outage starts and the time the backup generation systems begin to operate? *[READ AND RECORD RESPONSE FOR EACH]*
1. Salaried employees: ____

2. Hourly employees: ____
3. Contract employees: ____

[ASK IF Q24 = 3]
[OPEN-ENDED RESPONSE]
Q24_3_2 How many employees will be present at the facility once the backup generation systems begin to operate? *[READ AND RECORD RESPONSE FOR EACH]*
1. Salaried employees: _____
2. Hourly employees: ______
3. Contract employees: ______

[ASK IF Q24 = 3 AND (Q13_2 > 0 OR 14_2 > 0)] [i.e., hourly employees > 0]
[SINGLE RESPONSE]
Q24_3_3 Would you pay hourly employees during the period of non-operation?
1. No
2. Yes
3. Not applicable
4. Other. Please explain____
-98. Don't know

[ASK IF Q24_3_3 = 1 or 4]
[OPEN-ENDED RESPONSE]
Q24_3_4 Approximately how much would your company save in labor costs during the time it is not in operation?
1. $_________
- 98. Don't know

[ASK IF Q24 = 3]
[SINGLE RESPONSE]
Q24_3_5 Do you have an existing arrangement with a generator supply company to supply standby generation in the event of a long duration outage?
1. No
2. Yes
-98. Don't know

[ASK IF Q24_3_5 = 2]
[OPEN-ENDED RESPONSE]
Q24_3_6 How long after the onset of an outage will the standby generation system be delivered? Please estimate in hours.
1. Hours _____
-98. Don't know

[ASK IF Q24_3_5 = 2]
[SINGLE RESPONSE]
Q24_3_7 Is the output from the standby generator sufficient to support full scale operation of the facility?
1. No
2. Yes
-98. Don't know

[ASK IF Q24_3_7 = 1]
[SINGLE RESPONSE]
Q24_3_23 What percentage of the facilities' operation will the standby generator support? *(Only read if necessary)*

1. 99% - 75%
2. 50% - 74%
3. 25% - 49%
4. 1% - 24%
-98. Don't know

[ASK IF Q24_3_5 = 1]
[OPEN-ENDED RESPONSE]
Q24_3_9 How long after onset of an outage do you think it would take before a rented standby generator could be delivered and begin operating? Please estimate in hours.
1. Hours _____
-98. Don't know

[ASK IF Q24_3_5 = 1]
[SINGLE RESPONSE]
Q24_3_10 Would the output from the rented standby generator be sufficient to support full scale operation of the facility?
1. No
2. Yes
-98. Don't know

[ASK IF Q24_3_10 = 1]
[SINGLE RESPONSE]
Q24_3_24 What percentage of the facilities' operation will the *rented* standby generator support?
(Only read if necessary)
1. 99% - 75%
2. 50% - 74%
3. 25% - 49%
4. 1% - 24%

-98. Don't know

[ASK IF Q24 = 3]
[OPEN-ENDED RESPONSE]
Q24_3_12 What will be the daily cost of the standby generator (including rent and fuel)?
1. $_________
-98. Don't know

[ASK IF Q24 = 3]
[SINGLE RESPONSE]
Q24_3_13 Which of the following best describes your expected level of operation/production during the outage?
1. 100% of normal (no change)
2. 99% - 75% of normal
3. 50% - 74% of normal
4. 25% - 49% of normal
5. 1% - 24% of normal
-98. Don't know

[ASK IF Q24_2_13 = 2, 3, 4, 5 & Q20 NOT = -98]
[SINGLE RESPONSE]
Q24_3_14 You previously stated your annual revenue or budget is $*[insert value from Q20]*. Based on this, we estimate that your lost revenue from this <u>3-day</u> outage would be $*[insert revenue from Q20 * (1 - midpoint from Q24_3_13) * (3/300)]*. [*i.e., midpoint from 50% - 74% would be .62*]
Does that seem about right?
1. No
2. Yes
-98. Don't know

[ASK IF Q24_3_14 = 1 OR Q20 = -98]
[OPEN-ENDED RESPONSE]
Q24_3_15 What would you estimate the lost revenue to be for this <u>3-day</u> outage?
1. $ _______
-98. Don't know

[ASK IF Q24 = 3]
[OPEN-ENDED RESPONSE]
Q24_3_16 Approximately how much would you avoid on your electricity bill from this <u>3-day</u> power outage?
1. $_____
-98. Don't know

[ASK IF Q24 = 3]
[SINGLE RESPONSE]
Q24_3_17 Do you think you would make up any of the lost output over the two months following the outage?
1. No
2. Yes
-98. Don't know

[ASK IF Q24_3_17 = 2]
[OPEN-ENDED RESPONSE]
Q24_3_18 What percent of lost production would you be able to make up?
1. ______%
-98. Don't know

[ASK IF Q24_3_17 = 2]
[SINGLE RESPONSE]
Q24_3_19 Would your hourly employees have to work overtime or extra shifts to make up the lost production? *[READ IF NEEDED] (For example, if your hourly employees normally work 5 shifts in a week and now had to work 6 shifts to make up for the lost production, this would be one extra shift and could result in overtime.)*
1. No
2. Yes
-98. Don't know

[ASK IF Q24_3_19 = 2]
[OPEN-ENDED RESPONSE]
Q24_3_20 How much would the overtime or extra shifts cost the company for this <u>3-day</u> outage?
1. $______
-98. Don't know

[ASK IF Q24_3_17 = 2]
[SINGLE RESPONSE]
Q24_3_21 Besides labor costs, would there be any additional costs to make up for lost production? (For example, renting extra equipment.)
1. No
2. Yes
-98. Don't know

[ASK IF Q24_3_21 = 2]
[OPEN-ENDED RESPONSE]
Q24_3_22 Estimate the additional costs:
1. $____

-98. Don’t know

[ASK IF Q24 = 4]
[SINGLE RESPONSE]
Q24_4_1 Are there other locations operated by your organization outside the 20 mile radius of the outage that are available for you to quickly transfer business or other activities once the outage has started? For offices, this could include employee homes outside of service territory.
1. No
2. Yes
-98. Don’t know

[ASK IF Q24_4_1 = 2]
[OPEN-ENDED RESPONSE]
Q24_4_2 How long would it take you to transfer operations to those locations? Please estimate in days and hours.
1. Days ____
2. and hours ____

[ASK IF Q24 = 4]
[SINGLE RESPONSE]
Q24_4_3 What percent of your production do you expect to be able to carry out at these alternative locations? *(Only read if necessary)*
1. 100% of normal
2. 99% - 75% of normal
3. 50% - 74% of normal
4. 25% - 49% of normal
5. 1% - 24% of normal
-98. Don’t know

[ASK IF Q24 = 4]
[OPEN-ENDED RESPONSE]
Q24_4_4 What do you think it would cost for you to transfer production to these alternative locations? (Please include the cost of returning production to your current location if you intend to do so.)
1. $________
-.98 Don’t know

[ASK IF Q24_4_3 = 2, 3, 4, 5 & Q20 NOT = -98]
[SINGLE RESPONSE]
Q24_4_5 You previously stated your annual revenue or budget is $[insert value from Q20]. Based on this, we estimate that your lost revenue from this 3-day outage would be $ [insert revenue from Q20 * (1 - midpoint from Q24_4_3) * (3/300)]. [*i.e., midpoint from 50% - 74% would be .62*]

Does that seem about right?
1. No
2. Yes
-98. Don't know

[ASK IF Q24_4_5 = 1 OR Q20 = -98]
[OPEN-ENDED RESPONSE]
Q24_4_6 What would you estimate the lost revenue to be for this 3-day outage?
1. $ _______
-98. Don't know

[ASK IF Q24 = 4]
[OPEN-ENDED RESPONSE]
Q24_4_7 Approximately how much would you avoid on your electricity bill from this 3-day power outage?
1. $_____
-98. Don't know

[ASK IF Q24 = 4]
[SINGLE RESPONSE]
Q24_4_8 Do you think you would make up any of the lost output over the two months following the outage?

