Estimating the Economic Impacts of Power Interruptions (or the Value of Reliability/Resilience)

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ICE Calculator estimates customer costs of shorter duration interruptions

- Berkeley Lab's Interruption Cost Estimate (ICE) Calculator is the leading and only publicly-available tool for estimating the customer cost impacts of power interruptions

- Development of the ICE Calculator was sponsored by the US Department of Energy (DOE)

- ICE Calculator is being used to:
  - Support internal utility reliability planning activities
  - Provide a basis for discussing utility reliability investments with regulators
  - Assess the economic impact of past power outages

http://www.icecalculator.com/

Public-private partnership to update the ICE Calculator

- The ICE Calculator is based on utility-sponsored customer surveys
- Reliance on the ICE Calculator has been challenged because the surveys are:
  - Dated—many of the surveys are 25+ years old
  - Not statistically representative of all regions of the U.S.
  - Not appropriate for estimating costs of widespread, long-duration (> 24 hour) interruptions

Utility Company	Survey Year	Number of Observations			Min. Duration (Hours)	Max. Duration (hours)
		Medium and Large C&I	Small C&I	Residential		
Southeast-1	1997	90			0	1
Southeast-2	1993	3,926	1,559	3,107	0	4
	1997	3,055	2,787	3,608	0	12
Southeast-3	1990	2,095	765		0.5	4
	2011	7,941	2,480	3,969	1	8
Midwest-1	2002	3,171			0	8
Midwest-2	1996	1,956	206		0	4
West-1	2000	2,379	3,236	3,137	1	8
West-2	1989	2,025	5		0	4
	1993	1,790	825	2,005	0	4
	2005	3,052	3,223	4,257	0	8
	2012	5,342	4,632	4,106	0	24
Southwest	2000	3,991	2,247	3,598	0	4
Northwest-1	1989	2,210		2,126	0.25	8
Northwest-2	1999	7,091		4,299	0	12

With encouragement and support from the U.S. DOE, Berkeley Lab is updating the ICE Calculator through direct funding by sponsoring U.S. utilities.

Updating and upgrading the ICE Calculator

Berkeley Lab/Resource Innovations and sponsoring utilities will:

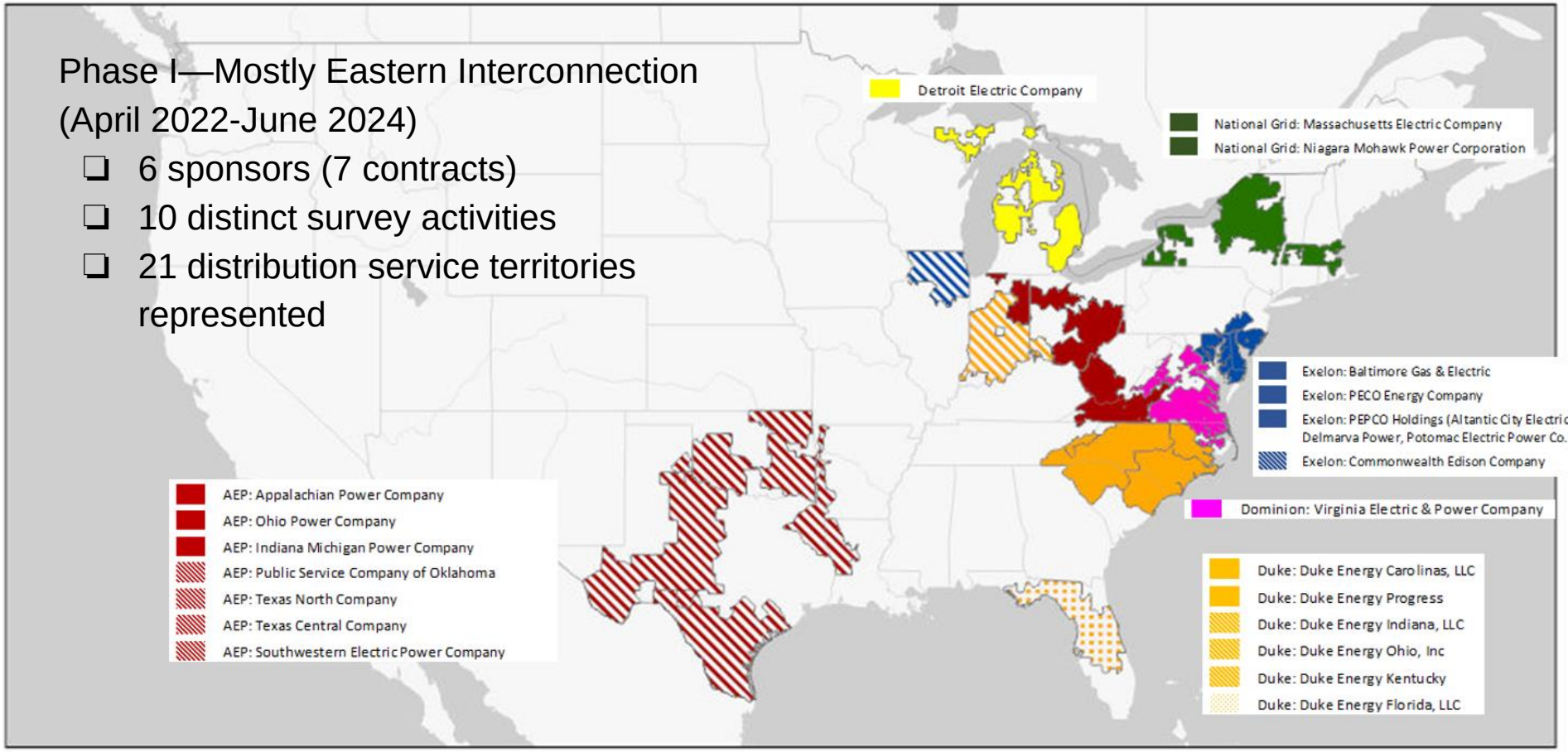
- ❑ Develop a consistent set of short duration (< 24 hours), customer interruption cost survey questions
- ❑ Coordinate administration of surveys to representative samples of sponsoring utility's customers
- ❑ Update ICE Calculator with new survey information as well as other suggested improvements to its design/performance

Organization	Roles and Responsibilities
Berkeley Lab and Resource Innovations	• Develop survey instrument and survey administration protocols • Conduct pre-testing and administer surveys • Process survey data • Produce utility-specific report of survey findings • Upgrade ICE Calculator with new survey information and enhanced functionalities
Sponsoring utilities	• Provide funding • Support sampling of customers and survey administration • Provide guidance on improvements to ICE Calculator functionalities

ICE Calculator upgrade being completed in two phases

Phase I—Mostly Eastern Interconnection
(April 2022-June 2024)

- ❑ 6 sponsors (7 contracts)
- ❑ 10 distinct survey activities
- ❑ 21 distribution service territories represented



Phase II—Mostly Western Interconnection
(January 2023-June 2025)

- ❑ Signed contract with **Puget Sound Energy**
- ❑ Signed contract with **Ameren (MO)**
- ❑ Active discussions with **four additional utilities and two ISOs**

Please contact me if you would like to learn more about sponsoring the ICE Calculator 2.0 initiative.

