A Method to Estimate the Economy-wide Consequences of Widespread, Long Duration Electric Power Interruptions

Supplementary information

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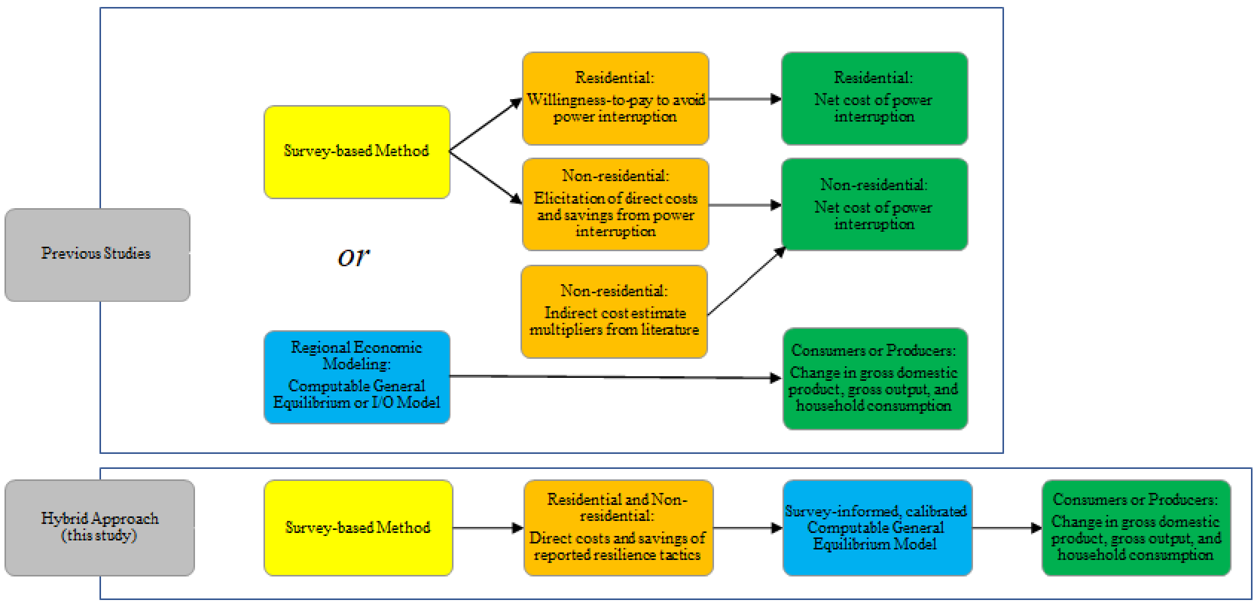


Supplementary Fig. 1. Steps to estimate economic impacts of power interruptions: previous studies versus the hybrid approach used in this study

Supplementary methods

A. Customer population and sampling strategy

Response targets were set at 600 completed surveys for residential customers, 200 for SMB customers, and 80 for LCI customers. A customer refers to a unique combination of customer number and service address in the utility'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.

Supplementary Table 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

Supplementary Table 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

B. Survey administration and responses

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. The residential customer survey effort collected 829 responses (Supplementary Table 3).

Supplementary Table 3. Residential survey responses by geographic area

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

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 with email addresses 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 ($100) 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 customers before assuming that they would not respond. The SMB survey effort collected 200 responses. Supplementary tables 4 and 5 summarize the number of responses received for the SMB survey by geographic area and industry sector, respectively.

Supplementary Table 4. SMB survey responses by geographic area

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

Supplementary Table 5. SMB survey responses by industry sector

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

Large commercial and industrial customers: The LCI survey was also conducted as a phone interview. Utility account representatives first contacted customers and identified the best person at each sampled business to call and recruit for the study. Subsequently, telephone recruiters 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 familiar with the costs associated with running the business or operating the facility. Once the target respondent was identified and had agreed to participate, an appointment was set up with field interviewers, 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. Of the total contact sample, interviewers were able to collect completed responses from 61 LCI customers. Supplementary Tables 6 and 7 summarize the responses received by geographic area and industry sector, respectively.

Supplementary Table 6. LCI survey responses by geographic area

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

Supplementary Table 7. LCI survey responses by industry sector

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

C. Survey responses

Supplementary Table 8. 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

Cost category	Residential	Non-residential
		generators ● Fuel/backup generator rental costs Savings regardless of backup generator operations ● Savings in labor costs during power interruptions

Residential customer costs and savings

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[1]. 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 interruptions.

After calculating total household lost income, outlier values (>98th percentile) were flagged and removed.

Costs of meals, lodging, and transportation: 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). Responses deemed to be invalid were excluded from the analysis, yielding a final sample of 753 observations (Supplementary Table 9).

Supplementary Table 9. Count of residential survey responses included in the analysis by geographic area

Area	Responses collected	Valid responses	% invalid
Rural	266	244	8.3%
Suburban	354	319	9.9%
Urban	209	190	9.1%
Total	829	753	9.2%