1. No
2. Yes
-98. Don't know

[ASK IF Q24_4_8 = 2]
[OPEN-ENDED RESPONSE]
Q24_4_9 What percent of lost production would you be able to make up?
1. ______%
-98. Don't know

[ASK IF Q24_4_8 = 2]
[SINGLE RESPONSE]
Q24_4_10 Would your hourly employees have to work overtime or extra shifts to make up the lost production? *[READ IF NEEDED] (For example, if your hourly employees normally work 5 shifts in a week and now had to work 6 shifts to make up for the lost production, this would be one extra shift and could result in overtime.)*
1. No
2. Yes
-98. Don't know

[ASK IF Q24_4_10 = 2]
[OPEN-ENDED RESPONSE]
Q24_4_11 How much would the overtime or extra shifts cost the company for this <u>3-day</u> outage?
1. $______
-98. Don't know

[ASK IF Q24_4_8 = 2]
[SINGLE RESPONSE]
Q24_4_12 Besides labor costs, would there be any additional costs to make up for lost production? (For example, renting extra equipment.)
1. No
2. Yes
-98. Don't know

[ASK IF Q24_4_12 = 2]
[OPEN-ENDED RESPONSE]
Q24_4_13 Estimate the additional costs:
1. $____
-98. Don't know

Start of Block: Scenario C (Long Duration)

Scenario C

Scenario Description:

[DISPLAY ALL]
This scenario is similar to the previous scenario, but the outage lasts for **<u>2 weeks</u>**. The following questions will be similar to those you previously answered, but it is important to understand if your responses differ for longer outages.

[DISPLAY IF CAUSE = "SEVERE THUNDERSTORM"]
A severe thunderstorm with high winds in July causes widespread damage to the region. Your facility does not experience any property damages from the storm, but the power goes out.

[DISPLAY IF CAUSE = "ICE STORM"]
An ice storm in January causes widespread damage to the region. Your facility does not experience any property damages from the storm, but the power goes out.

[DISPLAY ALL]
After a few hours, your utility announces that the outage will last for **<u>2 weeks</u>** and affect an area covering a **20-mile radius from your facility**.

[DISPLAY IF CAUSE = "SEVERE THUNDERSTORM"]
Weather is expected to be "typical" summer weather throughout the duration of the outage. Meteorologists do not expect any heatwaves or other large storms.

[DISPLAY IF CAUSE = "ICE STORM"]
Weather is expected to be "typical" winter weather throughout the duration of the outage. Meteorologists do not expect any other snow or ice storms.

[ASK ALL]
[SINGLE RESPONSE]
Q25 Does your organization have a written plan for how to respond to such an outage?

1. No
2. Yes
-98. Don't know

[DISPLAY IF CAUSE = "SEVERE THUNDERSTORM"]
Q26 Which of the following sentences best describes how your facility would react to this <u>2-week</u> outage caused by a severe thunderstorm.

[DISPLAY IF CAUSE = "ICE STORM"]
Q26 Which of the following sentences best describes how your facility would react to this <u>2-week</u> outage caused by an ice storm.

[DISPLAY ALL]
[SINGLE RESPONSE]
[READ LIST]
1. Shut down the facility except for staff needed to support safety and security
2. Continue to operate the facility performing tasks that do not require electricity and, if present, use emergency backup systems, other generation systems, batteries, or other fuels
3. Temporarily shut down the facility until backup power supply systems can be rented
4. Transfer production or service delivery to locations outside the area affected by the outage. This could include some of your workforce if they are able to work from home and live outside the outage area.

[ASK IF Q26 = 1]
[OPEN-ENDED RESPONSE]
Q26_1_1 After electricity service is restored, how long will it take for the facility to return to normal operation? Please estimate in days and hours.
1. ____ days and
2. ____ hours

[ASK IF Q26 = 1 AND (Q13_2 > 0 OR 14_2 > 0)] [i.e., hourly employees > 0]
[SINGLE RESPONSE]
Q26_1_2 Would you pay hourly employees during this period of non-operation?
1. No
2. Yes
3. Not applicable
4. Other. Please explain______________________________________
-98. Don't know

[ASK IF Q26_1_2 = 1 or 4]
[OPEN-ENDED RESPONSE]
Q26_1_3 Approximately how much would your company save in labor costs during the time it is not in operation?
1. $_________

[ASK IF Q26 = 1]
[SINGLE RESPONSE]
Q26_1_6 Would there be any extra costs to ensure safety or security while the facility was shut down?
1. No
2. Yes
-98. Don't know

[ASK IF Q26_1_6 = 2]
[OPEN-ENDED RESPONSE]
Q26_1_7 Estimate extra cost of additional safety and security:
1. $________

[ASK IF Q26 = 1]
[SINGLE RESPONSE]
Q26_1_8 Would any employees be laid off or furloughed during the outage?
1. No
2. Yes
-98. Don't know

[ASK IF Q26_1_8 = 2]
[OPEN-ENDED RESPONSE]
Q26_1_9 About how many employees would be laid off or furloughed?
1. ______ employees

[ASK IF Q26 = 1]
[SINGLE RESPONSE]

Q26_1_10 Would there be any damage to inventory or feedstocks as a result of the loss of electric power during the outage (e.g., spoilage of refrigerated products)?

1. No
2. Yes

-98. Don't know

[ASK IF Q26_1_10 = 2]
[OPEN-ENDED RESPONSE]
Q26_1_11 What is the approximate value of the damage?

1. $_______

[ASK IF Q26 = 1]
[SINGLE RESPONSE]
Q26_1_4 Would there be any other costs to restore operation to normal?

1. No
2. Yes

-98. Don't know

[ASK IF Q26_1_4 = 2]
[OPEN-ENDED RESPONSE]
Q26_1_5 Estimate the other costs to restore operation:

1. $________

[ASK IF Q26 = 1 & Q20 NOT = -98]
[SINGLE RESPONSE]
Q26_1_12 You previously stated your annual revenue or budget is $*[insert value from Q20]*. Based on this, we estimate that your lost revenue from this <u>2-week</u> outage would be $*[insert revenue from Q20 * (14/365)]*. [*i.e., two weeks of revenue or budget*]
Does that seem about right?

1. No
2. Yes

-98. Don't know

[ASK IF Q26_1_12 = 1 OR Q20 = -98]
[OPEN-ENDED RESPONSE]
Q26_1_13 What would you estimate the lost revenue to be for this <u>2-week</u> outage?

1. $ _______

[ASK IF Q26 = 1]
[OPEN-ENDED RESPONSE]
Q26_1_14 Approximately how much would you avoid on your electricity bill from this <u>2-week</u> power outage?

1. $_____

[ASK IF Q26 = 1]
[SINGLE RESPONSE]
Q26_1_15 Do you think you would make up any of the lost output over the two months following the outage?
1. No
2. Yes
-98. Don't know

[ASK IF Q26_1_15 = 2]
[OPEN-ENDED RESPONSE]
Q26_1_16 What percent of lost production would you be able to make up?
1. ______%

[ASK IF Q26_1_15 = 2]
[SINGLE RESPONSE]
Q26_1_17 Would your hourly employees have to work overtime or extra shifts to make up the lost production? *[READ IF NEEDED] (For example, if your hourly employees normally work 5 shifts in a week and now had to work 6 shifts to make up for the lost production, this would be one extra shift and could result in overtime.)*
1. No
2. Yes
-98. Don't know

[ASK IF Q26_1_17 = 2]
[OPEN-ENDED RESPONSE]
Q26_1_18 How much would the overtime or extra shifts cost the company for this <u>2-week</u> outage?
1. $______

[ASK IF Q26_1_15 = 2]
[SINGLE RESPONSE]
Q26_1_19 Besides labor costs, would there be any additional costs to make up for lost production? (For example, renting extra equipment.)
1. No
2. Yes
-98. Don't know

[ASK IF Q26_1_19 = 2]
[OPEN-ENDED RESPONSE]
Q26_1_20 Estimate the additional costs:
1. $_____

[ASK IF Q26 = 2]
[OPEN-ENDED RESPONSE]
Q26_2_1 About how many employees would be present at the facility during this time? *[READ AND RECORD RESPONSE FOR EACH]*
1. Salaried employees: _________
2. Hourly employees: __________
3. Contract employees: _________

[ASK IF Q26 = 2 AND (Q13_2 > 0 OR 14_2 > 0)] [i.e., hourly employees > 0]
[SINGLE RESPONSE]
Q26_2_2 Would you pay hourly employees during any period of non-operation?
1. No
2. Yes
3. Not applicable
4. Other. Please explain______________________________________
-98. Don't know