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Introduction

- Berkeley Lab, in conjunction with ComEd, has demonstrated an innovative new tool that estimates the regional economic impacts of widespread and long-duration (WLD) power interruptions

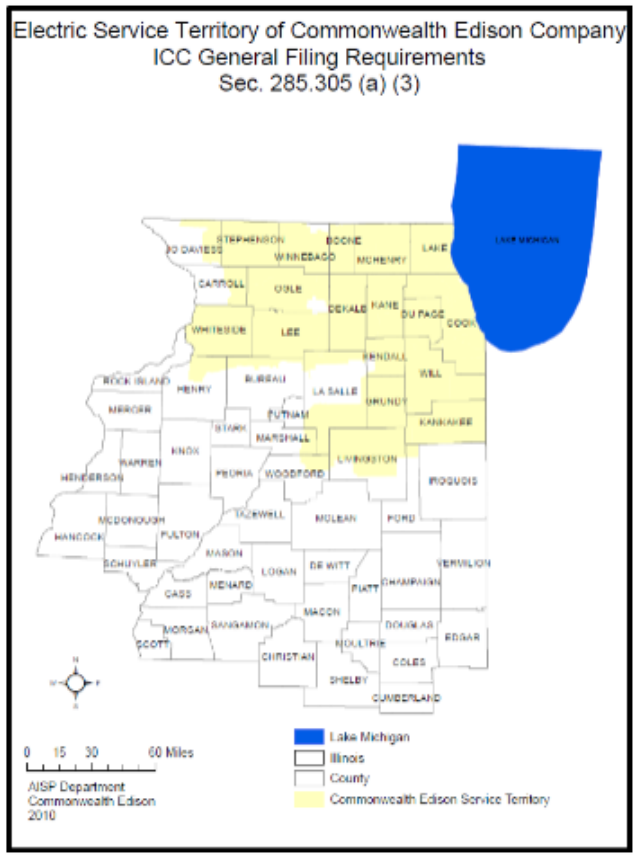
- The Power Outage Economics Tool or "POET" is a state-of-the-art, regional economic model that incorporates both survey information on ComEd customers' preparedness for WLD power interruptions and economic information for a three state region that includes and surrounds ComEd's service territory

- This demonstration estimated the economic impacts from one, three, and 14 day power interruptions of varying geographic extents centered within the ComEd service territory, including the reductions in these impacts that could result from increased backup generation deployed by customers

- **POET could be replicated in other parts of the country to estimate the costs of WLD power interruptions and the economic value of investments in power system resilience**

Key research questions

- What are the impacts of WLD power interruptions on the regional economy?
- Which industrial sectors experience the largest impacts from power interruptions?
- Which regions experience the largest impacts from power interruptions?
- Which sector-region combinations are most vulnerable to WLD power interruptions?
- How do the impacts vary by household income group?
- To what extent can backup generation mitigate economic impacts of WLD power interruptions?



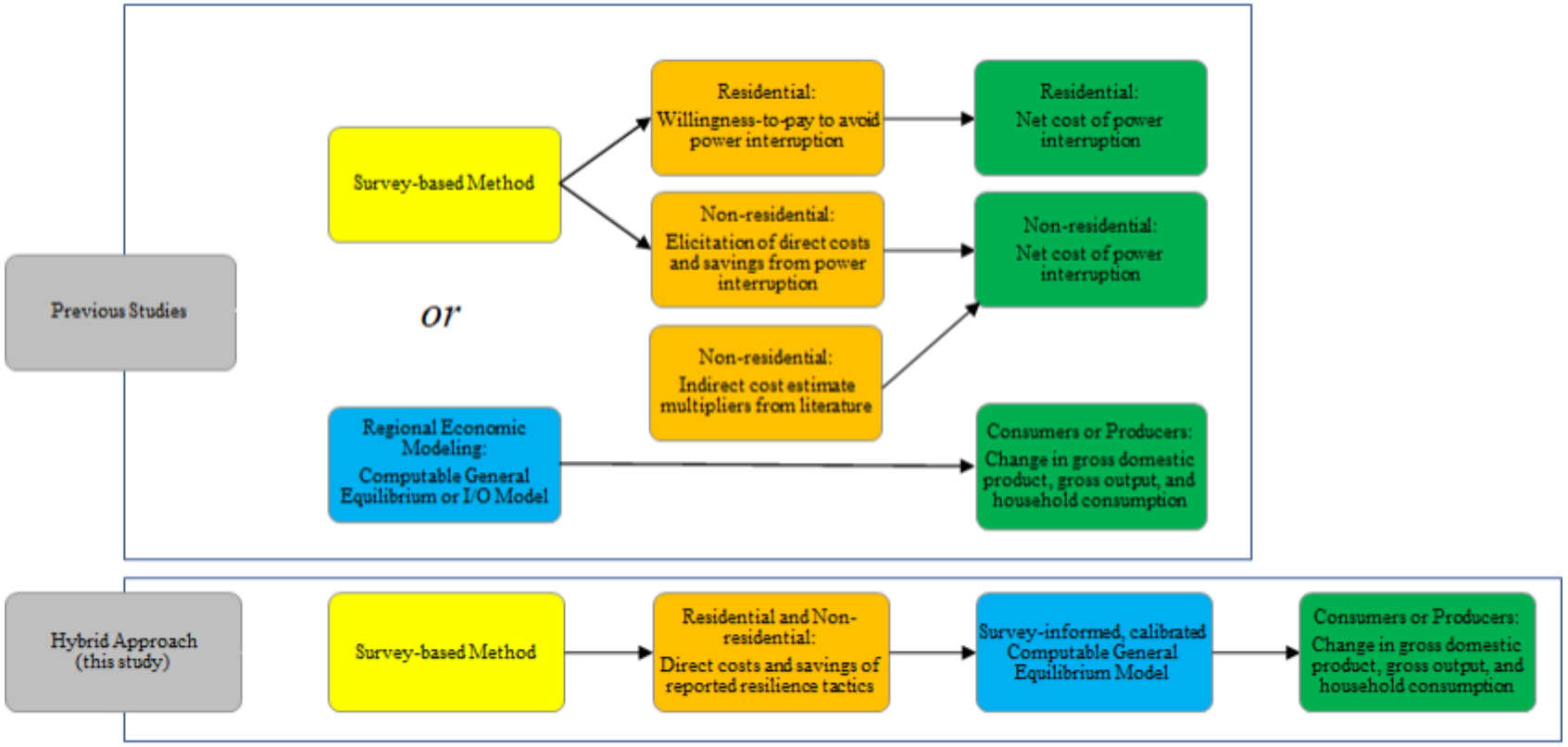
POET addresses a gap in current approaches for estimating the economic costs of WLD power interruptions

- Customer interruption cost (CIC) surveys have been widely used to estimate direct power interruption costs, but they are limited in their applicability for WLD power interruptions because it is difficult for respondents to estimate direct and spillover impacts across industry sectors and regional economies.
- Computable General Equilibrium (CGE) models can estimate these direct and spillover impacts, but they must rely on assumptions about household and firm behaviors that are difficult to observe.

	CIC Surveys	CGE Models
Pros	• Well suited for gathering information on costs of short and localized power interruptions and ancillary information • Do not rely on other data or assumptions • Results are easy to understand for utilities, regulators, and lay audience	• Can measure sector-level impacts • Can estimate spillover impacts of power interruptions • Can re-evaluate impacts for a range of resilience options
Cons	• Significant effort and resources required to conduct surveys • Possible cognitive biases • Potential difficulties in understanding the consequences of WLD power interruptions without adequate assistance • Cannot estimate cascading economic impacts between businesses and across industries	• Significant data requirements • Involve a complex mathematical formulation that is difficult to model, analyze, and interpret by utilities, regulators, and lay audience • Rely on key assumptions and parameters that have not been empirically validated

POET is a hybrid valuation approach

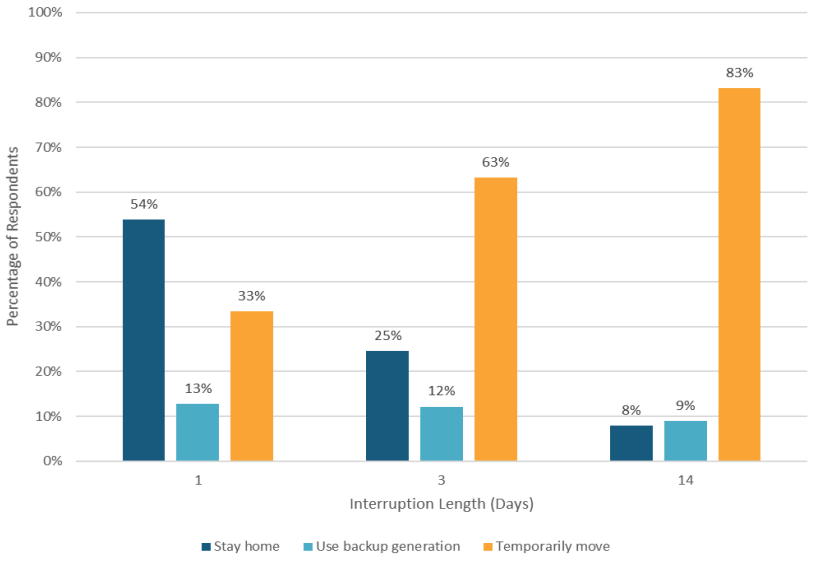
- POET's hybrid valuation approach relies on CIC surveys to collect information on household and firm behaviors and then uses this information used to calibrate a CGE model
- The resulting valuation estimates are, therefore, both grounded empirically and based on a consistent, integrated representation of the functioning of a regional economy