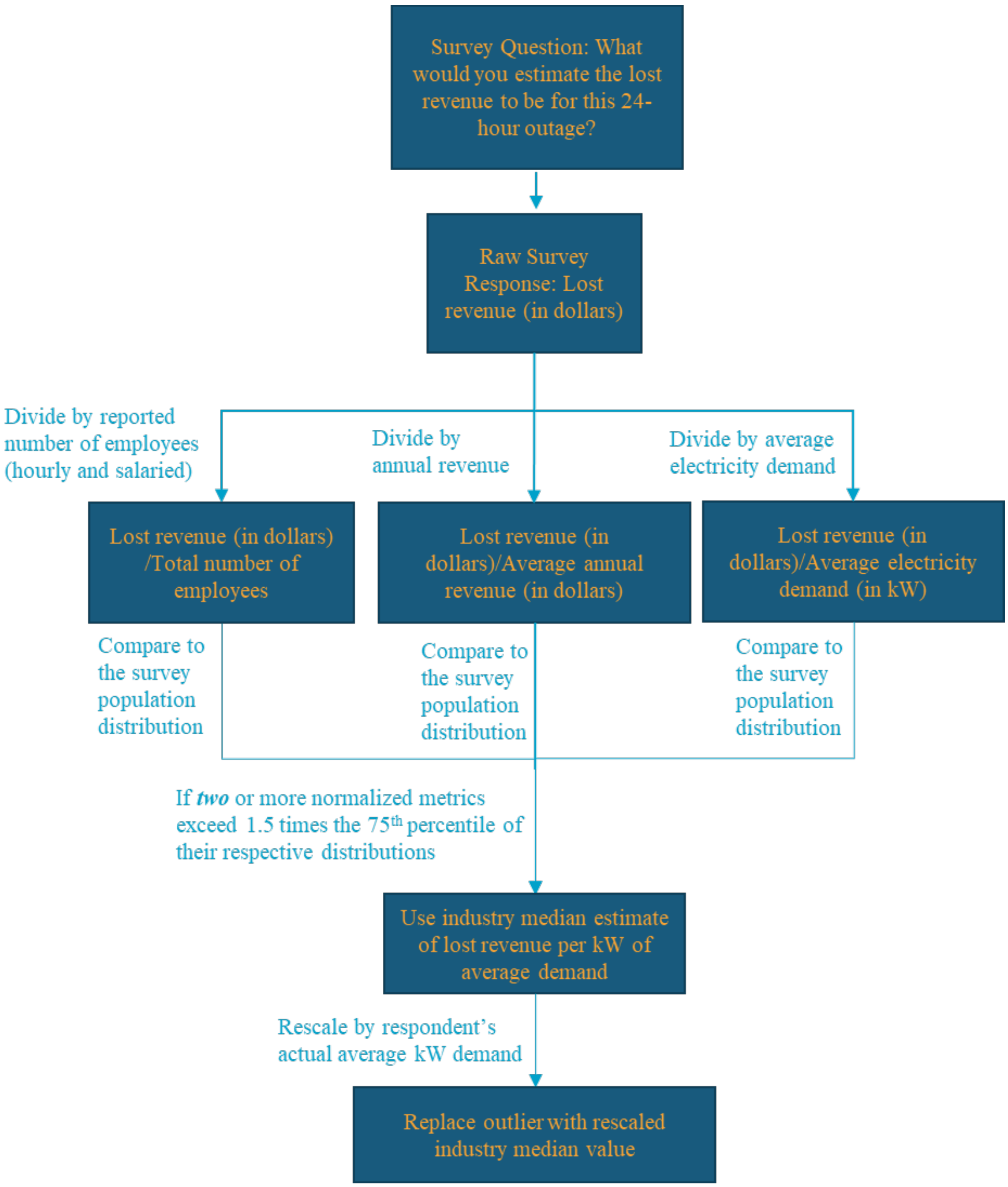
Non-residential customer costs and savings

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 was inaccurate estimates of the 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).

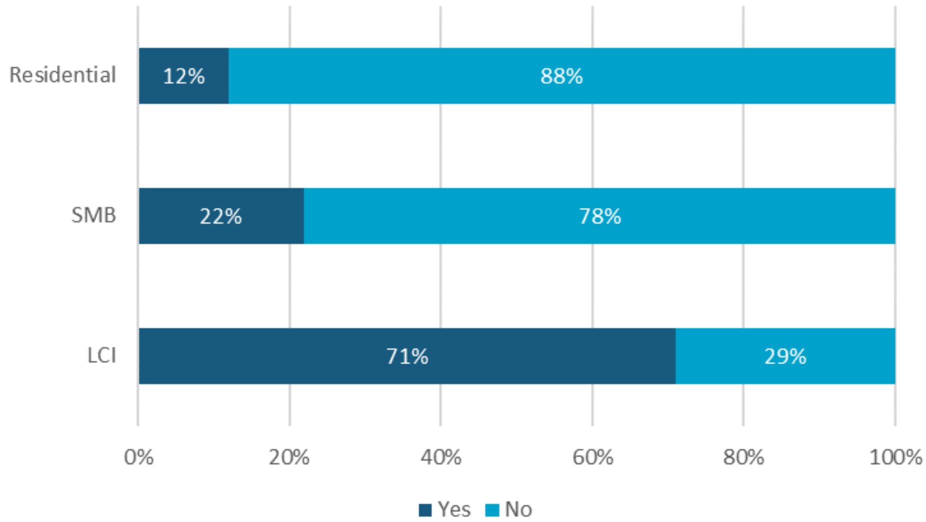
If a respondent's reported answer to a given cost or savings question exceeded 1.5 times the 75th percentile of the distribution of normalized values of the entire survey population after normalization by two or three of the three metrics, the respondent's reported answer was determined to be implausibly 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 75^{th} 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 S2 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.

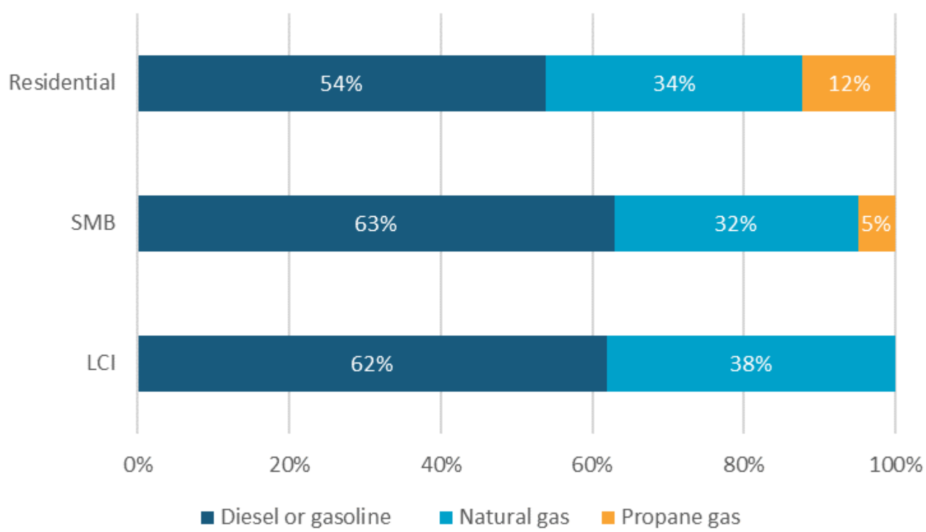


Supplementary Fig. 2. Methodology for adjusting non-residential outliers for costs and savings questions

