BERKELEY LAB

Estimating the Economic Impacts of Widespread, Long-Duration Power Interruptions in the Commonwealth Edison Service Territory

POET project team

BERKELEY LAB

Peter Larsen, Principal Investigator

Sunhee Baik

Juan Pablo Carvallo

Alan Sanstad

BOSTON UNIVERSITY

Ian Sue Wing

resource innovations

Ridge Peterson

Chris Ramee

Jeremy Smith

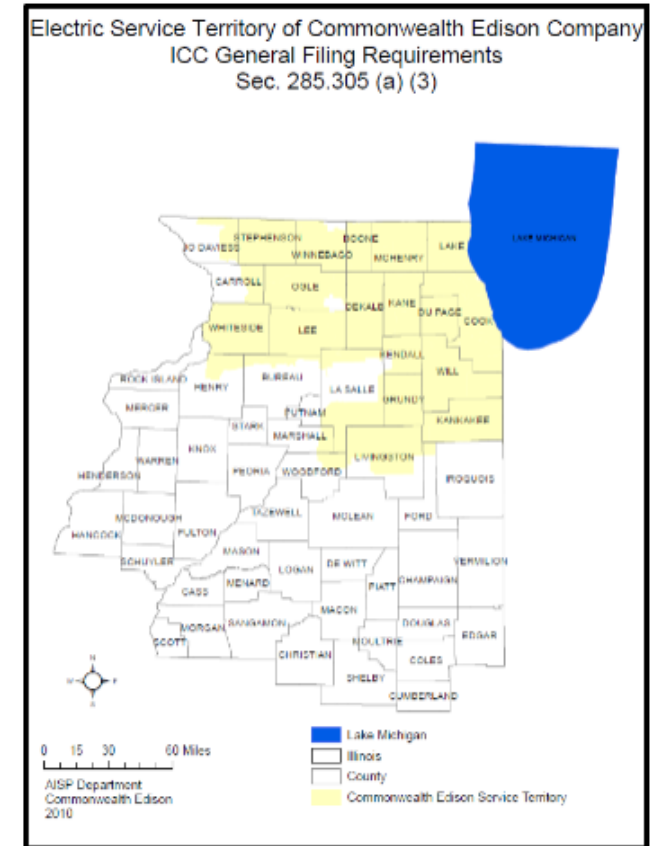**USC Price — Sol Price School of Public Policy**

Adam Rose

Dan Wei

Executive summary

❑ Berkeley Lab, in conjunction with ComEd, has demonstrated an innovative new tool that estimates the regional economic impacts of widespread, 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 (e.g., other Exelon utilities) to estimate the costs of WLD power interruptions and the economic value of investments in power system resilience**

Executive summary (cont.)

❑ 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?

Electric Service Territory of Commonwealth Edison Company
ICC General Filing Requirements
Sec. 285.305 (a) (3)

0   15   30   60 Miles

AISP Department
Commonwealth Edison
2010

■ Lake Michigan
☐ Illinois
☐ County
☐ Commonwealth Edison Service Territory

Executive summary (cont.)

❑ A **system-wide power interruption** could result in significant losses to gross output, gross domestic product (GDP), and annual household consumption in ComEd's counties

| Economic impact metrics	Definition
Gross output	% and dollar change to industry revenue relative to business as usual (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

Impacts on ComEd's service territory from a system-wide interruption (relative to BaU)	Gross output ($ billion and % change)	GDP ($ billion and % change)	Annual household consumption ($ billion and % change)
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%)

Executive summary (cont.)