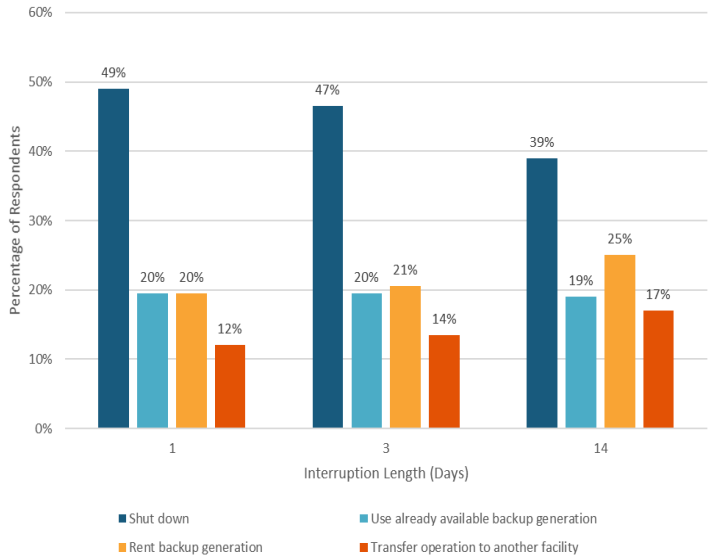
Survey finding #1: Resilience tactics change based on interruption duration

- About half of the survey respondents indicated that they would choose to remain at home or temporarily shut down the facility during short-duration power interruptions
- The majority of residential survey respondents indicated that they would temporarily relocate during longer-duration power interruptions
- Non-residential survey respondents indicated that they would either rent backup generation or transfer operations during longer-duration power interruptions

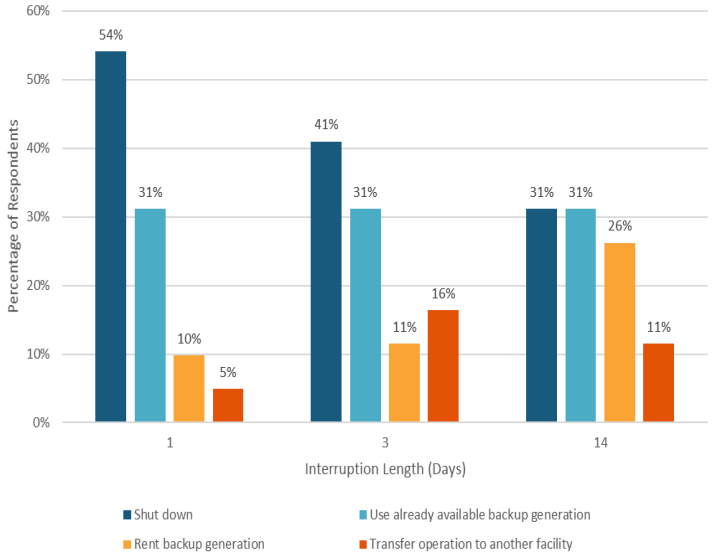
Residential



Small/Medium Business (SMB)



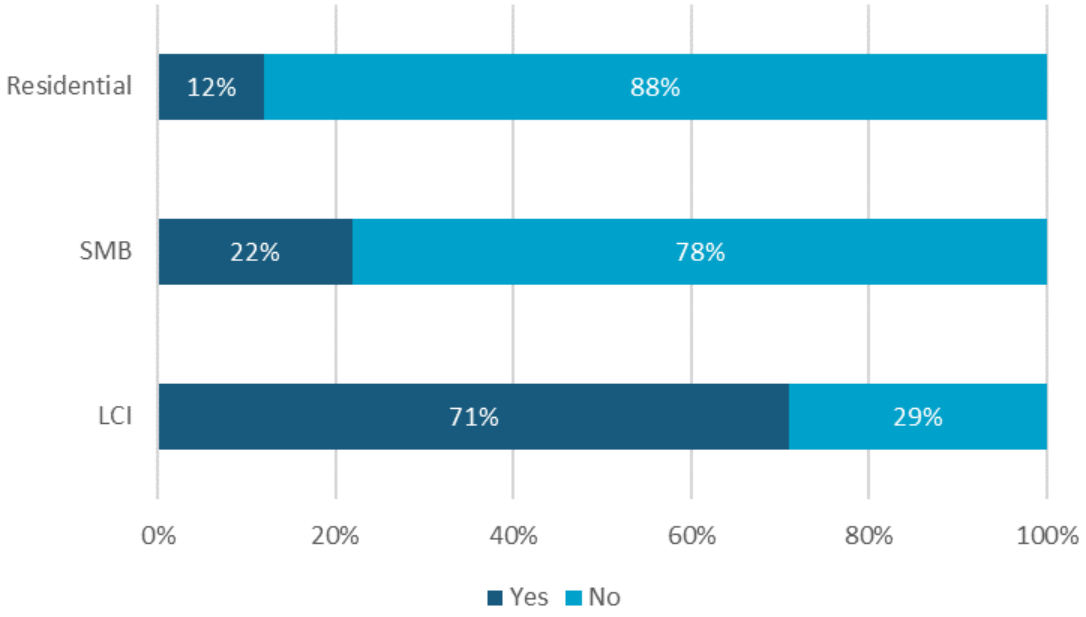
Large Commercial & Industrial (LCI)



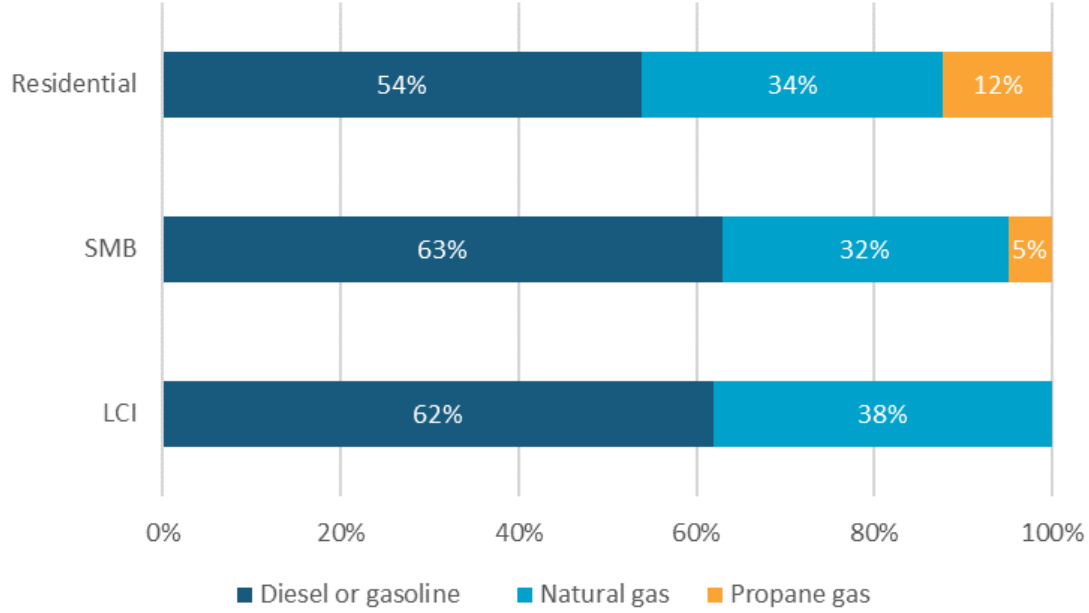
Survey finding #2: Most LCI customers have backup generation capabilities

- Large commercial and industrial (LCI) customers are more likely to have backup generation than residential and small-medium business (SMB) customers
- The most common fuel source for all three customer groups is diesel or gasoline