[ASK IF Q26_2_2 = 1 or 4]
[OPEN-ENDED RESPONSE]
Q26_2_3 Approximately how much would your company avoid in labor costs during the time it is not in operation?
1. $_________
-98. Don't know

[ASK IF Q26 = 2]
[SINGLE RESPONSE]
Q26_2_4 Which of the following best describes your expected level of operation/production during the outage?
1. 100% of normal (no change)
2. 99% - 75% of normal
3. 50% - 74% of normal
4. 25% - 49% of normal
5. 1% - 24% of normal
-98. Don't know

[ASK IF Q26 = 2]
[OPEN-ENDED RESPONSE]
Q26_2_5 What would be the daily cost to A) operate on-site power generation systems and B) supply any needed substitute fuels to your facility during the outage?
1. On-site power generation: $__________
2. Substitute fuels: $__________
-98. Don't know

[ASK IF Q26_2_4 = 3, 4, 5 or 6 & Q20 NOT = -98]
[SINGLE RESPONSE]

Q26_2_6 You previously stated your annual revenue or budget is $*[insert value from Q20]*. Based on this, we estimate that your lost revenue from this 2-week outage would be $*[insert revenue from Q20 * (1 – midpoint from Q26_2_4) * (14/365)]*. [*i.e., midpoint from 50% - 74% would be .62*] **Does that seem about right?**

1. No
2. Yes
-98. Don't know

[ASK IF Q26_2_6 = 1 OR Q20 = -98]
[OPEN-ENDED RESPONSE]

Q26_2_7 What would you estimate the lost revenue to be for this 2-week outage?

1. $ _______
-98. Don't know

[ASK IF Q26 = 2]
[OPEN-ENDED RESPONSE]

Q26_2_8 Approximately how much would you avoid on your electricity bill from this 2-week power outage?

1. $_____
-98. Don't know

[ASK IF Q26 = 2]
[SINGLE RESPONSE]

Q26_2_9 Do you think you would make up any of the lost output over the two months following the outage?

1. No
2. Yes
-98. Don't know

[ASK IF Q26_2_9 = 2]
[OPEN-ENDED RESPONSE]

Q26_2_10 What percent of lost production would you be able to make up?

1. ______%
-98. Don't know

[ASK IF Q26_2_9 = 2]
[SINGLE RESPONSE]

Q26_2_11 Would your hourly employees have to work overtime or extra shifts to make up the lost production? *[READ IF NEEDED] (For example, if your hourly employees normally work 5 shifts in a week and now had to work 6 shifts to make up for the lost production, this would be one extra shift* *and could result in overtime.)*

1. No
2. Yes

-98. Don't know

[ASK IF Q26_2_11 = 2]
[OPEN-ENDED RESPONSE]

Q26_2_12 How much would the overtime or extra shifts cost the company for this <u>24-hour</u> outage?

1. $______

-98. Don't know

[ASK IF Q26_2_9 = 2]
[SINGLE RESPONSE]

Q26_2_13 Besides labor costs, would there be any additional costs to make up for lost production? (For example, renting extra equipment.)

1. No
2. Yes

-98. Don't know

[ASK IF Q26_2_13 = 2]
[OPEN-ENDED RESPONSE]

Q26_2_14 Estimate the additional costs:

1. $____

-98. Don't know

[ASK IF Q26 = 3]
[OPEN-ENDED RESPONSE]

Q26_3_1 How many employees would be present at the facility during the time between when the outage starts and the time the backup generation systems begin to operate?

[READ AND RECORD RESPONSE FOR EACH]

1. Salaried employees:_____
2. Hourly employees:______
3. Contract employees:______

[ASK IF Q26 = 3]
[OPEN-ENDED RESPONSE]

Q26_3_2 How many employees will be present at the facility once the backup generation systems begin to operate? *[READ AND RECORD RESPONSE FOR EACH]*

1. Salaried employees: ______
2. Hourly employees: ______
3. Contract employees: ______

[ASK IF Q26 = 3 AND (Q13_2 > 0 OR 14_2 > 0)] [i.e. hourly employees > 0]
[SINGLE RESPONSE]
Q26_3_3 Would you pay hourly employees during the period of non-operation?

1. No
2. Yes
3. Not applicable
4. Other. Please explain_______________________________________

-98. Don't know

[ASK IF Q26_3_3 = 1 or 4]
[OPEN-ENDED RESPONSE]
Q26_3_4 Approximately how much would your company save in labor costs during the time it is not in operation?

1. $_________

-98. Don't know

[ASK IF Q26 = 3]
[SINGLE RESPONSE]
Q26_3_5 Do you have an existing arrangement with a generator supply company to supply standby generation in the event of a long duration outage?

1. No
2. Yes

-98. Don't know

[ASK IF Q26_3_5 = 2]
[OPEN-ENDED RESPONSE]
Q26_3_6 How long after the onset of an outage will the standby generation system be delivered? Please estimate in hours.

1. Hours _____

-98. Don't know

[ASK IF Q26_3_5 = 2]
[SINGLE RESPONSE]
Q26_3_7 Is the output from the standby generator sufficient to support full scale operation of the facility?

1. No
2. Yes

-98. Don't know

[ASK IF Q26_3_7 = 1]
[SINGLE RESPONSE]

Q26_3_23 What percentage of the facilities' operation will the standby generator support? *(Only read if necessary)*

1. 99% - 75%
2. 50% - 74%
3. 25% - 49%
4. 1% - 24%
-98. Don't know

[ASK IF Q26_3_5 = 1]
[OPEN-ENDED RESPONSE]
Q26_3_9 How long after onset of an outage do you think it would take before a rented standby generator could be delivered and begin operating? Please estimate in hours.
1. Hours _____
-98. Don't know

[ASK IF Q26_3_5 = 1]
[SINGLE RESPONSE]
Q26_3_10 Would the output from the rented standby generator be sufficient to support full scale operation of the facility?
1. No
2. Yes
-98. Don't know

[ASK IF Q26_3_10 = 1]
[SINGLE RESPONSE]
Q26_3_24 What percentage of the facilities' operation will the *rented* standby generator support?
(Only read if necessary)
1. 99% - 75%
2. 50% - 74%
3. 25% - 49%
4. 1% - 24%
-98. Don't know

[ASK IF Q26 = 3]
[OPEN-ENDED RESPONSE]
Q26_3_12 What will be the daily cost of the standby generator (including rent and fuel)?
1. $_________
-98. Don't know

[ASK IF Q26 = 3]
[SINGLE RESPONSE]

Q26_3_13 Which of the following best describes your expected level of operation/production during the outage?

1. 100% of normal (no change)
2. 99% - 75% of normal
3. 50% - 74% of normal
4. 25% - 49% of normal
5. 1% - 24% of normal

-98. Don't know

[ASK IF Q26_2_13 = 2, 3, 4, 5 & Q20 NOT = -98]
[SINGLE RESPONSE]

Q26_3_14 You previously stated your annual revenue or budget is $*[insert value from Q20]*. Based on this, we estimate that your lost revenue from this <u>2-week</u> outage would be $*[insert revenue from Q20 * (1 – midpoint from Q26_3_13) * (14/365)]*. [*i.e., midpoint from 50% - 74% would be .62*]

Does that seem about right?

1. No
2. Yes

-98. Don't know

[ASK IF Q26_3_14 = 1 OR Q20 = -98]
[OPEN-ENDED RESPONSE]

Q26_3_15 What would you estimate the lost revenue to be for this <u>2-week</u> outage?

1. $ _______

-98. Don't know

[ASK IF Q26 = 3]
[OPEN-ENDED RESPONSE]

Q26_3_16 Approximately how much would you avoid on your electricity bill from this <u>2-week</u> power outage?

1. $_____

-98. Don't know

[ASK IF Q26 = 3]
[SINGLE RESPONSE]

Q26_3_17 Do you think you would make up any of the lost output over the two months following the outage?