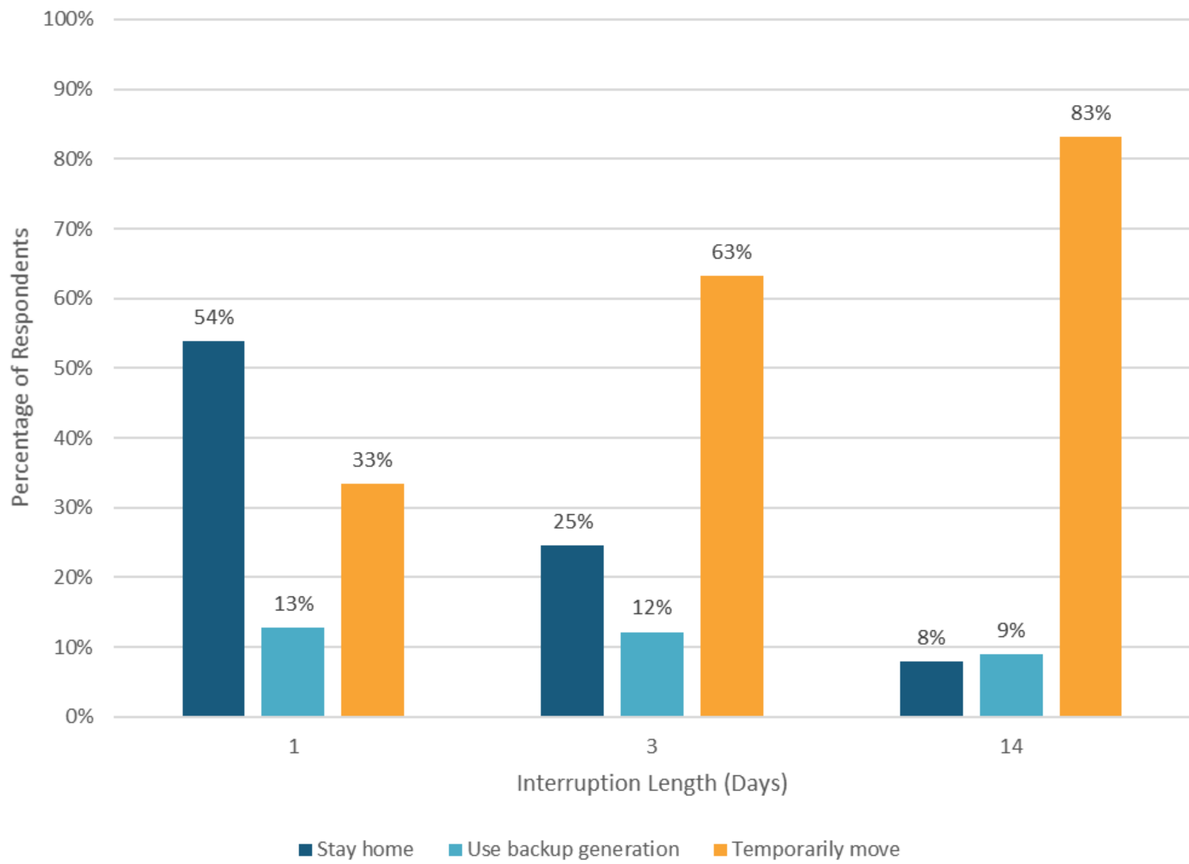
Customers' backup generation and their fuel source



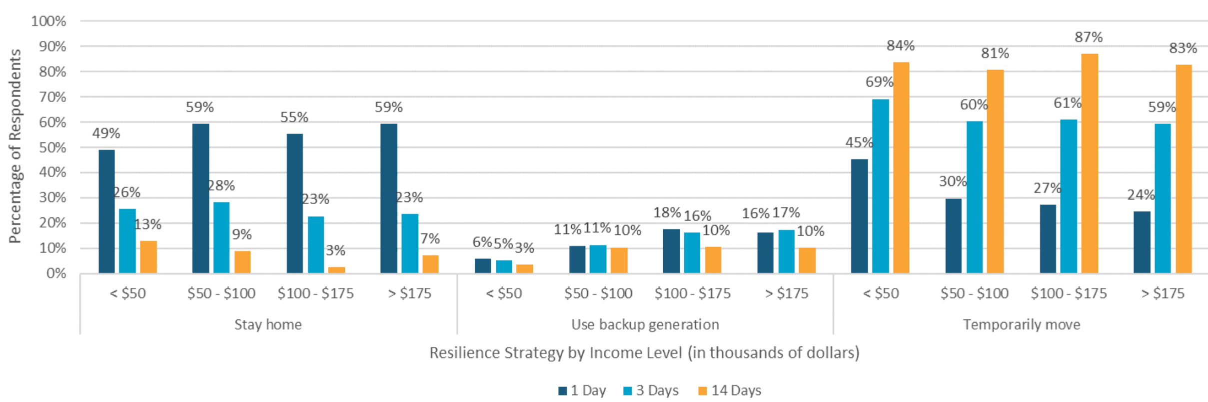
Supplementary Fig. 3. Percentage of customers with backup generation



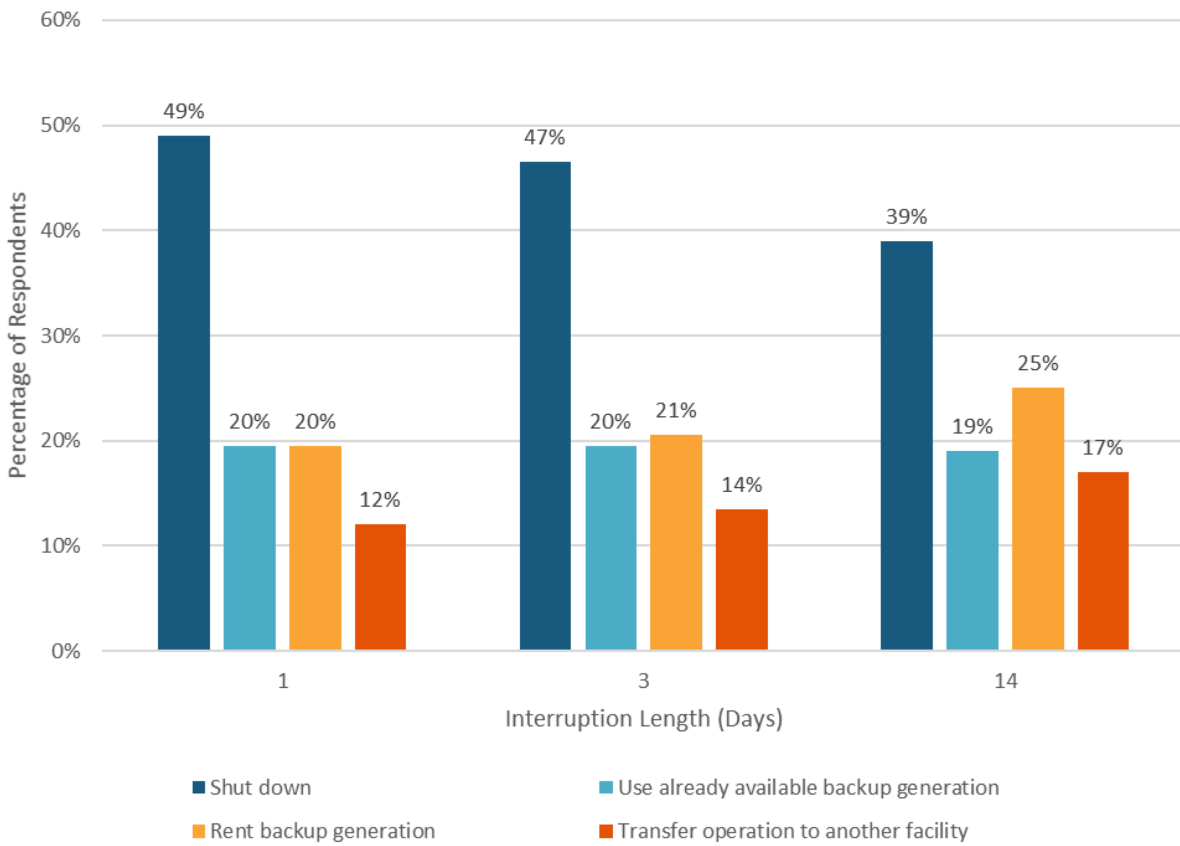
Supplementary Fig. 4. Fuel source for backup generators