% customers with backup generation

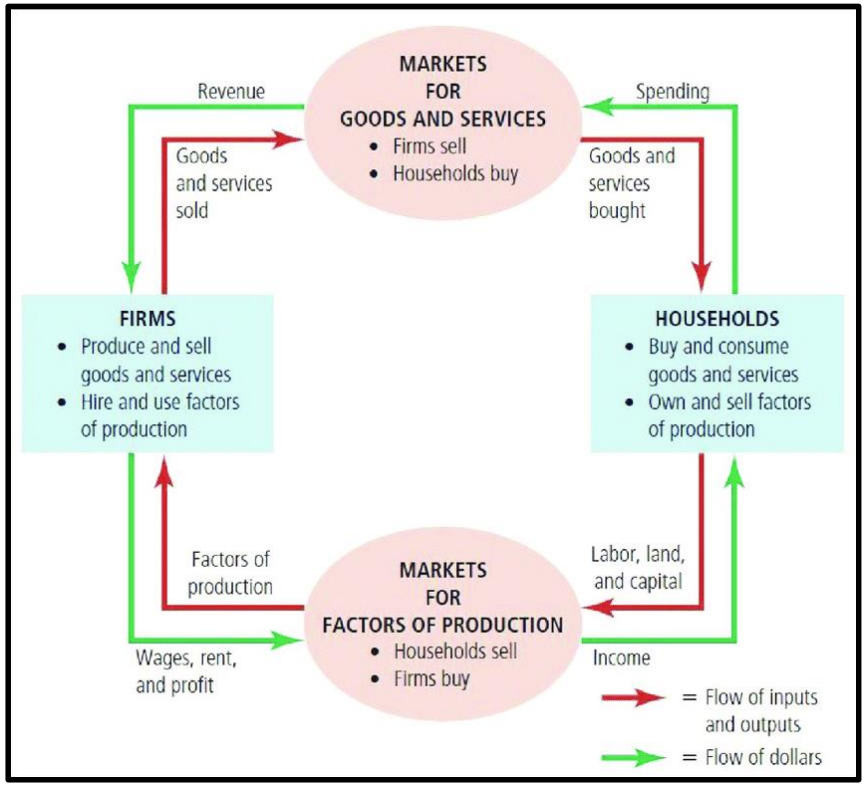


Fuel source for backup generators



Computable general equilibrium model calibrated with survey responses

- CGE is a stylized computational representation of the flow of dollars or inputs/outputs among sectors within the economy
  - Households are endowed with factors of production to firms
  - Firms use these factors to produce outputs
  - Households purchase goods from firms with money earned from selling factors of production
- Power interruptions involve both curtailment in the availability of electricity and resulting disruptions in market function
- CGE simulates the equilibrium states of the regional economy in the Upper Midwest tri-state area (IL-IN-WI) roughly 3 months after the "shock" caused by the power interruption
- All results are compared to a "business as usual" (BaU) representing three months' of economic activity without a power interruption



Source: Mankiw (2021)

Modeled scenarios and impact metrics

- POET was used to evaluate three WLD power interruptions (one-day, three-day, 14-day), including:
  - An extreme case where the entire service territory is without power
  - Less extreme cases where only portions of the service territory are without power
- POET estimates three measures of economic activity (gross output, GDP, and household consumption) for a business as usual baseline and for each of the three interruption scenarios
  - The difference between business as usual and each power interruption scenario is reported
- POET estimated economic impacts for 15 micro-regions and 38 industrial sectors in ComEd's service area as well as the greater region
- We also estimated the impacts of doubling the penetration of backup generation across ComEd's service territory

Economic impact metric	Definition
Gross output	% and dollar change industry revenue relative to BaU
GDP	% and dollar change of the total value of final goods and services generated by the economy relative to BaU
Change in household consumption	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 BaU

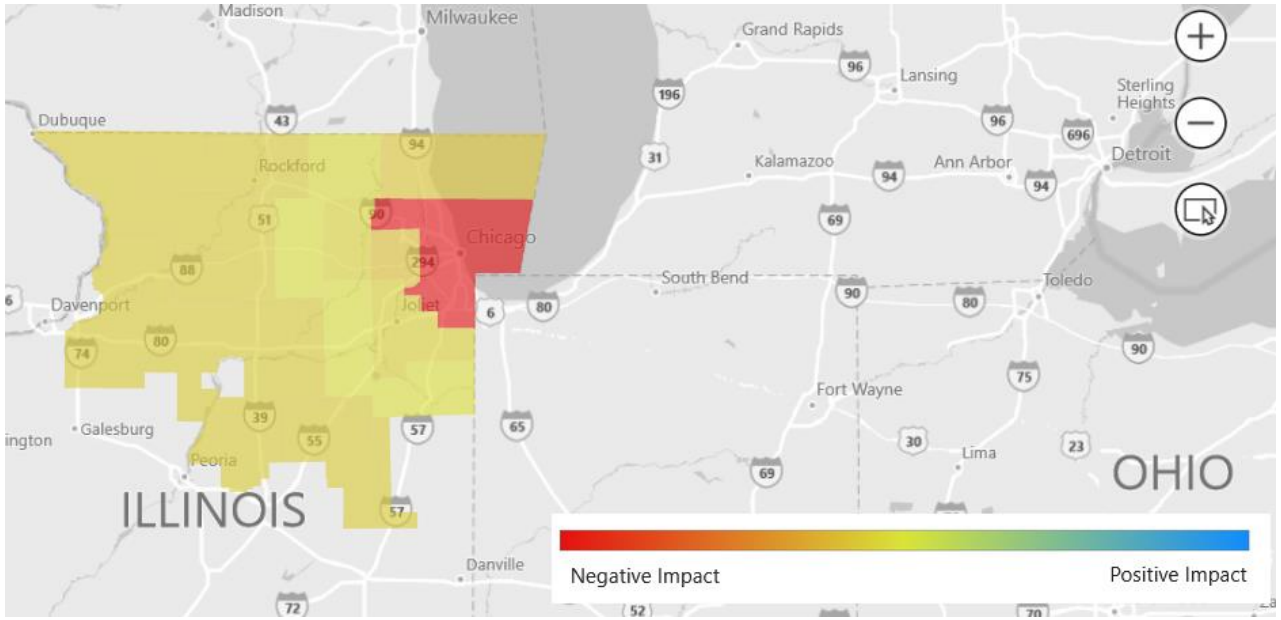
Significant economic losses are likely to occur if there is a system-wide, long duration power interruption

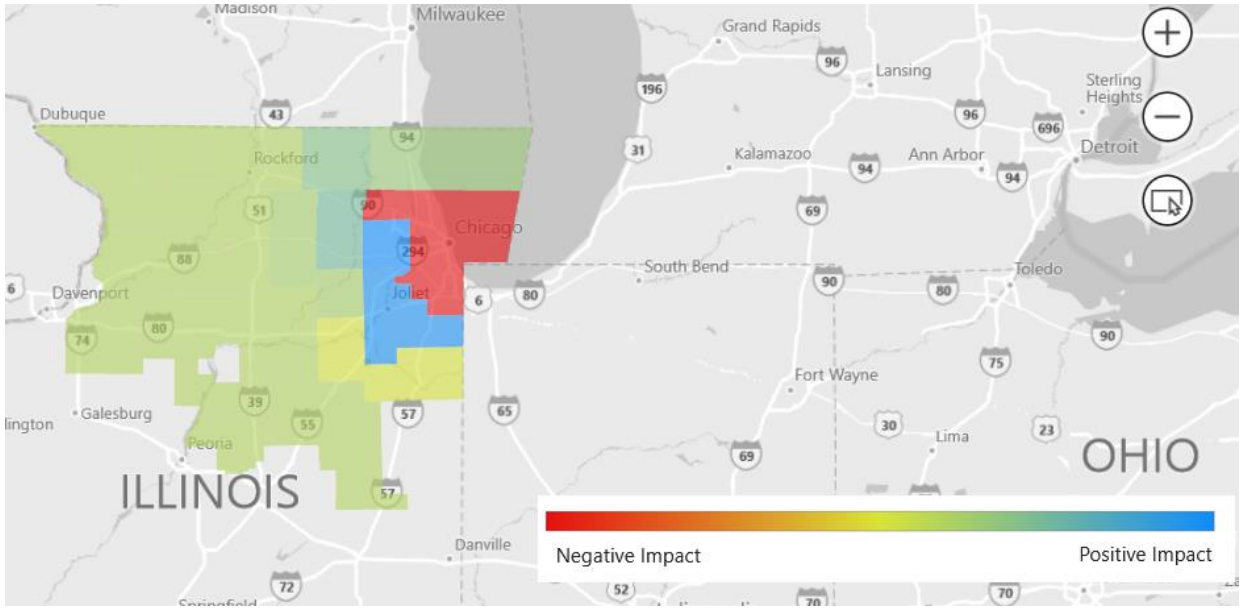
- Gross output losses from an **interruption affecting the entire service territory** range from $2.7B (one day) to $8.5B (14 days); GDP losses range from $2.2B (one day) to $17.1B (14 days)
- GDP losses for one day or three day power interruptions were not significantly different from gross output results; GDP losses for 14 day power interruptions are almost double those of gross output
- Losses to household consumption range from $2.1B (one day) to $16.7B (14 days)