1. No
2. Yes

-98. Don't know

[ASK IF Q26_3_17 = 2]
[OPEN-ENDED RESPONSE]

Q26_3_18 What percent of lost production would you be able to make up?
1. ______%
-98. Don't know

[ASK IF Q26_3_17 = 2]
[SINGLE RESPONSE]
Q26_3_19 Would your hourly employees have to work overtime or extra shifts to make up the lost production? *[READ IF NEEDED] (For example, if your hourly employees normally work 5 shifts in a week and now had to work 6 shifts to make up for the lost production, this would be one extra shift and could result in overtime.)*
1. No
2. Yes
-98. Don't know

[ASK IF Q26_3_19 = 2]
[OPEN-ENDED RESPONSE]
Q26_3_20 How much would the overtime or extra shifts cost the company for this <u>2-week</u> outage?
1. $______
-98. Don't know

[ASK IF Q26_3_17 = 2]
[SINGLE RESPONSE]
Q26_3_21 Besides labor costs, would there be any additional costs to make up for lost production? (For example, renting extra equipment.)
1. No
2. Yes
-98. Don't know

[ASK IF Q26_3_21 = 2]
[OPEN-ENDED RESPONSE]
Q26_3_22 Estimate the additional costs:
1. $____
-98. Don't know

[ASK IF Q26 = 4]
[SINGLE RESPONSE]
Q26_4_1 Are there other locations operated by your organization outside the 20 mile radius of the outage that are available for you to quickly transfer business or other activities once the outage has started? For offices, this could include employee homes outside of service territory.
1. No
2. Yes
-98. Don't know

[ASK IF Q26_4_1 = 2]
[OPEN-ENDED RESPONSE]
Q26_4_2 How long would it take you to transfer operations to those locations? Please estimate in days and hours.
1. Days ____
2. and hours ____

[ASK IF Q26 = 4]
[SINGLE RESPONSE]
Q26_4_3 What percent of your production do you expect to be able to carry out at these alternative locations? *(Only read if necessary)*
1. 100% of normal (no change)
2. 99% - 75% of normal
3. 50% - 74% of normal
4. 25% - 49% of normal
5. 1% - 24% of normal
-98. Don't know

[ASK IF Q26 = 4]
[OPEN-ENDED RESPONSE]
Q26_4_4 What do you think it would cost for you to transfer production to these alternative locations? (Please include the cost of returning production to your current location if you intend to do so.)
1. $________
-.98 Don't know

[ASK IF Q26_4_3 = 2, 3, 4, 5 & Q20 NOT = -98]
[SINGLE RESPONSE]
Q26_4_5 You previously stated your annual revenue or budget is $*[insert value from Q20]* Based on your answers to the survey, we estimate that your lost revenue from this outage would be $*[insert revenue from Q20 * (1 - midpoint from Q26_4_3) * (14/365)]*. Does that seem about right? [*i.e., midpoint from 50% - 74% would be .62*]
1. No
2. Yes
-98. Don't know

[ASK IF Q26_4_5 = 1 OR Q20 = -98]
[OPEN-ENDED RESPONSE]
Q26_4_6 What would you estimate the lost revenue to be for this <u>2-week</u> outage?
1. $ _______
-98. Don't know

[ASK IF Q26 = 4]
[OPEN-ENDED RESPONSE]
Q26_4_7 Approximately how much would you avoid on your electricity bill from this 2-week power outage?
1. $_____
-98. Don't know

[ASK IF Q26 = 4]
[SINGLE RESPONSE]
Q26_4_8 Do you think you would make up any of the lost output over the two months following the outage?
1. No
2. Yes
-98. Don't know

[ASK IF Q26_4_8 = 2]
[OPEN-ENDED RESPONSE]
Q26_4_9 What percent of lost production would you be able to make up?
1. ______%
-98. Don't know

[ASK IF Q26_4_8 = 2]
[SINGLE RESPONSE]
Q26_4_10 Would your hourly employees have to work overtime or extra shifts to make up the lost production? *[READ IF NEEDED] (For example, if your hourly employees normally work 5 shifts in a week and now had to work 6 shifts to make up for the lost production, this would be one extra shift and could result in overtime.)*
1. No
2. Yes
-98. Don't know

[ASK IF Q26_4_10 = 2]
[OPEN-ENDED RESPONSE]
Q26_4_11 How much would the overtime or extra shifts cost the company for this 2-week outage?
1. $______
-98. Don't know

[ASK IF Q26_4_8 = 2]
[SINGLE RESPONSE]
Q26_4_12 Besides labor costs, would there be any additional costs to make up for lost production? (For example, renting extra equipment.)

1. No
2. Yes
-98. Don’t know

[ASK IF Q26_4_12 = 2]
[OPEN-ENDED RESPONSE]
Q26_4_13 Estimate the additional costs:
1. $____
-98. Don’t know

Start of Block: End

Please share any additional comments:
____
____
____
____
____

End of Survey

[ASK ALL]
5. **Thank you for your participation**

Please provide your contact information so that we may mail you the incentive check. The incentive check can be made out to your company, or any individual as designated by you. The check should arrive within 4-6 weeks after the survey has closed. If you choose not to accept any incentive, please write “decline.”

Option 1: Incentive to respondent

Name on check:____

Address (Line 1): ____

Address (Line 2): ____

City: ___________________ State: ______ Zip Code: ______________

APPENDIX B. Design, construction, and application of a static CGE simulation model

This appendix summarizes the design, construction, and application of a static CGE simulation model of the Upper Midwest Illinois-Indiana-Wisconsin regional economy. The application is over a time horizon of a single three-month period from the onset of an electricity supply disruption.

The CGE model is a stylized computational representation of the circular flow of the economy. It solves the set of commodity and factor prices and activity levels of firms' outputs and households' incomes that equalize supply and demand across all markets in the economy (Sue Wing, 2008; 2011; Sue Wing and Balistreri, 2018). Our model divides the regional economy into 17 micro-regions: 12 interruption-impacted ComEd micro-regions—Cook, DuPage, Kane, Lake, McHenry and Will counties, and three county aggregates (De Kalb and Kendall, Grundy and Kankakee, and 15 rural counties in the ComEd service area), three state-specific aggregates of counties abutting ComEd's service area (10 in Illinois, four in Indiana and one in Wisconsin), and aggregates of the remaining counties in Indiana (89 counties) and Wisconsin (71 counties), all of ComEd, and all counties in the three state region, as well as 38 industry sectors (Tables 5.1 and 5.2), each of which is modeled as a representative firm characterized by a constant elasticity of substitution (CES) technology to produce a single good or service. The model groups households into nine income classes, each of which is modeled by a representative agent with CES preferences and a constant marginal propensity to save and invest out of income. The government is also represented in a simplified fashion. Its role in the circular flow of the economy is passive: collecting taxes from industries and passing some of the resulting revenue to the households as a lump-sum transfer, in addition to purchasing commodities to create a composite government good which is consumed by the households. Two factors of production are represented within the model: labor, and sector-specific capital, both of which are owned by the representative agent and rented out to the firms in exchange for factor income. The region is modeled as an open economy which engages in trade with the rest of the United States and the rest of the world using the Armington (1969) specification (imports from other states and the rest of the world are imperfect substitutes for goods produced in each state).

The model computes the prices and quantities of goods and factors that equalize supply and demand in all markets in the economy, subject to constraints on the external balance of payments. The impacts of an electricity interruption are modeled as a curtailment of the use of the electricity distribution service commodity by industries, households and government entities, which has the effect of increasing the marginal cost of the residual electricity distribution demanded over the simulation horizon.

Production

The supply side of the model employs a hierarchical nested CES production structure. In each region. The supply side of the model employs a hierarchical nested CES production structure. In each micro-region r and sector j, the quantity and price and of output are given by $QY_{j,r}$ and $PY_{j,r}$. At the top level of the hierarchy, output is produced by combining a bundle of capital, labor, and non-electric intermediate inputs ($QKLZ_{j,r}$, with price $PKLZ_{j,r}$) with a bundle of nonresidential electricity service lifeline inputs ($QVN_{j,r}$, with price $PVN_{j,r}$) and a vector of demands for intermediate inputs associated with additional disequilibrium impacts of electricity disruptions ($\Omega_{i,j,r}{}^{F}$, with price $PA_{i,r}$). This production relationship is represented in dual form by the unit cost function:

$$PY_{j,r} \leq (\Omega_{j,r}{}^{Y})^{-1}[\alpha_{KLZ,j,r}{}^{\sigma_Y} PKLZ_{j,r}{}^{1-\sigma_Y} + \alpha_{V,j,r}{}^{\sigma_Y} PVN_{j,r}{}^{1-\sigma_Y} + \sum_i \vartheta_{i,j,r}{}^{\sigma_Y} PA_{i,r}{}^{1-\sigma_Y}]^{\frac{1}{1-\sigma_Y}} \quad (1a)$$

Here, σ_Y denotes the top-level the elasticity of substitution between intermediate inputs and the value-added-lifelines composite, α_{KLV}, α_V and ϑ_i are the CES distribution parameters (input shares or technical coefficients), and $\Omega_{j,r}{}^{Y}$ is a sector- and region-specific input-neutral productivity parameter.