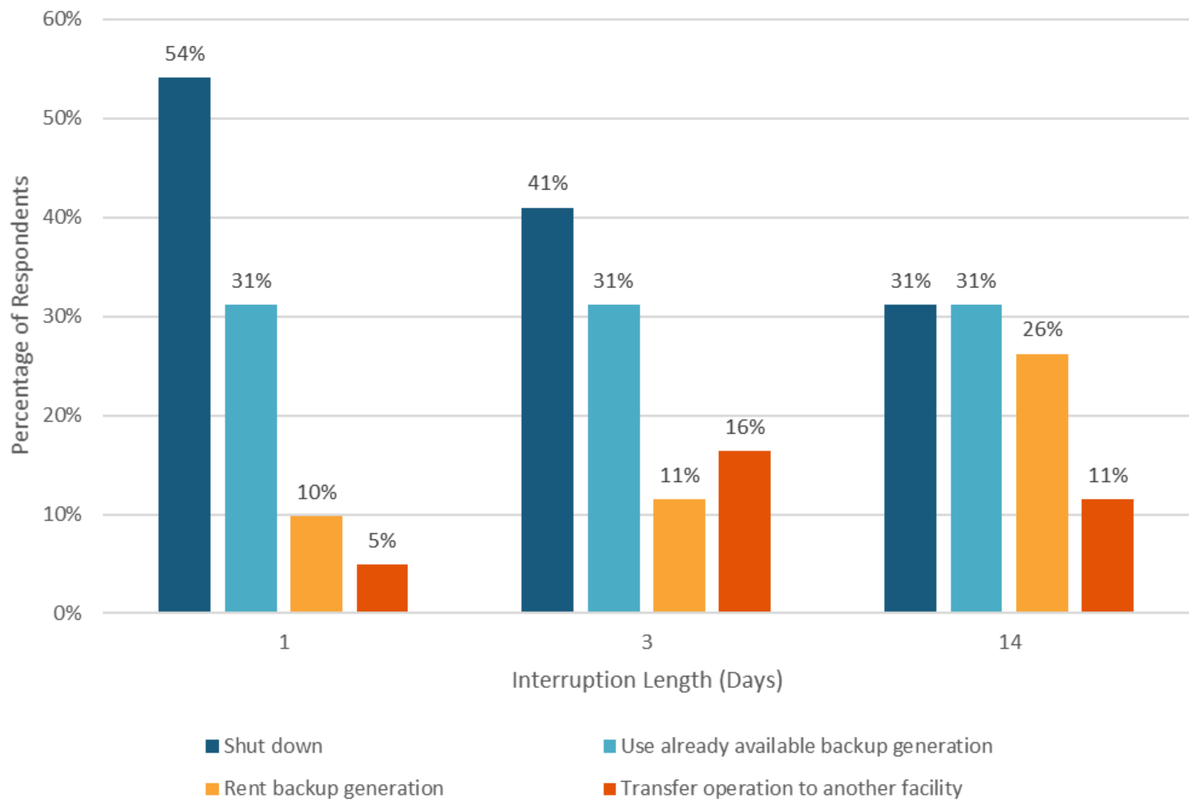
Supplementary Fig. 5. Residential resilience tactics by interruption duration



Supplementary Fig. 6. Residential resilience tactic by interruption duration and income level



Supplementary Fig. 7. SMB resilience tactic by interruption duration



Supplementary Fig. 8. LCI resilience tactic by interruption duration

D. Translating survey results into inputs to the CGE model

Residential customer information used for model calibration

Supplementary Table 10. Total number of households by income bracket by micro-region[2]

Micro regions: County or counties	Income <$50,000	Income $50,000-$100,000	Income >$100,000	Total
Cook	830,665	564,311	607,321	2,002,297
Dekalb and Kendall	26,624	28,090	30,021	84,735
DuPage	94,050	99,621	154,429	348,100
Grundy and Kankakee	24,299	21,044	16,390	61,733
Kane	57,100	54,950	68,542	180,592
Lake	72,035	68,961	108,674	249,670
McHenry	29,590	36,189	44,934	110,713
Will	65,391	73,371	96,328	235,090
Rural ComEd	154,589	112,753	75,304	342,646
All of ComEd	1,354,343	1,059,290	1,201,943	3,615,576

Note: Rural ComEd includes the following counties: Winnebago, Boone, Ford, La Salle, Lee, Stephenson, Jo Daviess, Carroll, Whiteside, Marshall, Ogle, Woodford, Bureau, Henry, and Livingston.

Supplementary Table 11. Counts and percentages of residential responses by income group and interruption duration (Base Case scenario)

Income group	1d	3d	14d	1d	3d	14d
	Count			Percentage		
	Tactic 1: Stay home and do activities that do not require electricity					
Income < $50,000	85	44	23	49%	25%	13%
Income $50,000 - $100,000	127	60	19	59%	28%	8.9%
Income > $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					
Income < $50,000	10	10	7	5.7%	5.7%	4.0%
Income $50,000 - $100,000	23	24	22	11%	11%	10%
Income > $100,000	43	42	26	17%	16%	10%
Refused to answer	29	24	18	16%	13%	9.7%
	Tactic 3: Temporarily move					
Income < $50,000	78	119	144	45%	68%	83%
Income $50,000 - $100,000	64	128	172	30%	60%	80%
Income > $100,000	67	154	217	26%	60%	85%
Refused to answer	66	119	149	36%	64%	81%
	Respondent did not select any resilience tactic					
Income < $50,000	1	1	0	0.6%	0.6%	0.0%
Income $50,000 - $100,000	0	2	1	0.0%	0.9%	0.5%
Income > $100,000	2	2	2	0.8%	0.8%	0.8%
Refused to answer	2	2	6	1.1%	1.1%	3.2%
	Total					
Income < $50,000	174	174	174	100%	100%	100%
Income $50,000 - $100,000	214	214	214	100%	100%	100%
Income > $100,000	256	256	256	100%	100%	100%
Refused to answer	185	185	185	100%	100%	100%
Grand total	829	829	829	100%	100%	100%

Supplementary Table 12. Key additional assumptions for calibrating residential sector shocks in the CGE model

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 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[3]. 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 Supplementary Table 13 below). 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).