❏ 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

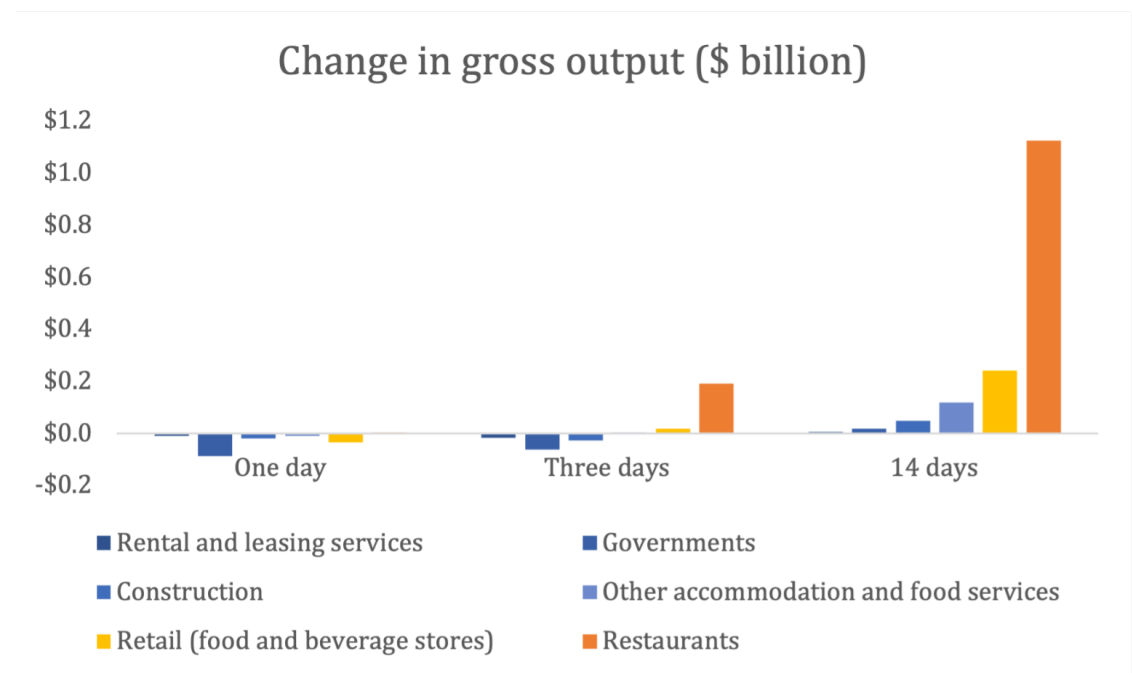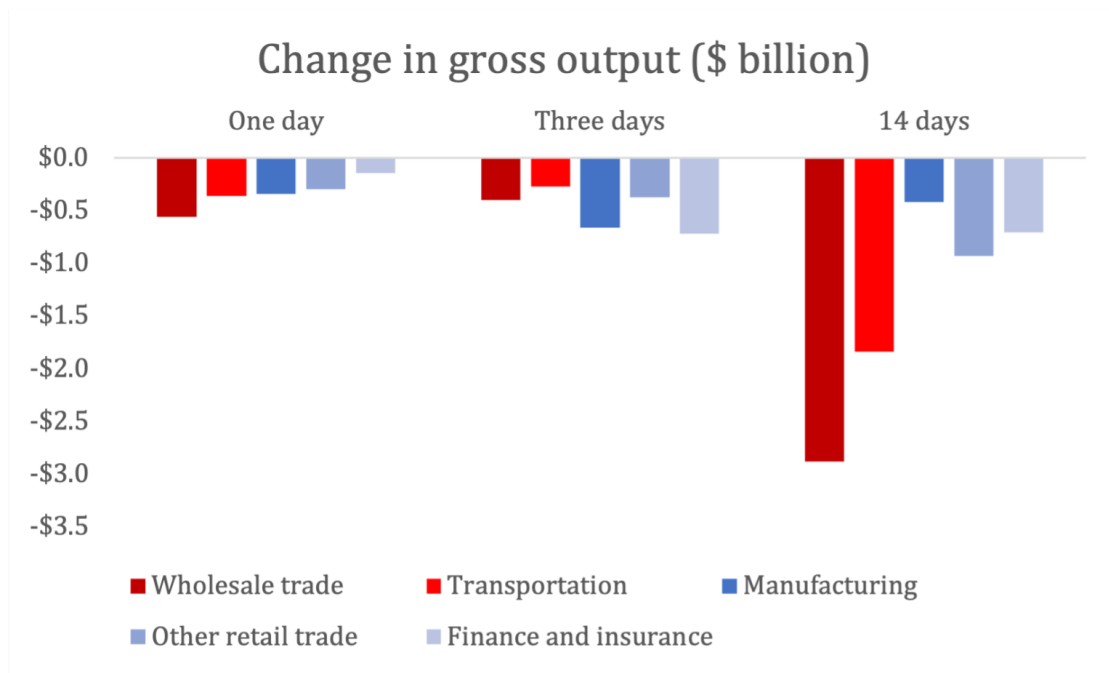| Impacts ($ billions)	Lost gross output	Lost GDP	Lost household consumption
Impacts within the ComEd service territory	-$8.5	-$17.1	-$16.7
Impacts on the rest of regional economy	-$0.9	-$0.6	-$0.6
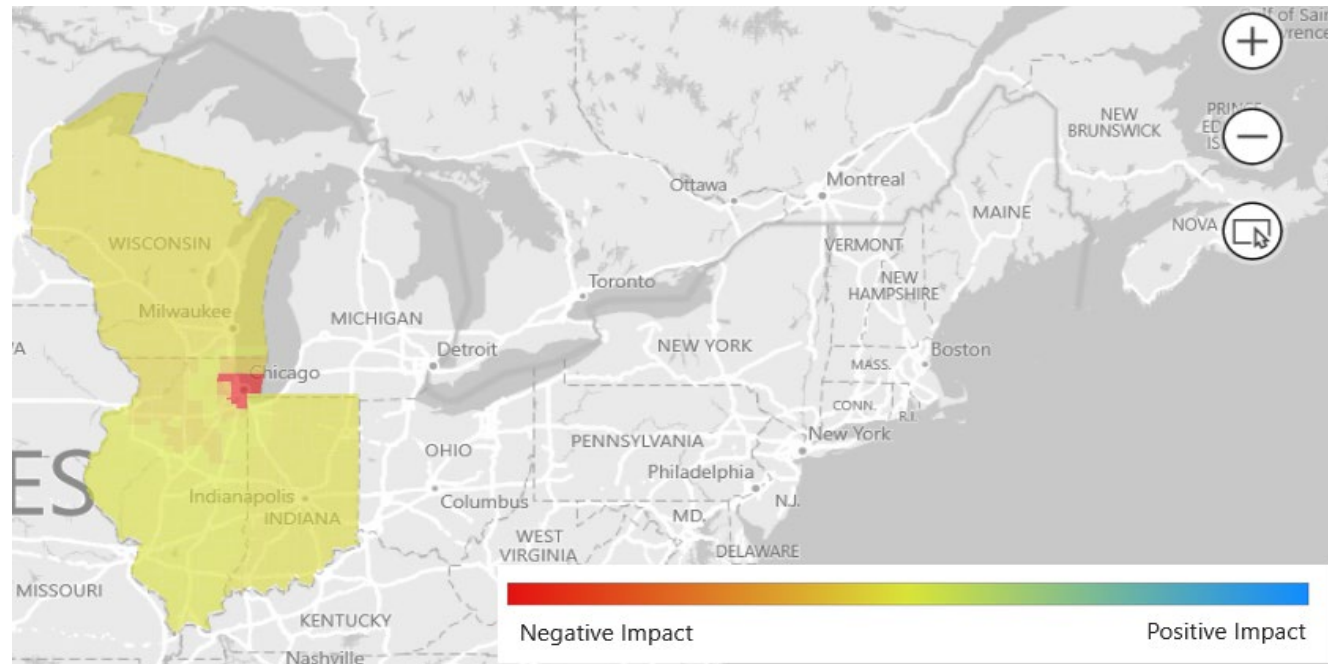
Executive summary (cont.)