Duration	Geographic extent of power interruption: All of ComEd		
	Change in Gross Output ($ billions and % change)	Change in Gross Domestic Product ($ billions and % change)	Change in Annual Household Consumption ($ billions and % change)
Business as usual	$315.3	$165.2	$116.0
One day	-$2.7 (-0.9%)	-$2.2 (-1.3%)	-$2.1 (-1.8%)
Three days	-$4.2 (-1.3%)	-$4.3 (-2.6%)	-$4.2 (-3.6%)
14 days	-$8.5 (-2.7%)	-$17.1 (-10.4%)	-$16.7 (-14.4%)

Losses vary by location and gains are possible if extent is limited

- GDP losses are largest in Cook County and suburban Chicago during a 14-day, **system-wide power interruption**
- **If only Cook County is without power,** then some counties will likely have increased economic activity

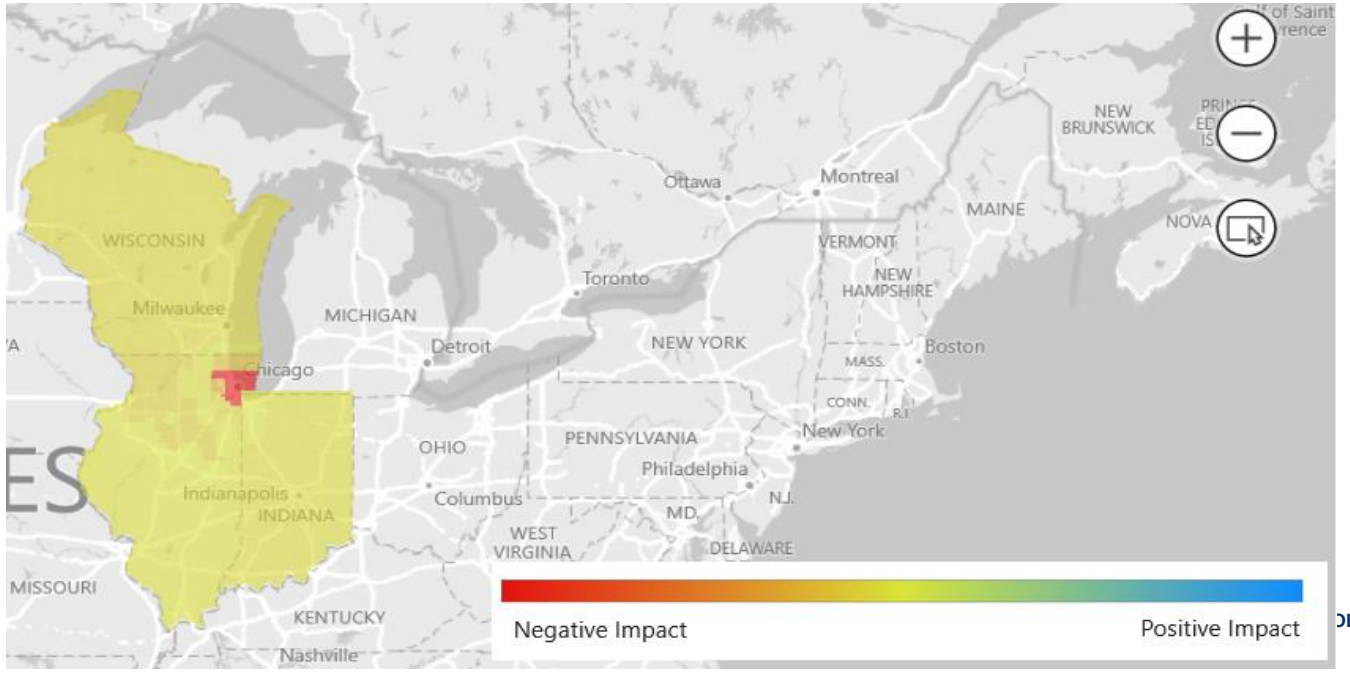




Broader region is also affected by a system-wide interruption

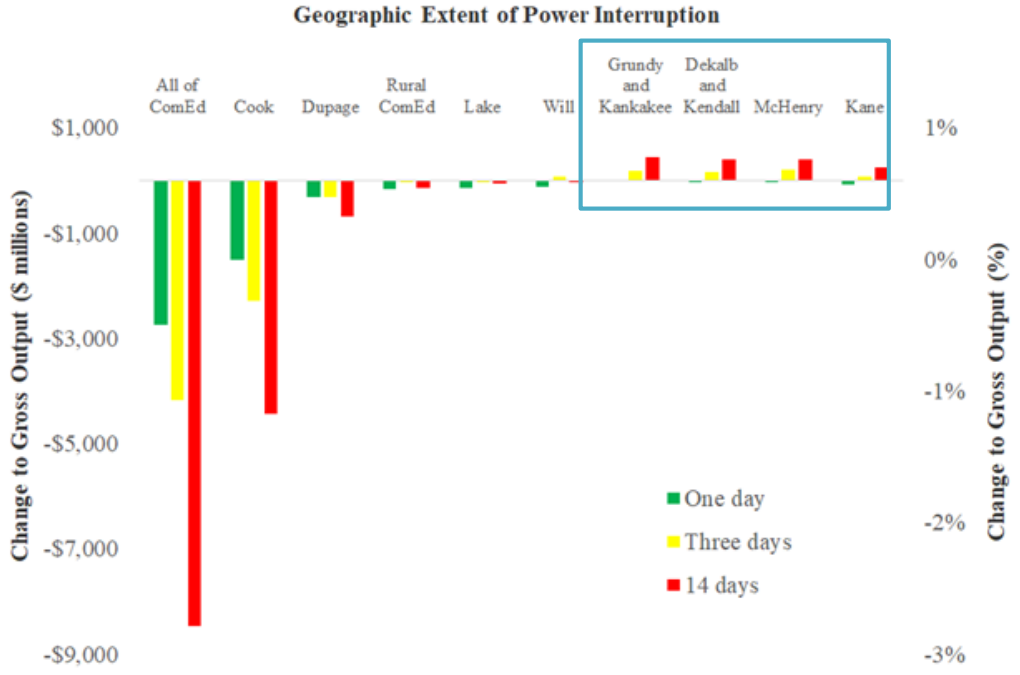
- Figure shows the impact of a 14 day, system-wide power disruption on gross output, GDP, and annual household consumption across the tri-state economy
- Impacts primarily occur within ComEd's service territory, but the rest of the broader region is also affected