Supplementary Table 13. Expenditures on petroleum products and associated transportation and trade margins[2]

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

Note: The table summarizes the division of expenditures on transportation fuels between the sector producing them (Petroleum Refineries) and the various margin sectors associated with the transportation and trade services to deliver and sell petroleum products.

Supplementary Table 14 presents the total costs incurred by residential customers in Cook County for the high backup generation scenario, calculated using eq. (1).

Supplementary Table 14. Total costs incurred by residential customers in Cook County by cost category and interruption duration (high backup generation scenario) ($ millions)

Cost category	1 day			3 day			14 day		
	< $50k	$50k - $100k	> $100k	< $50k	$50k - $100k	> $100k	< $50k	$50k - $100k	> $100k
Spoiled food (N)	79.9	81.0	93.7	71.0	70.3	72.3	38.8	13.8	0.0
Meal delivery (N)	1.1	1.5	3.1	3.5	8.6	8.8	4.5	2.9	0.0
Meals & transportation (N)	5.2	8.4	6.5	1.0	9.0	10.0	5.4	0.0	0.0
Fuel for generators (N)	0.5	1.2	2.3	1.3	2.9	6.2	4.5	13.2	17.5
Generator rental (N)	1.4	1.3	2.2	3.9	1.8	7.2	8.5	22.6	18.6
Evacuation/repatriation (N)	11.4	5.2	4.1	21.3	13.8	14.8	43.9	31.9	37.9
Avoided commuting (R)	-2.3	-1.1	-0.8	-10.9	-7.1	-7.6	-63.1	-45.9	-54.6
Meals & housing (R)	97.1	46.0	44.7	456.7	349.0	409.2	2613.1	2013.3	2781.8
Avoided food & beverages (R)	-14.5	-6.7	-5.3	-67.8	-43.9	-47.0	-391.5	-284.3	-338.3
Net income loss (N)	438.2	559.6	542.6	0.0	0.0	0.0	0.0	0.0	0.0
Total	618.1	696.5	693.2	480.0	404.5	473.8	2264.1	1767.6	2462.9

Notes: R = relocating households N = non-relocating households

Non-residential customer information used for model calibration

Since the magnitude of the costs/savings reported by the individual non-residential respondents vary substantially depending on the size of the business/enterprise, we normalized 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). Because more respondents answered questions on employment (n = 226) than on revenue (n = 133), we 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) in Supplementary Table 15.

Supplementary Table 15. 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

Supplementary Table 16. Total employment by sector and micro-region[2]

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
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

Supplementary Table 17. Counts and percentage of responses (in terms of number of employees) by industry and interruption duration (base case scenario)

		1d	3d	14d	1d	3d	14d
		Count total			Percentage total		
Industry sector		Tactic 1: Shut down their facility except for safety and security staff					
1	Agricultural, construction, mining	169	116	129	15%	10%	11%
2	Electricity, natural gas, 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	Telecoms, 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 svcs.	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%
Industry sector		Tactic 2: Continue to perform tasks that do not require electricity or operate on backup power systems					
1	Agricultural, construction, mining	111	118	102	10%	10%	9%
2	Electricity, natural gas, 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	Telecoms, 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 svcs.	100	83	93	5%	4%	5%
10	Government	269	229	193	2%	2%	2%
Subtotal		12,309	12,061	12,472	30%	29%	30%
Industry sector		Tactic 3: Temporarily shut down the facility until backup power systems can be rented					
1	Agricultural, construction, mining	34	45	66	3%	4%	6%
2	Electricity, natural gas, 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	Telecoms, 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 svcs.	63	94	382	3%	5%	20%
10	Government	24	432	497	0%	4%	4%
Subtotal		1,296	2,201	3,616	3%	5%	9%

		1d	3d	14d	1d	3d	14d
		Count total			Percentage total		
Industry sector		Tactic 4: Transfer operations to locations outside the area affected by the interruption					
1	Agricultural, construction, mining	850	885	867	73%	76%	74%
2	Electricity, natural gas, 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	Telecoms, 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 svcs.	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%
Industry sector		Total: All tactics					
1	Agricultural, construction, mining	1,164	1,164	1,164	100%	100%	100%
2	Electricity, natural gas, 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	Telecoms, 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 svcs.	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%

Supplementary Table 18. Key additional assumptions for calibrating shocks to industries in the CGE model

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.

Supplementary Table 19 presents the total costs incurred by the non-residential customers in Cook County for the high backup generation scenario, calculated using eq. (2).

Supplementary Table 19. Total costs incurred by non-residential customers in Cook County by cost category and interruption duration (high backup generation scenario) ($ millions)