At the second level of the hierarchy, the bundle $QKLZ_{j,r}$ is produced from a value-added composite of labor and capital ($QKL_{j,r}$, with price $PKL_{j,r}$) and a composite of intermediate inputs ($QZF_{j,r}$, with price $PZF_{j,r}$) according to the unit cost function:

$$PKLZ_{j,r} \leq [\alpha_{KL,j,r}{}^{\sigma_{KLZ}} PKL_{j,r}{}^{1-\sigma_{KLZ}} + \alpha_{Z,j,r}{}^{\sigma_{KLZ}}\, PZF_{j,r}{}^{1-\sigma_{KLZ}}]^{1/(1-\sigma_{KLZ})} \quad (1b)$$

in which σ_{KLZ} is the elasticity of substitution between value-added and intermediate inputs and, α_{KL} and α_Z are technical coefficients.

At the third level, the value-added composite is produced from sector-specific capital ($QK_{j,r}$, with price $PK_{j,r}$) and inter-sectorally mobile labor ($QL_{j,r}$, with region- and sector-specific wage $PL_{j,r}$) according to the unit cost function:

$$PKL_{j,r} \leq [\alpha_{K,j,r}{}^{\sigma_{KL}} PK_{j,r}{}^{1-\sigma_{KL}} + \alpha_{L,j,r}{}^{\sigma_{KL}}\, PL_{j,r}{}^{1-\sigma_{KL}}]^{1/(1-\sigma_{KL})} \quad (1c)$$

where σ_{KL}, α_K and α_L denote the capital-labor elasticity of substitution and associated technical coefficients. The bundle of intermediate inputs ($QZ_{j,r}$) is modeled in a similar way, combining non-lifeline Armington intermediate commodity uses ($q_{i,F,j,r}$, with prices $PA_{i,r}$):

$$PZF_{j,r} \leq [\sum_{i \neq \{EGEN,ETD\}} \alpha_{i,j,r}{}^{\sigma_Z} PA_{i,r}{}^{1-\sigma_Z}]^{1/(1-\sigma_Z)} \quad (1d)$$

with elasticity of substitution, σ_Z, and associated technical coefficients, α_i.

In line with the study's focus, the lifeline inputs of interest are electricity and its transmission and distribution. The lifeline input bundle is produced from electric power generation and electricity transmission and distribution service ($i = EGEN, ETD$, with quantities and prices $q_{i,F,j,r}$, and $PA_{i,r}$), similar to eq. (1d). The modeling device used to represent the impact of a nonresidential electricity outage is that lifeline inputs are assumed to enter into a Leontief fixed-coefficient relationship with a nonresidential electricity service "fixed factor", whose supply is exogenously determined and subject to curtailment. The resulting component of production is described by the unit cost function:

$$PVN_{j,r} \leq \alpha_{FF} PFF_{\chi(j),r} + \alpha_{Elec,r} [\textstyle\sum_{i \in \{EGEN,ETD\}} \alpha_{i,j,r}{}^{\sigma_V} PA_{i,r}{}^{1-\sigma_V}]^{1/(1-\sigma_V)} \qquad (1e)$$

Here, σ_V is the elasticity of substitution, and α_{FF}, α_{Elec}, α_{EGEN} and α_{ETD} are technical coefficients. The index $\chi(j) \in \{Industrial, Commercial\}$ denotes industry j's customer class, for which the price of the electricity fixed factor (PFF) is constant. In the economy's baseline state, 100% reliable electricity service is modeled by assuming that the fixed factor is in excess supply, so that $PFF = 0$, and the quantity of nonresidential electricity service demanded is competitively determined via sectors' cost minimization behavior. An outage is modeled as curtailment of the quantity of the fixed factor with which the various classes of customers are endowed, so that the supply falls short of the quantity demanded in (1e), leading to scarcity bidding up the price, $PFF > 0$. Through this mechanism, the distortionary effect of a nonresidential outage ripples through the rest of the production structure, (1a)-(1d), inducing simultaneous substitution and price adjustments across the full range of impacted sectors.

Trade and Commodity Supply

Trade is modeled according to an Armington (1969) formulation, in which the output of a sector in a particular region is allocated between consumption of locally produced goods and exports. In turn, exports are divided between goods destined for other regions within the United States and goods that satisfy foreign demand. Symmetrically, on the demand side, each consumed commodity is a composite of domestic and imported varieties, where the latter is an amalgam of imports from other U.S. regions and from abroad.

The calibration dataset does not record bilateral trade among micro-regions. We use the variable $QXUS_{i,r}$ to denote units of the i^{th} commodity exported by region r to U.S. consumers in other locales, and model these quantities as feeding into an aggregate national pool at a commodity-specific nationwide price (PUS_i). Similarly, we use the variable $QXF_{i,r}$ to denote units of commodity i exported to consumers abroad. These quantities are treated as feeding an international pool at a single price (the generalized price of foreign exchange, PFX). Using the variable $PYT_{i,r} = (1 + \tau_{i,r}{}^{Y}) PY_{i,r}$ to represent the gross-of-tax price of commodity i in region r (where $\tau_{i,r}{}^{Y}$ denotes the production tax rate), the transformation of regional output into exports (quantity $QX_{i,r}$) is specified in terms of the dual by the following constant elasticity of transformation (CET) equation:

$$PYT_{i,r} \geq [\beta_{XCA,i}{}^{\eta_{X.i}} PUS_i{}^{1+\eta_{X.i}} + \beta_{XF,i}{}^{\eta_{X.i}} \, PFX^{1+\eta_{X.i}}]^{1/(1+\eta_{X.i})} \qquad (2a)$$

Where (suppressing the commodity subscript for the sake of brevity) η_X is the commodity-specific elasticity of transformation between domestic and international export destinations, and β_{XCA} and β_{XF} are commodity-specific technical coefficients. Symmetrically, region r imports $QMUS_{i,r}$ units of i from other US regions and $QMF_{i,r}$ units from abroad. Its aggregate imports of each commodity (quantity $QM_{i,r}$ with price $PM_{i,r}$) are modeled as a CES composite of these quantities, given in terms of the dual by

$$PM_{i,r} \leq [\beta_{MUS,i,r}{}^{\sigma_{MM,i}} PUS_i{}^{1-\sigma_{MM,i}} + \beta_{MF,i,r}{}^{\sigma_{MM,i}} \; PFX^{1-\sigma_{MM,i}}]^{1/(1-\sigma_{MM,i})} \tag{2b}$$

in which (suppressing the commodity subscript) σ_{MM} is the elasticity of substitution among import origins, and β_{MUS} and β_{MF} are commodity-specific technical coefficients. In turn, within each region, sectors' intermediate demands and households' final demands for a particular commodity are satisfied by the Armington total supply of that good ($QA_{i,r}$, with price $PA_{i,r}$). Armington total supply is modeled as a CES composite of domestic and imported varieties of the good, given in dual form by

$$PA_{i,r} \leq [\beta_{D,i,r}{}^{\sigma_{DM,i}} PY_i{}^{1-\sigma_{DM,i}} + \beta_{M,i,r}{}^{\sigma_{DM,i}} \; PM^{1-\sigma_{DM,i}}]^{1/(1-\sigma_{DM,i})} \tag{2c}$$

where (suppressing the commodity subscript) σ_{DM} is the commodity-specific elasticity of substitution, and β_D and β_M are commodity-specific technical coefficients.