❑ 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
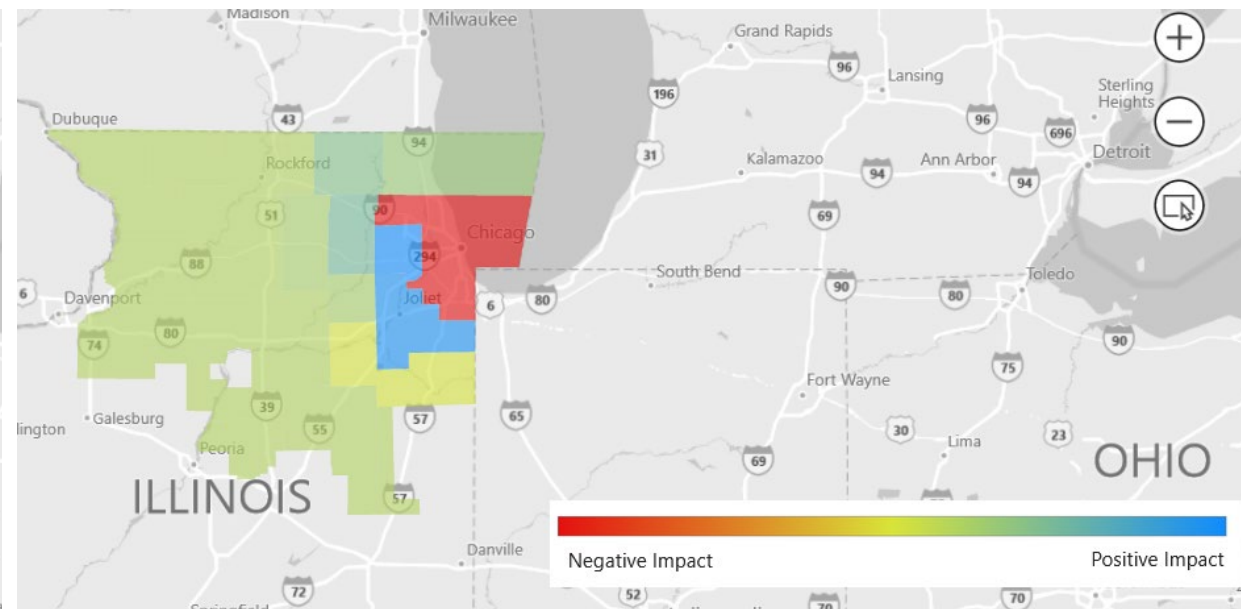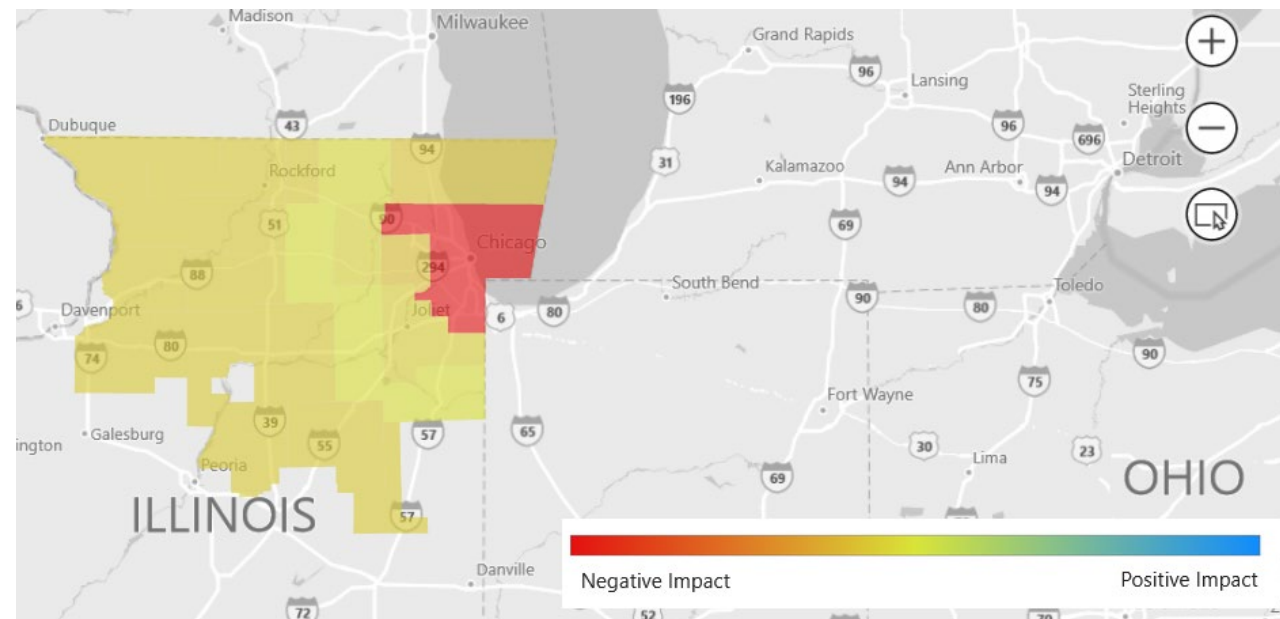
Executive summary (cont.)

❏ Left graphic: 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)

Change in gross output ($ billion)

One day   Three days   14 days

■ Wholesale trade   ■ Transportation   ■ Manufacturing
■ Other retail trade   ■ Finance and insurance

Change in gross output ($ billion)

One day   Three days   14 days

■ Rental and leasing services   ■ Governments
■ Construction   ■ Other accommodation and food services
■ Retail (food and beverage stores)   ■ Restaurants

Executive summary (cont.)

❏ On a percentage basis, some sector-region combinations could experience significant losses. For example:

  ❏ Transportation in Cook, Dekalb and Kendall, McHenry, and rural counties

  ❏ Wholesale trade in Dekalb and Kendall, and McHenry counties

  ❏ Warehousing and storage in Dekalb and Kendall, Grundy and Kankakee, Will, and rural counties

❏ Losses in household consumption vary inversely with household income and interruption duration

  ❏ High-income households are more proportionately affected by short-duration power interruptions

  ❏ Low-income households were more proportionately affected by longer-duration power interruptions

❏ Benefits of increasing backup generation generally exceed the costs, although there are exceptions

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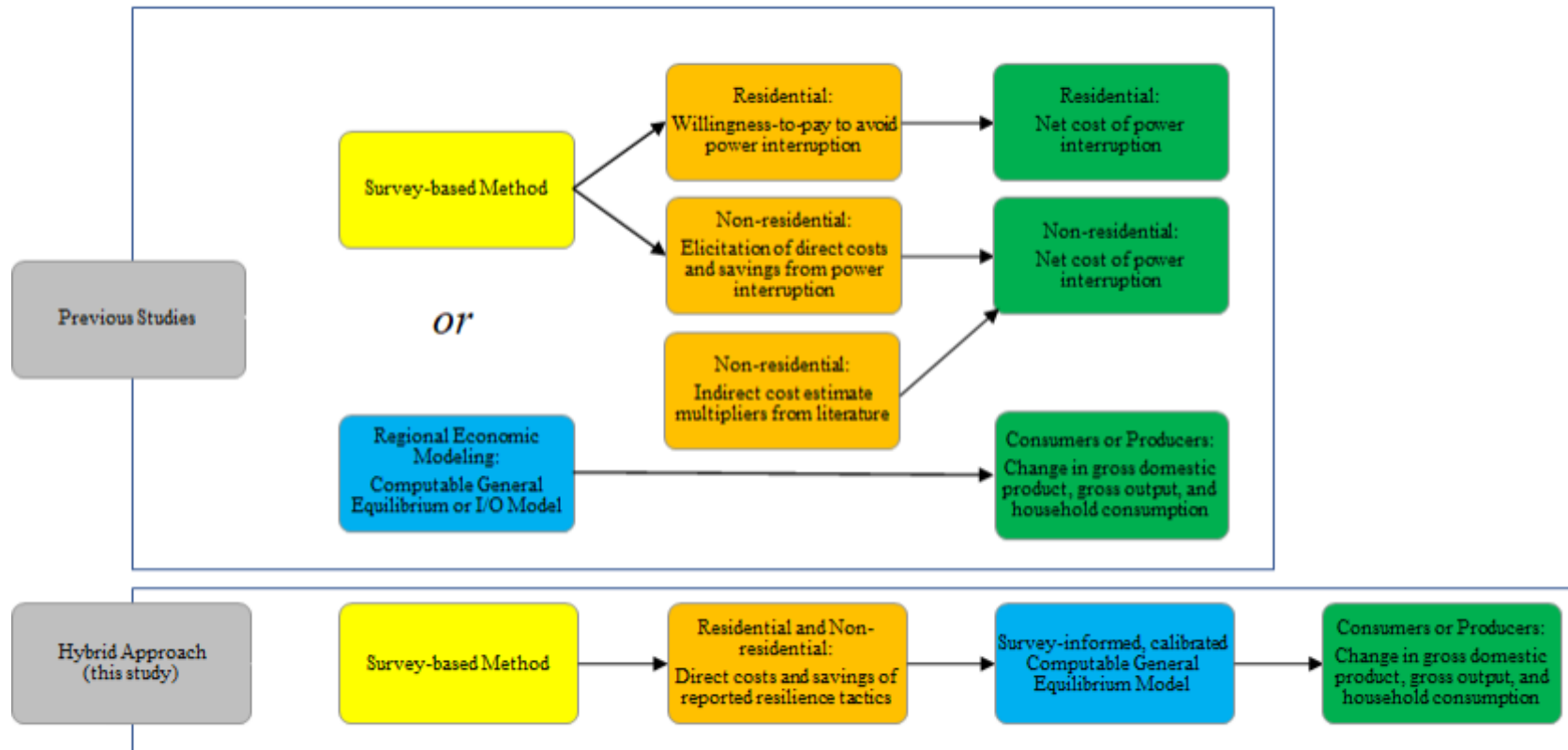
Survey finding #1: Resilience tactics change based on interruption duration