Cost category	Agriculture + Construction + Mining	Electricity + Gas + Water	Manu-facturing	Wholesale trade + Transport	Retail	Telecomms + finance + data proc.	Education	Hospitals	Restaurants + Entertainment + Other	Government
				1 day						
Overtime pay for recapture	11.6	2.6	36.7	19.8	8.3	6.1	0.2	0.0	18.7	9.6
Petroleum cost for generators	1.6	8.8	4.8	1.0	2.2	25.2	0.1	0.7	2.2	0.9
Natural gas cost for generators	0.9	0.1	0.0	0.7	0.1	22.6	0.0	0.6	1.3	0.8
Generator rental cost	0.5	10.6	5.8	0.0	2.6	1.2	0.2	0.0	0.3	0.0
Production relocation cost	17.4	0.0	0.0	0.1	1.6	0.0	0.0	0.0	0.0	0.0
Additional recapture costs	0.5	0.0	3.2	4.7	0.4	14.2	1.6	0.0	2.9	0.4
Cost to restore operations	0.0	0.0	57.7	26.0	171.0	7.9	0.2	0.0	33.9	29.0
Safety + security costs	0.3	0.0	13.0	3.2	0.0	15.2	1.4	0.0	6.8	0.4
Inventory/feedstock losses	12.0	0.0	116.9	713.2	70.9	3.2	5.2	0.0	117.5	36.0
Total	44.8	22.2	238.0	768.8	257.0	95.7	9.0	1.3	183.6	77.1
				3 day						
Overtime pay for recapture	46.2	0.0	244.4	85.8	26.2	94.3	1.7	0.0	27.1	15.0
Petroleum cost for generators	7.0	26.5	20.1	4.4	13.4	47.5	0.5	2.1	10.7	1.9
Natural gas cost for generators	5.1	0.4	0.9	2.9	2.2	38.5	0.0	1.9	6.1	1.6
Generator rental cost	1.1	31.9	22.9	0.0	12.4	7.0	0.6	0.0	4.0	0.2
Production relocation cost	18.8	0.0	16.8	17.3	0.0	210.7	0.7	0.0	0.0	17.0
Additional recapture costs	1.0	0.0	13.8	24.9	11.5	58.2	2.9	0.0	0.0	0.0
Cost to restore operations	0.6	0.0	52.9	224.8	241.3	29.4	4.5	0.0	69.1	0.4
Safety + security costs	1.1	0.0	11.6	149.0	21.5	73.1	2.7	0.0	35.7	0.3
Inventory/feedstock losses	112.9	0.0	97.7	404.4	51.2	469.3	5.4	0.0	342.2	0.4
Total	145.2	58.8	464.1	890.9	369.4	922.3	19.2	4.0	478.1	36.8
				14 day						
Overtime pay for recapture	25.6	0.0	54.7	162.8	113.2	90.9	5.8	0.0	411.7	92.2
Petroleum cost for generators	32.9	68.4	44.5	150.1	75.3	324.8	8.7	9.8	53.9	18.6
Natural gas cost for generators	23.8	1.3	6.9	23.5	5.7	240.7	0.7	8.9	28.6	15.3
Generator rental cost	2.1	81.9	41.7	141.4	84.6	85.2	9.4	0.0	21.9	2.6
Production relocation cost	15.2	0.0	25.6	3.9	0.0	121.0	0.1	0.0	14.6	82.5
Additional recapture costs	0.8	0.0	6.6	24.2	77.5	192.8	4.1	0.0	20.9	0.4
Cost to restore operations	11.6	0.0	7.3	428.5	123.6	146.1	21.1	0.0	51.9	0.3
Safety + security costs	4.6	0.0	2.6	234.4	32.4	358.9	5.4	0.0	24.4	0.0
Inventory/feedstock losses	4.9	0.0	12.8	3511.8	29.0	362.7	11.9	0.0	178.9	0.6
Total	121.4	151.5	202.7	4680.5	541.3	1923.1	67.0	18.7	806.8	212.6

Construction of shocks to households and sectors in the CGE model

Supplementary Table 20. 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-interruption 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 interruptions 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 interruption 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.

Supplementary Table 21. 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%)
	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 interruption periods	Agriculture Food products Food & beverage stores Restaurants
	Avoided transportation	Average household expenditures on Transportation, Petroleum over the interruption periods	Transportation Petroleum

Supplementary Table 22. 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
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

Design, construction, and application of a static CGE simulation model

This section 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.

Supplementary Table 23. CGE model micro-regions

Regions and constituent counties	
Cook	
Dekalb and Kendall	
DuPage	
Grundy and Kankakee	
Kane	
Lake	
McHenry	
Will	
Rural ComEd	Winnebago, Boone, Ford, LaSalle, Lee, Stephenson, Jo Daviess, Carroll, Whiteside, Marshall, Ogle, Woodford, Bureau, Henry, and Livingston
Illinois counties adjacent to ComEd	Iroquois, McLean, Tazewell, Peoria, Stark, Putnam, Rock Island, Mercer, Knox, and Champaign
Remainder of Illinois counties	
Indiana counties adjacent to ComEd	Porter, Newton, Lake, and Jasper
Remainder of Indiana counties	
Wisconsin counties adjacent to ComEd	Kenosha
Remainder of Wisconsin counties	

Supplementary Table 24. CGE model sectoring scheme

Sectors used in customer surveys	CGE model sectors
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
	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

Sectors used in customer surveys	CGE model sectors
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	Government

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 (Supplementary Table 23) and sector j (Supplementary Table 24), 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 non-residential 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:

$$PY_{j,r} \leq ({\Omega_{j,r}}^Y)^{-1}[{\alpha_{KLZ,j,r}}^{\sigma_Y} {PKLZ_{j,r}}^{1-\sigma_Y} + {\alpha_{V,j,r}}^{\sigma_Y} {PVN_{j,r}}^{1-\sigma_Y} + \textstyle\sum_i {\vartheta_{i,j,r}}^{\sigma_Y} {PA_{i,r}}^{1-\sigma_Y}]^{\frac{1}{1-\sigma_Y}} \quad \text{(S1a)}$$

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:

$$PKLZ_{j,r} \leq [\alpha_{KL,j,r}{}^{\sigma_{KLZ}} PKL_{j,r}{}^{1-\sigma_{KLZ}} + \alpha_{Z,j,r}{}^{\sigma_{KLZ}}\, PZF_{j,r}{}^{1-\sigma_{KLZ}}]^{1/(1-\sigma_{KLZ})} \tag{S1b}$$

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:

$$PKL_{j,r} \leq [\alpha_{K,j,r}{}^{\sigma_{KL}} PK_{j,r}{}^{1-\sigma_{KL}} + \alpha_{L,j,r}{}^{\sigma_{KL}}\, PL_{j,r}{}^{1-\sigma_{KL}}]^{1/(1-\sigma_{KL})} \tag{S1c}$$

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 $PA_{i,r}$):

$$PZF_{j,r} \leq [\textstyle\sum_{i\neq\{EGEN,ETD\}} \alpha_{i,j,r}{}^{\sigma_Z} PA_{i,r}{}^{1-\sigma_Z}]^{1/(1-\sigma_Z)} \tag{S1d}$$

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 non-residential electricity interruption is that lifeline inputs are assumed to enter into a Leontief fixed-coefficient relationship with a non-residential 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:

$$PVN_{j,r} \leq \alpha_{FF} PFF_{\chi(j),r} + \alpha_{Elec,r}[\textstyle\sum_{i\in\{EGEN,ETD\}} \alpha_{i,j,r}{}^{\sigma_V} PA_{i,r}{}^{1-\sigma_V}]^{1/(1-\sigma_V)} \tag{S1e}$$

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 non-residential electricity service demanded is competitively determined via sectors' cost minimization behavior. An interruption 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 non-residential interruption 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 formulation[4], 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:

$$PYT_{i,r} \geq [\beta_{XCA,i}{}^{\eta_{X.i}} PUS_i{}^{1+\eta_{X.i}} + \beta_{XF,i}{}^{\eta_{X.i}}\ PFX^{1+\eta_{X.i}}]^{1/(1+\eta_{X.i})} \tag{S2a}$$