A simple trade closure (account balance relating to exogenous and endogenous variables) is adopted for the model. Each micro-region is treated as a small open economy which cannot affect the price of foreign exchange. Following open-economy modeling convention, foreign exchange is treated as the unit of account; accordingly, the price of foreign exchange (PFX) is designated as the numeraire price by fixing its value at unity. The model only resolves regions within the Upper Midwest region, and not elsewhere in the US, so in general trade flows of a particular good recorded by the benchmark input-output accounts will not balance. The study region's net export position vis-a-vis the rest of the US is calculated by applying Shephard's lemma (duality relationship), yielding the supply-demand balance condition:

$$\sum_r QXUS_{i,r} \geq \sum_r QMUS_{i,r} + QBUS_i \;\Rightarrow \sum_r \frac{\partial PYT_{i,r}}{\partial PUS_i} QX_{i,r} \;\geq \sum_r \frac{\partial PM_{i,r}}{\partial PUS_i} QM_{i,r} + QBUS_i \tag{2d}$$

where $QBUS_i$ is introduced as an exogenous balancing quantity of net exports of good i. The corresponding expression for trade supply-demand balance with foreign countries is

$$\sum_r QXF_{i,r} \geq \sum_r QMF_{i,r} + QBF_i \;\Rightarrow \sum_r \frac{\partial PYT_{i,r}}{\partial PF_i} QX_{i,r} \;\geq \sum_r \frac{\partial PM_{i,r}}{\partial PFX} QM_{i,r} + QBF_i \tag{2e}$$

with exogenous balancing quantity QBF_i.

Final Demands and Commodity Market Closures

In each region final consumption is allocated among h household income archetypes, each of which is modeled as a representative agent with preferences given by a nested CES utility function. At the top of the preference hierarchy, the associated dual expenditure function is a CES aggregation of a composite of consumption commodities ($QZC_{h,r}$, at price $PZC_{h,r}$) and a bundle of residential electricity service lifeline inputs ($QVR_{h,r}$, at price $PVR_{h,r}$):

$$PU_{h,r} \leq [\gamma_{Z,h,r}{}^{\sigma_U} PZC_{h,r}{}^{1-\sigma_U} + \gamma_{V,h,r}{}^{\sigma_U} \; PVR_{h,r}{}^{1-\sigma_U} + \sum_i \varpi_{i,h,r}{}^{\sigma_U} PA_{i,r}{}^{1-\sigma_U}]^{1/(1-\sigma_U)} \tag{3a}$$

where $PU_{h,r}$ is the households' unit expenditure index, and, suppressing subscripts for brevity, σ_U denotes households' elasticity of substitution between consumption and lifelines, and γ_Z and are γ_V are technical coefficients. At the second level of the hierarchy, aggregate consumption is a CES composite of consumption of non-electric commodities ($q_{i,C,h,r}$, at price $PA_{i,r}$):

$$PZC_{h,r} \leq [\sum_{i\neq\{EGEN,ETD\}} \gamma_{i,h,r}{}^{\sigma_C} PA_{i,r}{}^{1-\sigma_C}]^{1/(1-\sigma_C)} \tag{3b}$$

in which σ_C denotes households' elasticity of substitution over consumption goods, and γ_i are technical coefficients. Similar to (1e), the lifeline input bundle aggregates consumption of electric power generation and electricity transmission and distribution service ($i = EGEN, ETD$, with quantities and prices $q_{i,C,j,r}$, and $PA_{i,r}$). We model the impact of a residential electricity outage by assuming that lifeline inputs enter into a Leontief fixed-coefficient relationship with a residential electricity service fixed factor, whose supply is exogenously determined and subject to curtailment. The result is the unit expenditure function:

$$PVR_{h,r} \leq \gamma_{FF,r} PFF_{Residential,r} + \gamma_{Elec,r}[\sum_{i\in\{EGEN,ETD\}} \gamma_{i,h,r}{}^{\sigma_C} PA_{i,r}{}^{1-\sigma_C}]^{1/(1-\sigma_V)} \tag{3c}$$

in which σ_V is the elasticity of substitution, γ_{FF}, γ_{Elec} and γ_i are technical coefficients, and $PFF_{Residential}$ indicates the price of the residential electricity service fixed factor, which is zero in the baseline but positive during an outage.

There are also g levels of government, each of which consumes commodity inputs for the purpose of producing a government good (quantity $QG_{g,r}$, at price $PG_{g,r}$) with nested CES technology. At the top level of the hierarchy, the associated dual cost function is a CES aggregation of a composite of commodities ($QZG_{g,r}$, at price $PZG_{g,r}$) and a bundle of residential electricity service lifeline inputs ($QVG_{g,r}$, at price $PVG_{g,r}$)

$$PG_{g,r} \leq [\ \delta_{Z,g,r}{}^{\sigma_G} PZG_r{}^{1-\sigma_G} + \delta_{V,g,r}{}^{\sigma_G} PVG_{g,r}{}^{1-\sigma_G}]^{1/(1-\sigma_G)} \tag{3d}$$

in which σ_G denotes the elasticity of substitution, and (suppressing subscripts) δ_Z and δ_V are technical coefficients. At the second level of the hierarchy, aggregate consumption is a CES composite of consumption of non-electric commodities ($q_{i,G,g,r}$, at price $PA_{i,r}$):

$$PZG_{g,r} \leq [\sum_{i\neq\{EGEN,ETD\}} \delta_{i,g,r}{}^{\sigma_Z}\ PA_{i,r}{}^{1-\sigma_Z}]^{1/(1-\sigma_Z)} \tag{3e}$$

in which σ_Z denotes the elasticity of substitution, and (suppressing subscripts) $\delta_{i,G}$ are technical coefficients. The lifeline input bundle is produced from electric power generation and electricity transmission and distribution service ($i = EGEN, ETD$, with quantities and prices $q_{i,G,g,r}$, and $PA_{i,r}$). The impact of a residential electricity outage is modeled in a manner identical to industries and households, given by the cost function:

$$PVG_{g,r} \leq \delta_{FF,r} PFF_{Commercial,r} + \delta_{Elec,r} [\textstyle\sum_{i \in \{EGEN,ETD\}} \delta_{i,G,g,r}{}^{\sigma_V} PA_{i,r}{}^{1-\sigma_V}]^{1/(1-\sigma_V)} \quad (3f)$$

in which σ_V is the elasticity of substitution, $\delta_{FF,r}$, δ_{Elec} and δ_i are technical coefficients, and $PFF_{Commercial}$ indicates the price of the commercial electricity service fixed factor, which is zero in the baseline but positive during an outage.

Each micro-region undertakes investment (indicated by the subscript, I) which is modeled as the production of an investment good (QI_r, at price PI_r) from a CES aggregation of commodities ($q_{i,I,r}$ at price $PA_{i,r}$), given in dual form by

$$PI_{g,r} \leq [\textstyle\sum_i \gamma_{i,I,r}{}^{\sigma_I} PA_{i,r}{}^{1-\sigma_I}]^{1/(1-\sigma_I)} \quad (3g)$$

where σ_I denotes the elasticity of substitution, and (suppressing subscripts) $\gamma_{i,I}$ are technical coefficients. It is assumed that each representative household exhibits a fixed marginal propensity to save (MPS) and invests out of income. Supply-demand balance for regional investment and households' savings ($QS_{h,r}$) requires

$$QI_r \leq \textstyle\sum_h QS_{h,r} \quad (3h)$$

while a fixed MPS implies a constant of proportionality, $\mu_{h,r}$, which allows households' savings to scale with their overall activity (utility) levels:

$$QS_{h,r} \leq \mu_{h,r} S_{h,r}$$

(3i)

Government consumption is financed out of tax revenue and transfers. Government g is modeled as claiming a fraction $\xi_{g,r}$ of the total tax revenue raised within region r, as well as receiving a net transfer, $GXFER_{g,r}$ (which for convenience is denominated in units of the numeraire). The activity level of public provision is then given by:

$$QG_{g,r} \leq (\xi_{g,r} \textstyle\sum_j \tau_{j,r}{}^Y PY_{j,r} QY_{j,r} + PFX \cdot GXFER_{g,r}) / PG_{g,r} \quad (3h)$$

The supply-demand balance for domestic output is given by

$$QY_{i,r} \geq QD_{i,r} + QX_{i,r} \quad (3i)$$

where the unconditional demand for domestic uses is given by Shephard's lemma: $QD_{i,r} = \frac{\partial PA_{i,r}}{\partial PY_{i,r}} QA_{i,r}$. The supply-demand balance for imports is given by Shephard's lemma:

$$QM_{i,r} \geq \frac{\partial PA_{i,r}}{\partial PM_{i,r}} QA_{i,r} \quad (3j)$$