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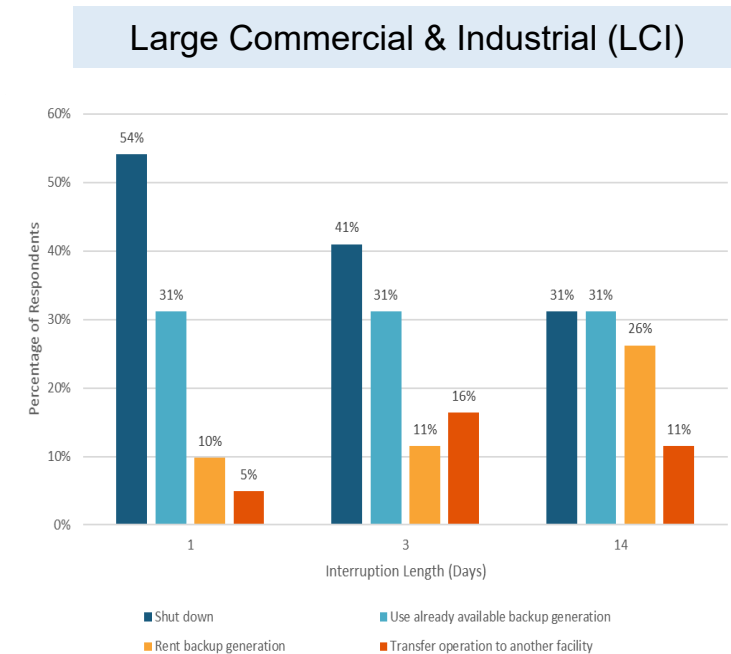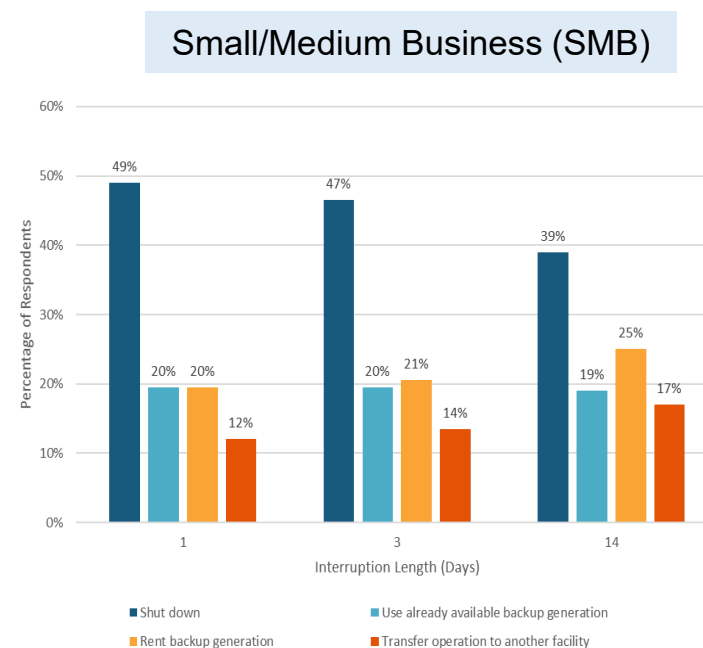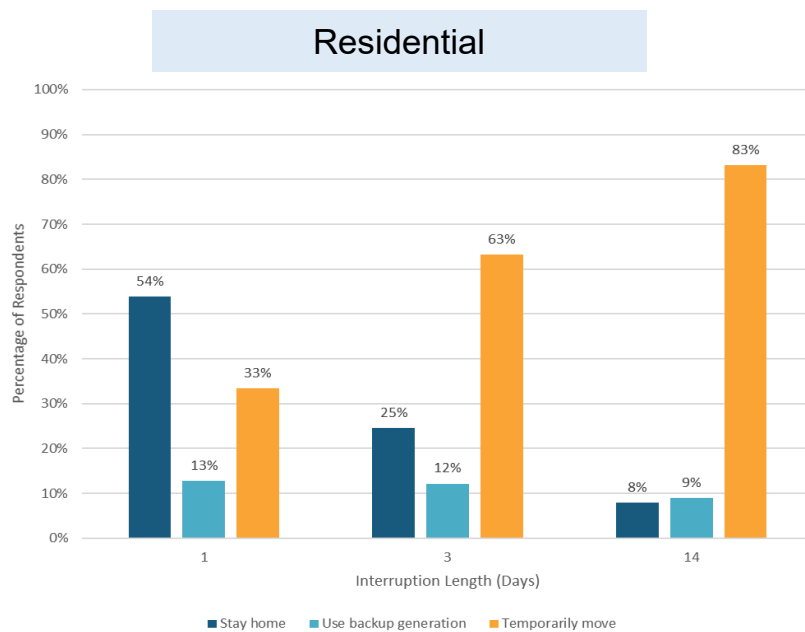
Survey finding #2: Most LCI customers have backup generation capabilities