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

$$PM_{i,r} \leq [\beta_{MUS,i,r}{}^{\sigma_{MM,i}} PUS_i{}^{1-\sigma_{MM,i}} + \beta_{MF,i,r}{}^{\sigma_{MM,i}}\ PFX^{1-\sigma_{MM,i}}]^{1/(1-\sigma_{MM,i})} \tag{S2b}$$

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

$$PA_{i,r} \leq [\beta_{D,i,r}{}^{\sigma_{DM,i}} PY_i{}^{1-\sigma_{DM,i}} + \beta_{M,i,r}{}^{\sigma_{DM,i}}\ PM^{1-\sigma_{DM,i}}]^{1/(1-\sigma_{DM,i})} \tag{S2c}$$

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:

$$\sum_r QXUS_{i,r} \geq \sum_r QMUS_{i,r} + QBUS_i \;\Rightarrow \sum_r \frac{\partial PYT_{i,r}}{\partial PUS_i} QX_{i,r} \;\geq \sum_r \frac{\partial PM_{i,r}}{\partial PUS_i} QM_{i,r} + QBUS_i \tag{S2d}$$

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

$$\sum_r QXF_{i,r} \geq \sum_r QMF_{i,r} + QBF_i \;\Rightarrow \sum_r \frac{\partial PYT_{i,r}}{\partial PF_i} QX_{i,r} \;\geq \sum_r \frac{\partial PM_{i,r}}{\partial PFX} QM_{i,r} + QBF_i \tag{S2e}$$

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 $PVR_{h,r}$):

$$PU_{h,r} \leq [\gamma_{Z,h,r}{}^{\sigma_U} PZC_{h,r}{}^{1-\sigma_U} + \gamma_{V,h,r}{}^{\sigma_U}\, PVR_{h,r}{}^{1-\sigma_U} + \sum_i \varpi_{i,h,r}{}^{\sigma_U} PA_{i,r}{}^{1-\sigma_U}]^{1/(1-\sigma_U)} \tag{S3a}$$

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 $PA_{i,r}$):

$$PZC_{h,r} \leq [\sum_{i \neq \{EGEN,ETD\}} \gamma_{i,h,r}{}^{\sigma_C} PA_{i,r}{}^{1-\sigma_C}\,]^{1/(1-\sigma_C)} \tag{S3b}$$

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 interruption 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:

$$PVR_{h,r} \leq \gamma_{FF,r} PFF_{Residential,r} + \gamma_{Elec,r}[\sum_{i \in \{EGEN,ETD\}} \gamma_{i,h,r}{}^{\sigma_C} PA_{i,r}{}^{1-\sigma_C}]^{1/(1-\sigma_V)} \tag{S3c}$$

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 interruption.

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 $PVG_{g,r}$)

$$PG_{g,r} \leq [\ \delta_{Z,g,r}{}^{\sigma_G} PZG_r{}^{1-\sigma_G} \ + \ \delta_{V,g,r}{}^{\sigma_G} PVG_{g,r}{}^{1-\sigma_G}]^{1/(1-\sigma_G)} \tag{S3d}$$

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 $PA_{i,r}$):

$$PZG_{g,r} \leq [\textstyle\sum_{i \neq \{EGEN,ETD\}} \delta_{i,g,r}{}^{\sigma_Z}\ PA_{i,r}{}^{1-\sigma_Z}]^{1/(1-\sigma_Z)} \tag{S3e}$$

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 interruption is modeled in a manner identical to industries and households, given by the cost function:

$$PVG_{g,r} \leq \delta_{FF,r} PFF_{Commercial,r} + \delta_{Elec,r}[\textstyle\sum_{i \in \{EGEN,ETD\}} \delta_{i,G,g,r}{}^{\sigma_V}\ PA_{i,r}{}^{1-\sigma_V}]^{1/(1-\sigma_V)} \tag{S3f}$$

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 interruption.

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

$$PI_{g,r} \leq [\textstyle\sum_i \gamma_{i,I,r}{}^{\sigma_I}\ PA_{i,r}{}^{1-\sigma_I}]^{1/(1-\sigma_I)} \tag{S3g}$$

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

$$QI_r \leq \textstyle\sum_h QS_{h,r}$$

(S3h)

while a fixed MPS implies a constant of proportionality, $\mu_{h,r}$, which allows households' savings to scale with their overall activity (utility) levels:

$$QS_{h,r} \leq \mu_{h,r} S_{h,r} \tag{S3i}$$

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:

$$QG_{g,r} \leq (\xi_{g,r} \sum_j \tau_{j,r}{}^Y PY_{j,r} QY_{j,r} + PFX \cdot GXFER_{g,r})/PG_{g,r} \tag{S3h}$$

The supply-demand balance for domestic output is given by

$$QY_{i,r} \geq QD_{i,r} + QX_{i,r} \tag{S3i}$$

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:

$$QM_{i,r} \geq \frac{\partial PA_{i,r}}{\partial PM_{i,r}} QA_{i,r} \tag{S3j}$$

Finally, the supply-demand balance for Armington commodities is closed via the condition

$$QA_{i,r} \geq \sum_j q_{i,F,j,r} + \sum_h q_{i,C,h,r} + \sum_g q_{i,G,g,r} + q_{i,I,r} + \sum_j \Omega_{i,j,r}{}^F + \sum_h \Omega_{i,h,r}{}^C \tag{S3k}$$

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:

$$q_{i,F,j,r} = \begin{cases} \frac{\partial PZF_{j,r}}{\partial PA_{i,r}} QZF_{j,r} \\ \frac{\partial PVN_{j,r}}{\partial PA_{i,r}} QVN_{j,r} \end{cases}, q_{i,C,h,r} = \begin{cases} \frac{\partial PZC_{h,r}}{\partial PA_{i,r}} QZC_{h,r} \\ \frac{\partial PVR_{h,r}}{\partial PA_{i,r}} QVR_{h,r} \end{cases}, q_{i,G,g,r} = \begin{cases} \frac{\partial PZG_{g,r}}{\partial PA_{i,r}} QZG_{g,r} \; i \neq \{EGEN, ETD\} \\ \frac{\partial PVG_{g,r}}{\partial PA_{i,r}} QVG_{g,r} \; i \in \{EGEN, ETD\} \end{cases}$$

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. (S3k), 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 ($\underline{\varepsilon}_{K,j,r}$):

$$\underline{\varepsilon}_{K,j,r} \ \geq \frac{\partial PKL_{j,r}}{\partial PK_{j,r}} QKL_{j,r} + {\Omega_{j,r}}^K \qquad \text{(S4a)}$$