Finally, the supply-demand balance for Armington commodities is closed via the condition

$$QA_{i,r} \geq \sum_j q_{i,F,j,r} + \sum_h q_{i,C,h,r} + \sum_g q_{i,G,g,r} + q_{i,I,r} + \sum_j {\Omega_{i,j,r}}^F + \sum_h {\Omega_{i,h,r}}^C \qquad (3k)$$

in which there are two groups of terms on the right-hand side. The first group is made up of the unconditional market demands for commodities. For sectors, households and governments these are:

$$q_{i,F,j,r} = \begin{cases} \frac{\partial PZF_{j,r}}{\partial PA_{i,r}} QZF_{j,r} \\ \frac{\partial PVN_{j,r}}{\partial PA_{i,r}} QVN_{j,r} \end{cases} \quad q_{i,C,h,r} = \begin{cases} \frac{\partial PZC_{h,r}}{\partial PA_{i,r}} QZC_{h,r} \\ \frac{\partial PVR_{h,r}}{\partial PA_{i,r}} QVR_{h,r} \end{cases} \quad q_{i,G,g,r} = \begin{cases} \frac{\partial PZG_{g,r}}{\partial PA_{i,r}} QZG_{g,r} & i \neq \{EGEN, ETD\} \\ \frac{\partial PVG_{g,r}}{\partial PA_{i,r}} QVG_{g,r} & i \in \{EGEN, ETD\} \end{cases}$$

where the intermediate activity levels are given by Shepard's Lemma: $QZF_{j,r} = \frac{\partial PKLZ_{j,r}}{\partial PZF_{j,r}} QKLZ_{j,r}$, $QKLZ_{j,r} = \frac{\partial PY_{j,r}}{\partial PKLZ_{j,r}} QY_{j,r}$, $QVN_{j,r} = \frac{\partial PY_{j,r}}{\partial PVN_{j,r}} QY_{j,r}$, $QZC_{h,r} = \frac{\partial PU_{h,r}}{\partial PZC_{h,r}} U_{h,r}$, $QVR_{h,r} = \frac{\partial PU_{h,r}}{\partial PVR_{h,r}} U_{h,r}$, $QZC_{h,r} = \frac{\partial PG_{g,r}}{\partial PZG_{g,r}} QG_{g,r}$, $QVG_{g,r} = \frac{\partial PG_{g,r}}{\partial PVG_{g,r}} QG_{g,r}$. For investment, the unconditional input demands are $q_{i,I,r} = \frac{\partial PI_r}{\partial PA_{i,r}} QI_r$. The second category is secular disequilibrium demands for intermediate inputs by firms, ${\Omega_{i,j,r}}^F = \frac{\partial PY_{j,r}}{\partial PA_{i,r}} QY_{j,r}$, and goods for final consumption by households, ${\Omega_{i,h,r}}^C = \frac{\partial PU_{h,r}}{\partial PA_{i,r}} U_{h,r}$. The left-hand sides of these expressions are exogenously imposed shocks. Their effect is therefore to induce adjustments in the endogenous right-hand side variables, which ends up having distortionary impacts on sectors' output prices and activity levels, household utility levels, and, via eq. (3k), Armington commodity supplies and prices in affected micro-regions.

Inter-Sectoral Factor Mobility and Static Income Closures

Given the brief duration of the period over which the equilibrium represented by the model is established, the assumption of frictionless inter-sectoral reallocation of capital commonly made by CGE models is unlikely to accurately capture the behavior of factor markets. Capital is modeled as a sectorally- and geographically-fixed factor, with instantaneous supply-demand balance determined by the region- and sector-specific endowment of capital input ($\underline{\varepsilon}_{K,j,r}$):

$$\underline{\varepsilon}_{K,j,r} \geq \frac{\partial PKL_{j,r}}{\partial PK_{j,r}} QKL_{j,r} + {\Omega_{j,r}}^K \qquad (4a)$$

where $QKL_{j,r} = \frac{\partial PKLZ_{j,r}}{\partial PKL_{j,r}} QKLZ_{j,r}$ and $QK_{j,r} = \frac{\partial PKL_{j,r}}{\partial PK_{j,r}} QKL_{j,r}$. Inputs of labor to the various sectors are treated as imperfect substitutes with sluggish intersectoral reallocation, i.e., limited ability to move across industries to arbitrage short-run intersectoral differences in labor's marginal product. Households in each micro-region are assumed to supply labor into a macro-regional pool (with aggregate quantity, $\underline{\varepsilon}_L$, at an average wage, W). We model the allocation of labor from this pool to satisfy micro-region by sector demands using the CET relationship

$$PW \geq [\, \sum_j \sum_r \lambda_{j,r}{}^{\eta_L} PL_{j,r}{}^{1+\eta_L} \,]^{1/(1+\eta_L)} \tag{4b}$$

Labor supply-demand balance at the macro-regional level is given by:

$$\underline{\varepsilon}_L \ \geq \sum_j \sum_r (QL_{j,r} + \Omega_{j,r}{}^{L}) \tag{4c}$$

in which the right-hand side terms are sectors' market demands for labor, $QL_{j,r} = \frac{\partial PKL_{j,r}}{\partial PL_{j,r}} QKL_{j,r}$, and secular disequilibrium labor demands, $\Omega_{j,r}{}^{L} = \frac{\partial PY_{j,r}}{\partial PL_{j,r}} QY_{j,r}$.

Within each micro-region, household, investment and government activities are linked by an income-expenditure balance condition that constrains the value of expenditure and saving to equal the value of factor returns plus net household transfers ($HXFER_{h,r}$, also denominated in units of the numeraire). Thus, using $\zeta_{K,h,r}$ and $\zeta_{L,h,r}$ to denote the shares of labor and capital remuneration going to the various household income groups within each micro-region, income balance is given by

$$\sum_j PK_{j,r} \zeta_{K,h,r} \underline{\varepsilon}_{K,j,r} + W \zeta_{L,h,r} (\underline{\varepsilon}_L - \Omega_{h,r}{}^{Inc}) + PFX \cdot HXFER_{h,r}$$

$$\geq PU_{h,r} U_{h,r} + PI_r QS_{h,r} + \sum_i PCA_i SA_{i,h,r} \tag{4d}$$

in which $\Omega_{h,r}{}^{Inc}$ is a secular disequilibrium shock to the labor earnings of a group of households in a micro-region.

The final closure rule is the statewide balance of payments constraint, which balances the net supply of foreign exchange against the demands for transfer payments that make up the idiosyncratic components of household and government income:

$$\sum_i PUS_i (QBUS_i + \sum_r PUS_i (QXUS_{i,r} - QMUS_{i,r})) + \sum_i PFX (QBF_i + \sum_r (QFX_{i,r} - QMF_{i,r}))$$

$$+ \sum_g \sum_r GXFER_{g,r} + \sum_h \sum_r HXFER_{h,r} = 0 \tag{4e}$$

The region's exports to, and imports from, international (U.S.) markets are both valued at the numeraire foreign exchange price (U.S. average commodity-specific domestic prices), with quantities given by the application of Shepard's lemma to equations (2a) and (2b): $QXUS_{i,r} = \frac{\partial PYT_{i,r}}{\partial PUS_i}$, $QMUS_{i,r} = \frac{\partial PM_{i,r}}{\partial PUS_i}$, $QXF_{i,r} = \frac{\partial PYT_{i,r}}{\partial PFX}$ and $QXF_{i,r} = \frac{\partial PM_{i,r}}{\partial PFX}$.

Modeling Market Impacts of Electricity Service Disruptions

The static equilibrium model made up of eqs. (1)-(4) is subjected to the shock of economic damage caused by the exogenous curtailment of electricity supply. The main forcing parameter is the fractional reduction in 3-month electricity supply, specified in the disruption scenarios described in the main report.

The consequence of disruptions is that customers consume smaller quantities of electricity distribution service at higher prices. Following Sue Wing and Rose (2020), the model implements this logic by introducing a markup on the price of electricity distribution service that is consistent with the target level of curtailment. As mentioned in the previous sections, the modeling device we employ is the addition of a small amount of fixed-factor capital, which is complementary to sectors' and households' uses of both the electricity distribution service and electric power commodities. This enables power disruptions to be modeled as a fractional reduction in the fixed-factor endowment, which ensures an identical concomitant fractional curtailment in the aggregate supply of electricity service throughout the affected economy.