❑ 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
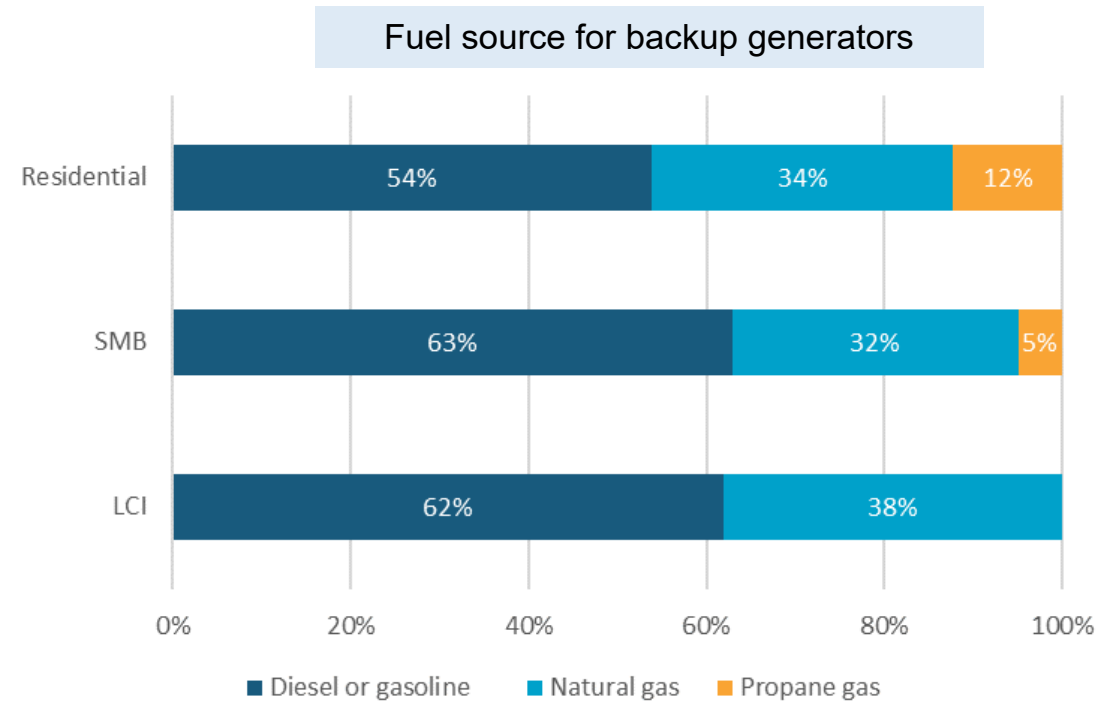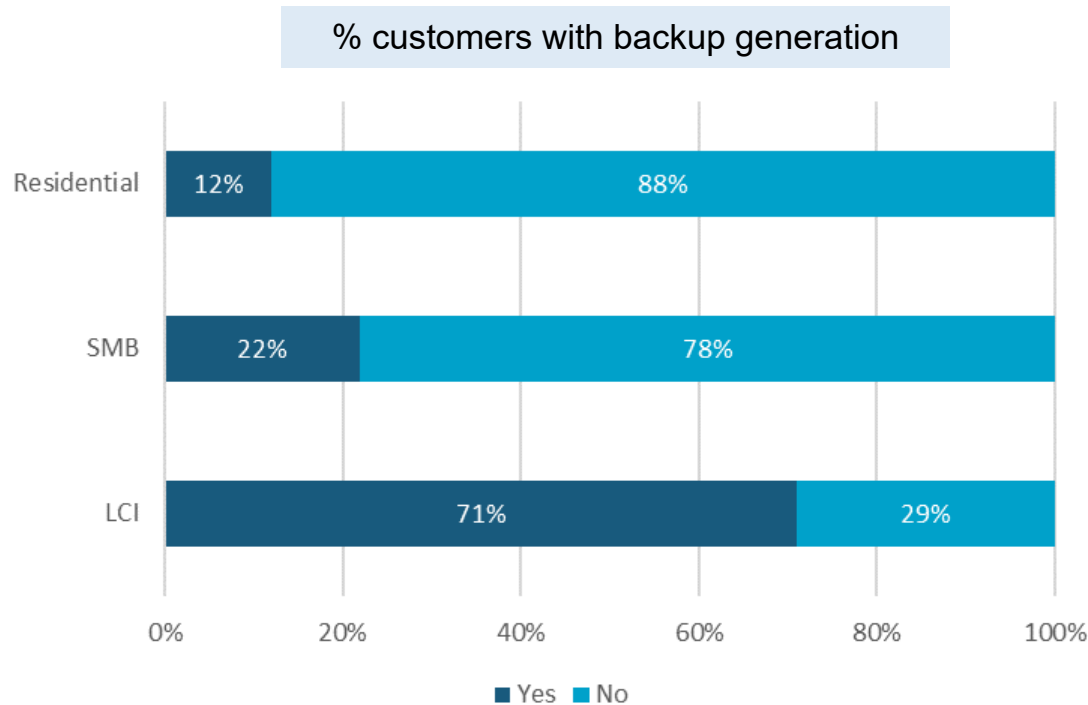
Computable general equilibrium model

❏ 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 three 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
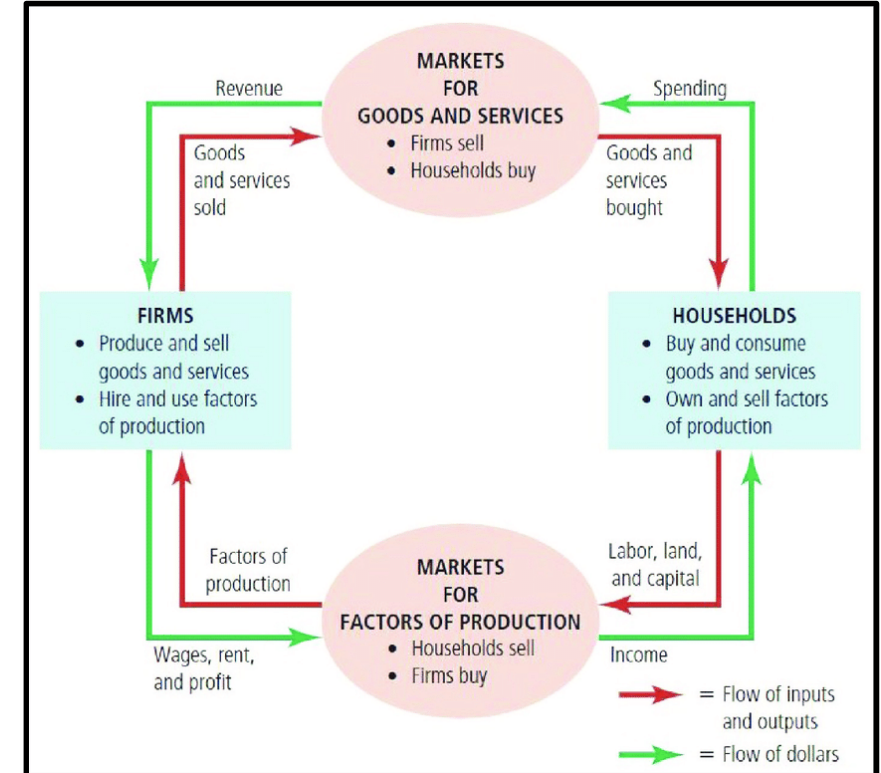
Source: Mankiw (2021)