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

$$PW \geq [\ \textstyle\sum_j \sum_r {\lambda_{j,r}}^{\eta_L} {PL_{j,r}}^{1+\eta_L}\ ]^{1/(1+\eta_L)} \qquad \text{(S4b)}$$

Labor supply-demand balance at the macro-regional level is given by:

$$\underline{\varepsilon}_L \ \geq \textstyle\sum_j \sum_r (QL_{j,r} + {\Omega_{j,r}}^L) \qquad \text{(S4c)}$$

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

$$\sum_j PK_{j,r}\zeta_{K,h,r}\underline{\varepsilon}_{K,j,r} + W\zeta_{L,h,r}\left(\underline{\varepsilon}_L - \Omega_{h,r}{}^{Inc}\right) + PFX \cdot HXFER_{h,r}$$
$$\geq PU_{h,r}U_{h,r} + PI_r QS_{h,r} + \sum_i PCA_i SA_{i,h,r} \tag{S4d}$$

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:

$$\sum_i PUS_i(QBUS_i + \sum_r PUS_i(QXUS_{i,r} - QMUS_{i,r})) + \sum_i PFX(QBF_i + \sum_r(QFX_{i,r} - QMF_{i,r}))$$
$$+ \sum_g \sum_r GXFER_{g,r} + \sum_h \sum_r HXFER_{h,r} = 0 \tag{S4e}$$

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 (S2a) and (S2b): $QXUS_{i,r} = \frac{\partial PYT_{i,r}}{\partial PUS_i}$, $QMUS_{i,r} = \frac{\partial PM_{i,r}}{\partial PUS_i}$, $QXF_{i,r} = \frac{\partial PYT_{i,r}}{\partial PFX}$ 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. (S1)-(S4) 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 three-month electricity supply, specified in the disruption scenarios described in the main text.

The consequence of disruptions is that customers consume smaller quantities of electricity distribution service at higher prices. Following earlier research[5], 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. (S1e) and (S3f) drives a wedge between the Armington price of electricity distribution service and the corresponding price at which that service is consumed by residential and non-residential customers. Introducing the calibration factor $\psi{\sim}10^{-3}$, the benchmark supply of electricity service fixed factor capital is calibrated as

$$\underline{\varepsilon}_{FF,Industrial,r} = \psi \sum_{j \in Industrial} \underline{QVN}_{j,r}$$
$$\underline{\varepsilon}_{FF,Commercial,r} = \psi \left(\sum_{j \in Commercial} \underline{QVN}_{j,r} + \sum_g \underline{QVG}_{g,r} \right)$$
$$\underline{\varepsilon}_{FF,Residential,r} = \psi \sum_h \underline{QVR}_{h,r} \tag{S5a}$$

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 interruptions 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:

$$(1 - o_{Industrial,r})\underline{\varepsilon}_{FF,Industrial,r} = \sum_{j \in Industrial} \frac{\partial PVN_{j,r}}{\partial PFF_{Industrial,r}} \underline{QVN}_{j,r}$$

$$(1 - o_{Commercial,r})\underline{\varepsilon}_{FF,Commercial,r} = \sum_{j \in Commercial} \frac{\partial PVN_{j,r}}{\partial PFF_{Commercial,r}} \underline{QVN}_{j,r} + \sum_{g} \frac{\partial PVG_{g,r}}{\partial PFF_{Commercial,r}} \underline{QVG}_{g,r}$$

$$(1 - o_{Residential,r})\underline{\varepsilon}_{FF,Residential,r} = \sum_{h} \frac{\partial PVR_{h,r}}{\partial PFF_{Residential,r}} \underline{QVR}_{h,r} \quad \text{(S5b)}$$

S.5.6 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, summarized in Summary Table 25, are imposed exogenously, with values calculated as described in Tables 1 and 2 in the main text.

Supplementary Table 25. 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 ($\Omega_{i,h,r}{}^{C}$)	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
Non-residential: firm intermediate input	Petroleum	Fuel cost of backup generation
	Natural Gas	Fuel cost of backup generation

A. Secular commodity demand shocks		
Customer segment	Commodity shock (i)	Constituent additional impacts
by sector ($\Omega_{i,j,r}{}^{F}$)	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 ($\Omega_{h,r}{}^{Inc}$)	Forgone income
Non-residential	Firm productivity ($\Omega_{j,r}{}^{Y}$)	Revenue recapture - Additional costs of recapture - Cost to restore operations - Damage to inventories/feedstocks
	Firm capital demand ($\Omega_{j,r}{}^{K}$)	Cost of backup generation: generators
	Firm labor demand ($\Omega_{j,r}{}^{L}$)	Cost of overtime pay for recapture

Model calibration, formulation, solution, and application

The vectors of technical coefficients $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$ in eqs. (S1)-(S4), and the benchmark endowments, $\underline{\varepsilon}_{K,j,r}$ and $\underline{\varepsilon}_{L,r}$, in eq. (4) are calibrated using IMPLAN county social accounting matrices for Illinois, Indiana and Wisconsin for the year 2019[2], 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[6,7]and is solved using the PATH solver[8].

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Supplementary notes

Example of informed consent provided to survey respondents

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.

How long will the survey take? The survey will take approximately 20-25 minutes to complete.

Who is eligible to complete the survey? To take part in the study, you must be at least 25 years old, have lived in ComEd service territory for two years or more (it's okay if you moved within the service territory during that time), and be aware of, or responsible for, your home's electricity bills.

How does the study work? 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.

How do we protect your privacy? The answers you provide will be kept strictly confidential and anonymized. Participants' names, other identifiers, and any private or sensitive information shared in the survey will be immediately removed before any analysis is performed. This process will help protect your private or sensitive information.

What are the benefits of this study? This study will help researchers understand how much ComEd customers value their electricity service during outages and how valuable it is to customers to avoid outages. The study will also give you a chance to think about how you can prepare for future power outages.

YOUR PARTICIPATION IS VOLUNTARY, AND YOUR RESPONSES WILL BE ANONYMOUS. You have the right to not take part in this study or to stop taking part at any time. By participating in this study, you are not waiving any legal claims or rights to which you are otherwise entitled. If you choose to withdraw from this study, you may do so at any time and ask for your records to be destroyed. Once the survey is closed and data is de-identified, we cannot remove your records from the dataset as the data cannot identify a specific individual. You may be asked to participate in additional research in the future, but you will be free to refuse to do so. This study has been approved by the LBNL's Institutional Review Board (Pro00023221). 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. By completing this survey, you are consenting to participate in this study.