The markup is the fixed-factor price, PFF, which in eqs. (1e) and (3f) drives a wedge between the Armington price of electricity distribution service and the corresponding price at which that service is consumed by residential and nonresidential customers. Introducing the calibration parameter, ψ ~10^{-3}, the benchmark supply of electricity service fixed factor capital is calibrated as

$$\underline{\varepsilon}_{FF,Industrial,r} = \psi \sum_{j \in Industrial} \underline{QVN}_{j,r}$$

$$\underline{\varepsilon}_{FF,Commercial,r} = \psi \left(\sum_{j \in Commercial} \underline{QVN}_{j,r} + \sum_{g} \underline{QVG}_{g,r} \right)$$

$$\underline{\varepsilon}_{FF,Residential,r} = \psi \textstyle\sum_{h} \underline{QVR}_{h,r} \tag{5a}$$

where $\underline{QVN}_{j,r}$, $\underline{QVG}_{g,r}$ and $\underline{QVR}_{h,r}$ denote the benchmark values of electric power and transmission/distribution service inputs to sectors, government and households in the calibration dataset. Given electricity outages expressed as fractions of the benchmark value of electricity service to different customers in each micro-region ($o_{\chi,r} < 1$), the corresponding fixed factor supply-demand balance conditions are given by Shepard's lemma:

$$(1 - o_{Industrial,r})\underline{\varepsilon}_{FF,Industrial,r} = \sum_{j \in Industrial} \frac{\partial PVN_{j,r}}{\partial PFF_{Industrial,r}} QVN_{j,r}$$

$$(1 - o_{Commercial,r})\underline{\varepsilon}_{FF,Commercial,r} = \textstyle\sum_{j \in Commercial} \frac{\partial PVN_{j,r}}{\partial PFF_{Commercial,r}} QVN_{j,r} + \sum_{g} \frac{\partial PVG_{g,r}}{\partial PFF_{Commercial,r}} QVG_{g,r}$$

$$(1 - o_{Residential,r})\underline{\varepsilon}_{FF,Residential,r} = \sum_h \frac{\partial PVR_{h,r}}{\partial PFF_{Residential,r}} QVR_{h,r} \qquad (5b)$$

Disequilibrium Impacts of Electricity Service Disruptions

Additional non-market impacts of interruptions are modeled using shocks to firms' labor, capital and productivity ($\Omega_{j,r}{}^{L}$,$\Omega_{j,r}{}^{K}$, $\Omega_{j,r}{}^{Y}$) as well as household groups' labor earnings ($\Omega_{h,r}{}^{Inc}$), in addition to the secular demands for commodities by firms and households ($\Omega_{i,j,r}{}^{F}$ and $\Omega_{i,h,r}{}^{C}$). These shocks are imposed exogenously, with values calculated as described in Table 5.13 in the main body of the report.

Model Calibration, Formulation, Solution, and Application

The vectors of technical coefficients α, β and γ in eqs. (1)-(4), and the benchmark endowments, $\underline{\varepsilon}_{K,j,r}$ and $\underline{\varepsilon}_{L,r}$, in eq. (4) are calibrated using IMPLAN SAMs for IL, IN and WI for the year 2019 (IMPLAN, 2020) in conjunction with values of the elasticities of substitution, transformation and supply based on a mix of assumptions and previous modeling studies. The model is formulated as a mixed complementarity problem using the MPSGE subsystem for GAMS (Rutherford, 1999; Brooke et al., 1988) and is solved using the PATH solver (Ferris and Munson, 2000).

Table B - 1. Summary of shocks to the CGE model

	A. Secular commodity demand shocks	
Customer segment	**Commodity shock (i)**	**Constituent additional impacts**
Residential: household consumption by income group ($\boldsymbol{\Omega_{i,h,r}{}^{C}}$)	Agriculture	Spoiled food - Avoided food consumption
	Food products	Spoiled food - Avoided food consumption
	Food & beverage stores	Delivered meals + Meals/lodging - Avoided food consumption
	Restaurants	Delivered meals + Meals/lodging + 90% of Meals/transportation - Avoided food consumption
	Accommodation & food services	Meals/lodging
	Hotels	Meals/lodging
	Transportation	Transportation - Avoided transportation
	Petroleum	10% of Meals/transportation + Transport + Fuel for generators - Avoided transportation
	Natural gas	Fuel for generators
	Motor & generator manufacturing	Generator capital
	Retail	1% of Generator capital
Nonresidential: firm intermediate input by sector ($\boldsymbol{\Omega_{i,j,r}{}^{F}}$)	Petroleum	Fuel cost of backup generation
	Natural Gas	Fuel cost of backup generation
	Transportation	Cost of transferring production to alternate locations
	Services	Additional costs of safety and security
	B. Secular shocks to output and factor demand/supply	

Customer segment	Type	Constituent additional impacts
Residential	Household labor remuneration by income group ($\boldsymbol{\Omega_{h,r}}^{\boldsymbol{Inc}}$)	Forgone income
Non-residential	Firm productivity ($\boldsymbol{\Omega_{j,r}}^{\boldsymbol{Y}}$)	Revenue recapture - Additional costs of recapture - Cost to restore operations - Damage to inventories/feedstocks
	Firm capital demand ($\boldsymbol{\Omega_{j,r}}^{\boldsymbol{K}}$)	Cost of backup generation: generators
	Firm labor demand ($\boldsymbol{\Omega_{j,r}}^{\boldsymbol{L}}$)	Cost of overtime pay for recapture

APPENDIX C. Total number of households and employment by micro-region

Table C - 1. Total number of households by income bracket by micro-region

Region	Micro regions: County or counties	Income group 1: Less than $50,000	Income group 2: $50,000 to $100,000	Income group 3: Greater than $100,000	Total
1	Cook	830,665	564,311	607,321	2,002,297
2	Dekalb and Kendall	26,624	28,090	30,021	84,735
3	DuPage	94,050	99,621	154,429	348,100
4	Grundy and Kankakee	24,299	21,044	16,390	61,733
5	Kane	57,100	54,950	68,542	180,592
6	Lake	72,035	68,961	108,674	249,670
7	McHenry	29,590	36,189	44,934	110,713
8	Will	65,391	73,371	96,328	235,090
9	Winnebago, Boone, Ford, La Salle, Lee, Stephenson, Jo Daviess, Carroll, Whiteside, Marshall, Ogle, Woodford, Bureau, Henry, Livingston	154,589	112,753	75,304	342,646
10	All of ComEd	1,354,343	1,059,290	1,201,943	3,615,576

Source: IMPLAN (2020)

Table C - 2. Total employment by sector and micro-region

Industry sector	Cook	Dekalb and Kendall	Dupage	Grundy and Kankakee	Kane	Lake	McHenry	Will	Rural ComEd	All of ComEd
Agricultural, Construction, and Mining	141,937	8,030	40,433	8,171	18,165	22,119	12,725	22,089	42,655	316,324
Electric Distribution, Natural Gas, and Water	5,448	93	2,889	1,304	283	2,007	172	1,887	2,997	17,080
Manufacturing	192,645	7,913	57,685	8,725	34,092	51,887	16,048	23,761	62,011	454,766
Wholesale Trade, Transportation	403,373	10,594	101,686	7,594	25,533	38,068	14,923	56,874	41,944	700,588
Retail	241,435	12,081	58,813	9,313	22,701	43,269	14,971	33,999	41,130	477,712

Industry sector	Cook	Dekalb and Kendall	Dupage	Grundy and Kankakee	Kane	Lake	McHenry	Will	Rural ComEd	All of ComEd
Telecommunications, Finance, Data Processing	1,394,066	23,499	330,587	20,411	84,811	172,296	39,304	96,708	103,763	2,265,444
Education	94,603	1,008	15,966	1,369	4,467	7,279	1,858	5,289	4,344	136,184
Hospitals	119,376	1,580	16,784	4,181	6,804	9,107	3,241	5,448	13,857	180,376
Restaurants, Entertainment, Other Services	741,102	18,673	125,868	15,092	50,643	78,575	26,502	62,570	75,076	1,194,101
Government	301,574	15,630	43,377	8,004	27,908	51,560	13,942	31,028	43,508	536,530
Total	3,635,559	99,100	794,087	84,162	275,407	476,167	143,685	339,653	431,284	6,279,103

Source: IMPLAN (2020)