Modeled scenarios and impact metrics

❑ POET was used to evaluate three WLD power interruptions (one day, three days, 14 days), 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%)

ComEd's service territory may experience increased revenue if some, but not all micro-regions experience a power interruption
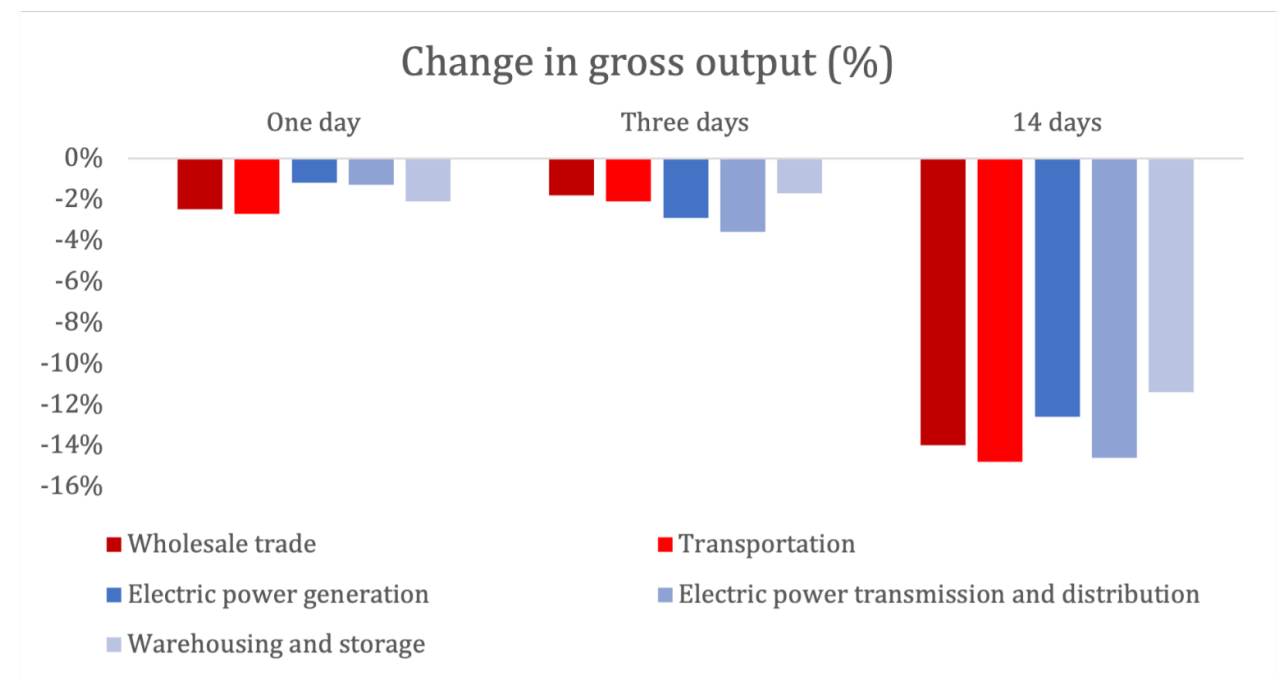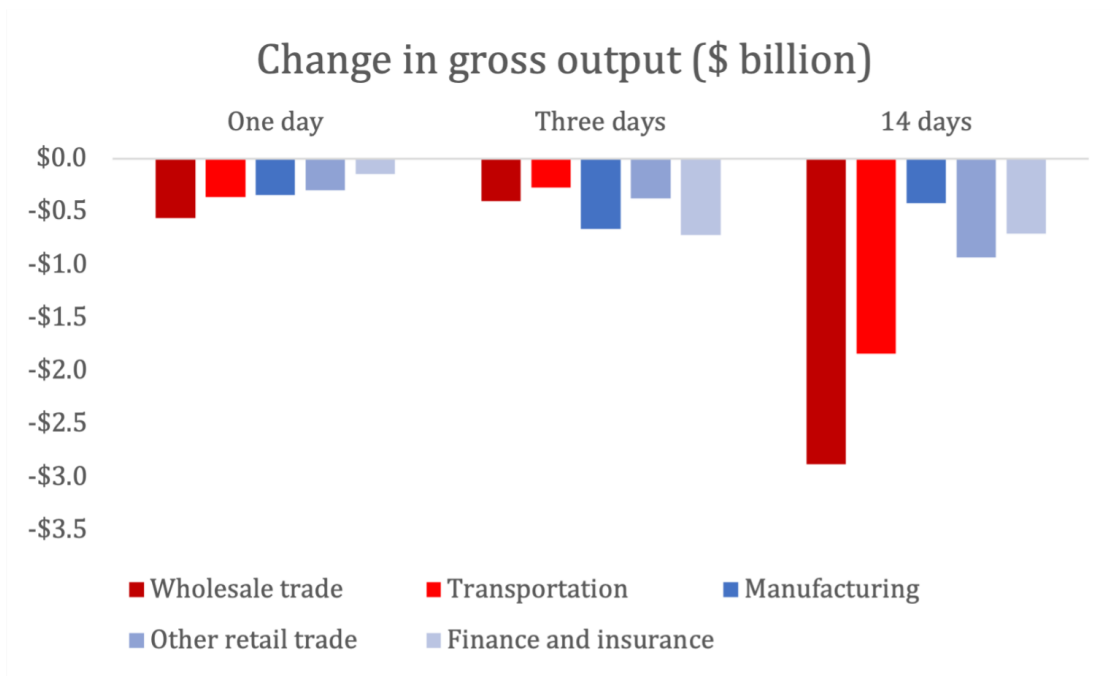
❏ Left figure: Longer power interruptions limited to some micro-regions may result in increased revenue in the regional economy because:

   ❏ 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

Geographic Extent of Power Interruption

Geographic Extent of Power Interruption
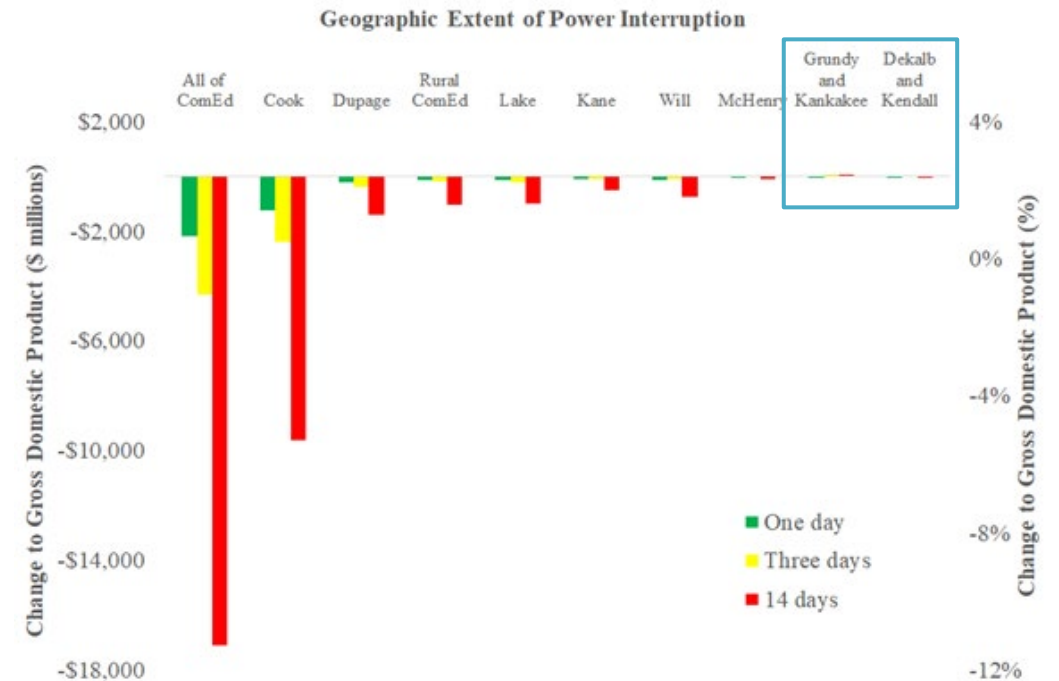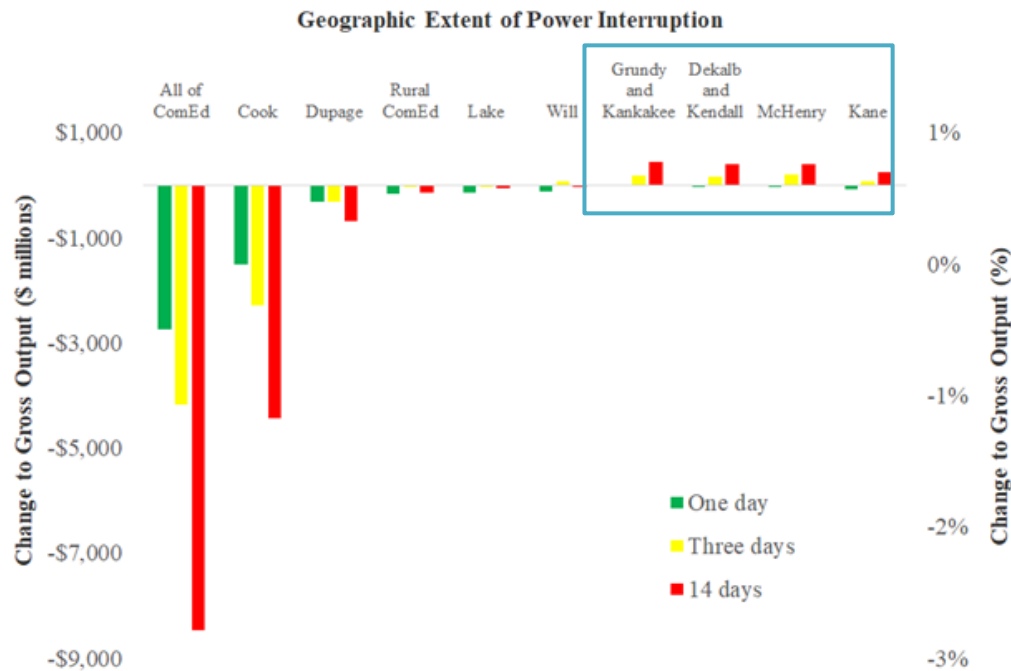
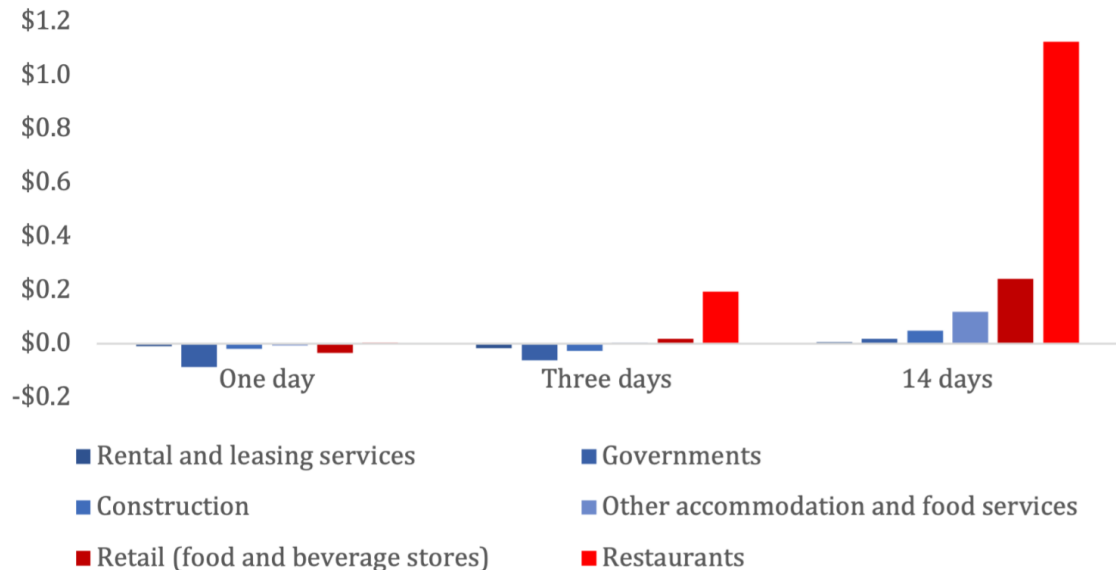# Wholesale trade and transportation sectors have the largest losses from WLD power interruptions

❏ Five sectors account for 60-80% of total service territory-wide gross output loss, regardless of interruption duration.

❏ A different set of five sectors have the highest percentage of sector output lost, with 10-15% of their output lost during a 14 day interruption.

❏ The wholesale trade and transportation sectors suffer significant losses, both relative to the overall economy and in terms of sector output.