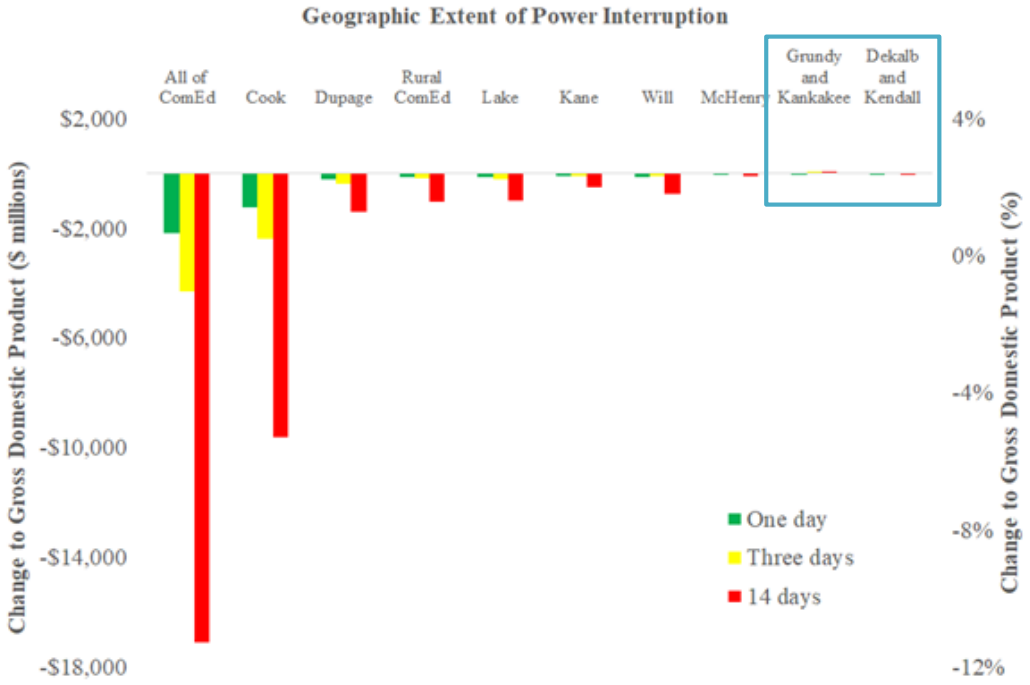
Impacts ($ billions)	Lost gross output	Lost GDP	Lost household consumption
Impacts within the ComEd service territory	-$8.5	-$17.1	-$16.7
Impacts on the rest of regional economy	-$0.9	-$0.6	-$0.6



ComEd's service territory may experience increased revenue if some, but not all micro-regions experience a power interruption

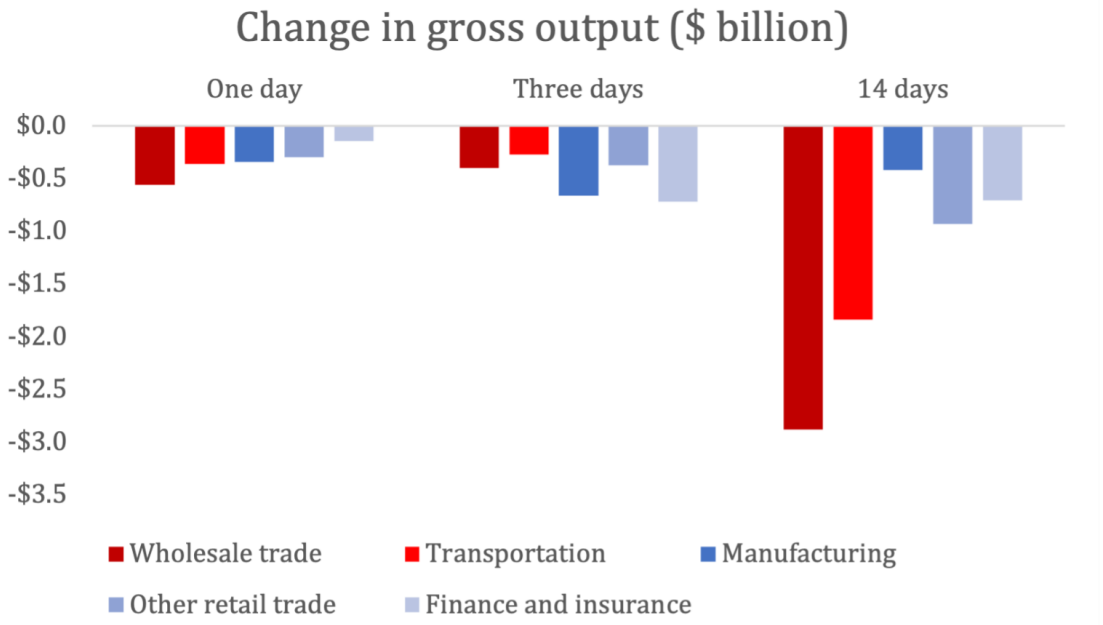
- Left figure: Longer power interruptions limited to some micro-regions may result in increased revenue in the regional economy because:
  - Neighboring micro-regions provide goods and services that the affected counties would have offered
  - Reallocation of lower-wage laborers from interrupted industries to labor-intensive industries in unaffected areas thereby increasing output
- Right figure: Power interruptions typically generally lead to larger reductions in GDP relative to output losses
  - Long duration interruptions limited to some micro-regions may lead to modest increases in GDP

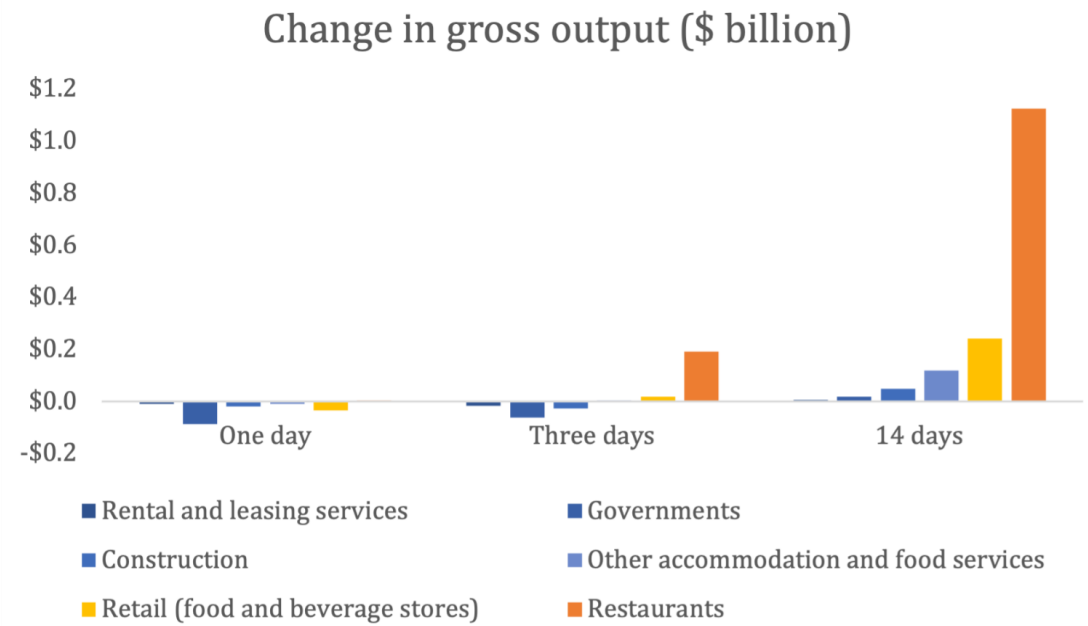




Most and least sensitive sectors

- Left figure: A system-wide interruption could result in large losses to the wholesale trade and transportation sectors
- Right graphic: Some sectors benefit from longer power interruptions (e.g., restaurants, retail–food and beverage, accommodations)





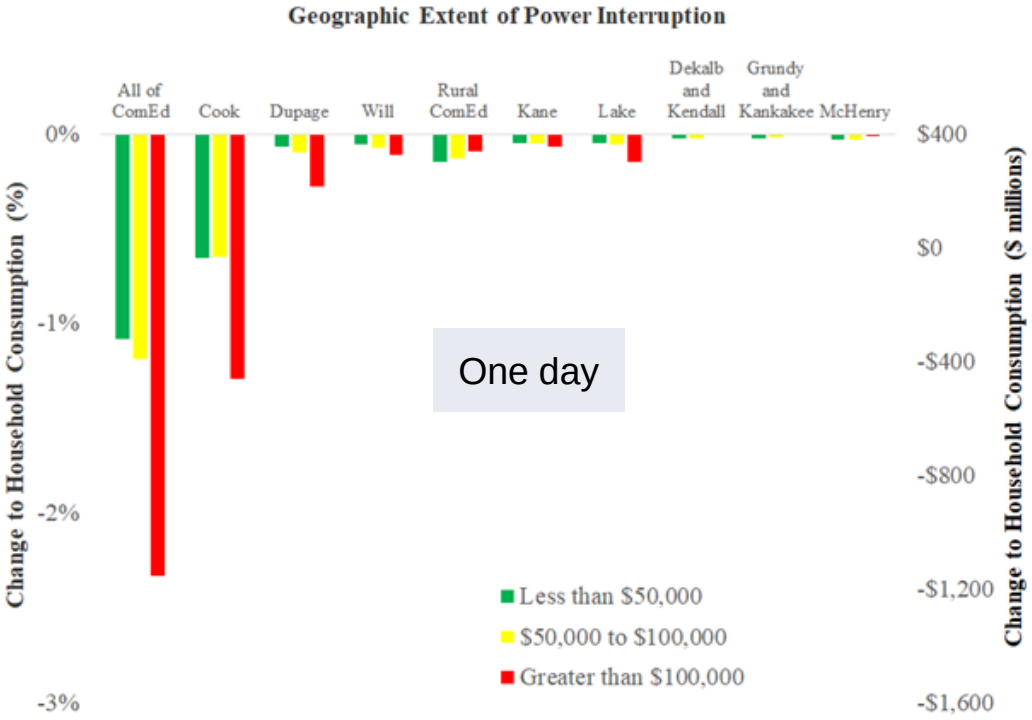
Certain sector-region combinations have greater losses during WLD power interruptions

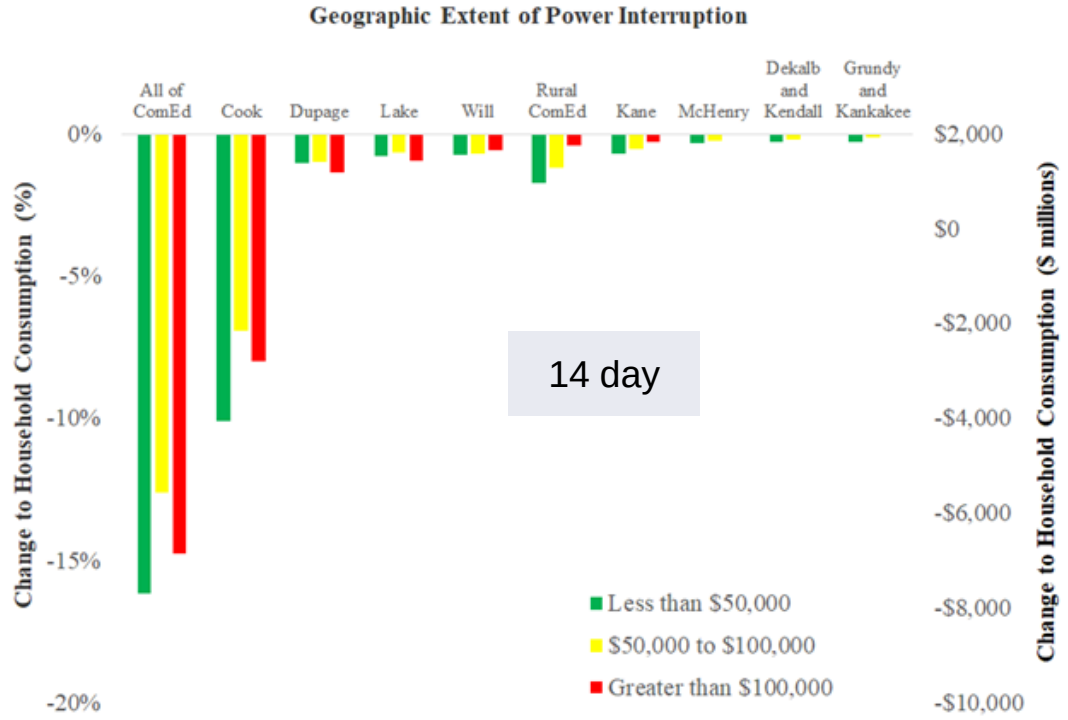
- The table below shows the sector-region combinations with the largest output losses during a 14-day interruption within a micro-region
- Electricity sector-related findings can be attributed to the specific location of power infrastructure within ComEd's territory, which plays a significant role in the economic output of those counties

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						✔			

Income levels affect how households are impacted by WLD power interruptions

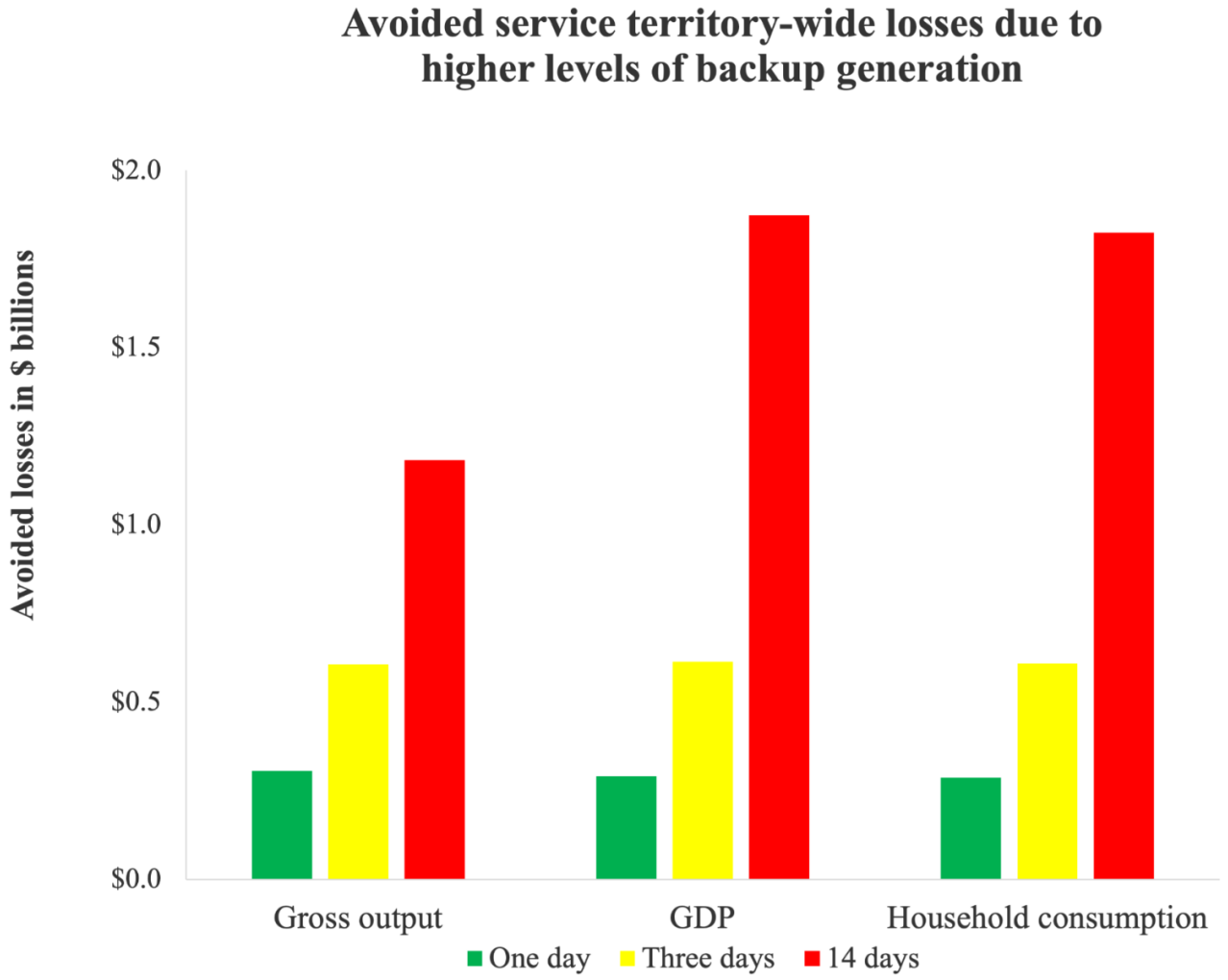
- Highest-income households are expected to lose the most during short duration interruptions
- Lower-income households may lose more than higher-income households during 14-day power interruptions, highlighting equity concerns
- Different consumption losses for each interruption duration between income groups may be related to resilience strategies (e.g., higher-income households are more likely to temporarily relocate)





In general, doubling amount of backup generation yields substantial benefits

- Doubling the backup generation capacity above existing levels and subtracting the associated procurement and operational costs leads to significant net benefits if there is a **system-wide interruption**
  - Avoided system-wide gross output losses are 11 to 15% of overall gross output
  - Avoided system-wide GDP are 11 to 14% of overall GDP
  - Avoided system-wide household consumption are 0.3% to 1.6% of total consumption losses

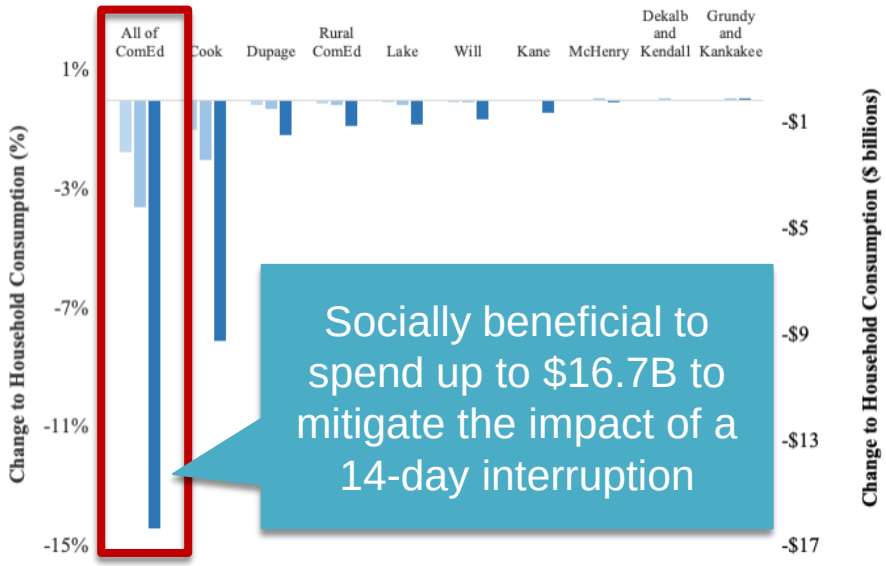


Using results in cost-benefit analysis

- **Decision-makers should run cost-benefit analyses using each economic metric presented in this report to evaluate the sensitivity of the results to the choice of metric**
- 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
- The overall benefit proposition for resilience investments requires policymakers to make a number of assumptions, including the:
  1. Likelihood of future power interruptions of varying durations and geographic extents
  2. Reduction in interruption risk due to the investment
  3. Economic impacts of power interruptions before and after the investment
  4. Lifespan of investment
  5. Discount rate
- The economic benefit of resilience tactics beyond high-penetration of rented backup generation was not assessed in this project

Important considerations when evaluating the benefit of resilience tactics

- This demonstration did not assess the annual likelihood or cause of interruptions
- In the future, POET could be used to evaluate a range of geographic extent combinations and likelihoods of interruptions and the associated impact to the regional economy



Power interruptions to be mitigated	• Short/localized, but frequent events • WLD, but infrequent events
Types of natural hazards to be addressed	• Extreme weather events • Operations errors • Physical or cyber attacks
Levels of mitigation (duration/geographical extent)	• Partial mitigation • Full mitigation

Key uncertainties and research needs

- **Low survey response rates for non-residential customers may mean some of the information we collected is not representative of the population of businesses** (REMEDY: Collect additional survey responses from non-residential customers and re-calibrate POET)
- **Backup generation rentals may not be widely-available during widespread, long duration interruptions** (REMEDY: Investigate existing stock of rental generators that might be available across ComEd's service territory and constrain POET to the actual amount of available generator rentals)
- **Uncertainty around why some sectoral and micro-region-level impacts have higher (lower) sensitivity to power interruptions** (REMEDY: Evaluate specific sectors and micro-regions 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** (REMEDY: Investigate restructuring the POET model to accommodate industry-specific resilience tactics)
- **Not all societal impacts of power interruptions were captured in the model, including pollution-related costs from running backup generators** (REMEDY: Include pollution-related costs into the costs of procuring backup rental generation; Investigate possibility of including other health/safety risks into economic impact analysis)

POET visualization tool

POWER OUTAGE ECONOMICS TOOL

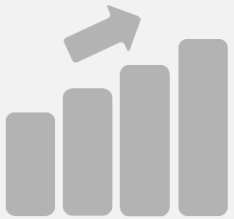
ComEd
An Exelon Company

Regional Impact Maps

Visualize impacts by selected metric, extent of outage, duration, and impacted region

Regional Impact Graphs

Change in selected metric (gross domestic product, gross output, value added, or household consumption) by region



Sectoral Impact Graphs

Change in gross output and value-added by industry sector

Household Impact Graphs

Change in household consumption by income category

Map of Impact by Selected Metric and Region

Interruption Scenario and Impact Location Options (Select from the following)

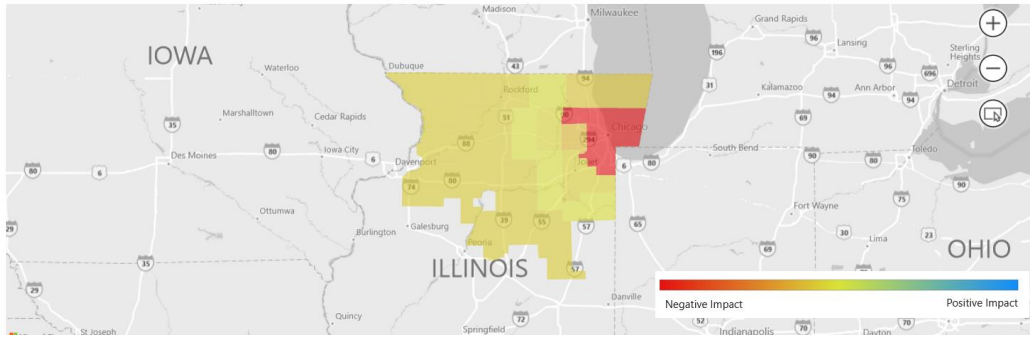
Metric	Impact Type	Interruption Extent	Backup Generator Penetration	Duration (days)	Impact Location
3-Month Total GDP	Absolute Impact	All Com Ed	Existing Penetration of Backup Generation	1	All Com Ed

Total Impact for Selected Region

All Com Ed

165.16	163.00	-2.16	-1.31%
Total Value (Billions USD) Under Business as Usual Scenario	Total Value (Billions USD) Under Outage Scenario	Change in Total Value (Billions USD) Due to Outage	Percentage Change in Total Value

Map of Absolute Impact: Three-Month GDP

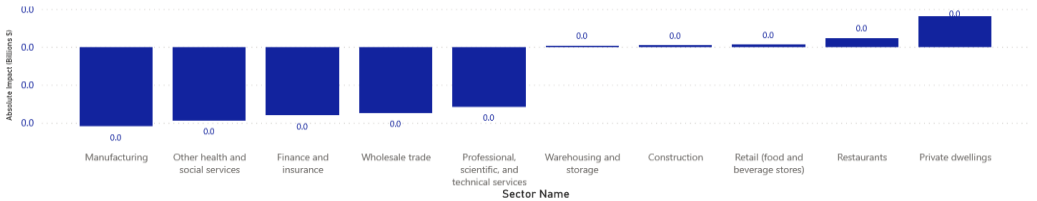


Sectoral Impacts: 3-Month Total Output and Value Added

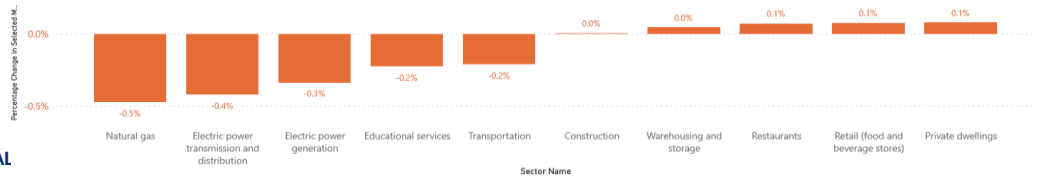
Interruption Scenario, Impact Location, and Metric Options (Select from the following)

Metric	Interruption Extent	Duration (days)	Backup Generator Penetration	Impact Location
3-Month Sectoral Value Added	All Com Ed	1	Existing Penetration of Backup Generation	Entire Region (IL, IN, and WI)

Top 5 Industry Losers and Gainers: Absolute Impact on Sectoral Value Added by Sector



Top 5 Industry Losers and Gainers: Percentage Impact on Sectoral Value Added by Sector



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- We thank **Kristina LaCommare** (Berkeley Lab) for her project management. **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

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