Change in gross output ($ billion)

Legend: Wholesale trade, Transportation, Manufacturing, Other retail trade, Finance and insurance

Change in gross output (%)

Legend: Wholesale trade, Transportation, Electric power generation, Electric power transmission and distribution, Warehousing and storage
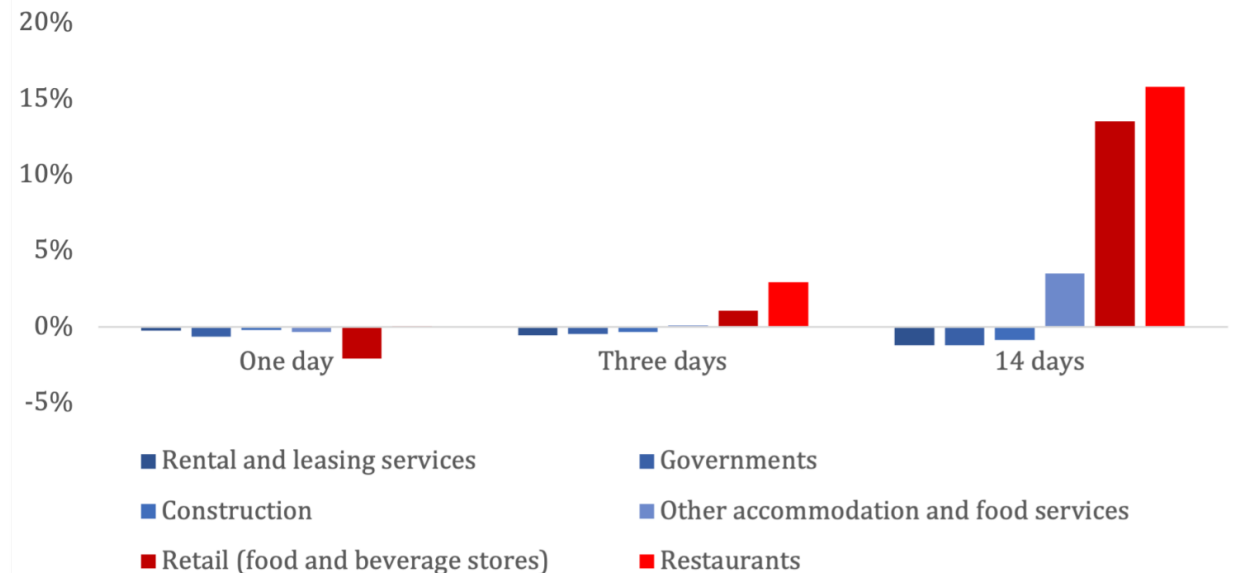
However, some sectors benefit from longer power interruptions

❏ A few sectors increase their output during WLD power interruptions as customer demand/labor supply patterns change

    ❏ For example, eating out, relocating, and reallocation of lower wage labors to labor-intensive industries in unaffected regions

❏ The restaurant sector consistently shows the highest increase in output across all three durations of power interruptions

❏ Retail (food and beverage stores) and lodging also see increases in output

# Some 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						✔			

High-income households have relatively larger consumption losses during one day interruptions; Low-income households have larger losses during longer interruptions
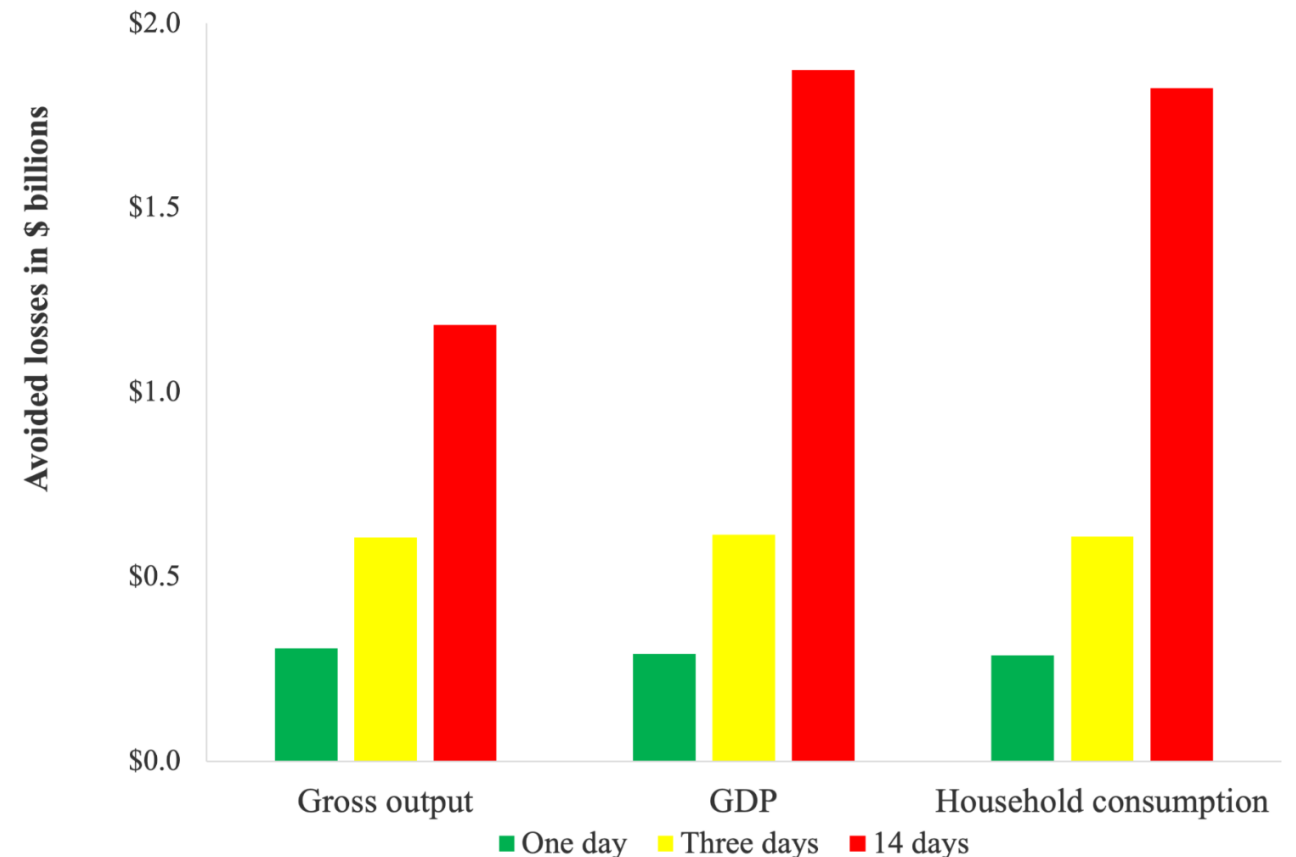
- ❑ Left figure: Highest-income households are expected to experience relatively higher losses to consumption during short duration interruptions

- ❑ Right figure: Lower-income households may experience more losses to consumption during a 14 day power interruption– 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)

Geographic Extent of Power Interruption (left and right figures)
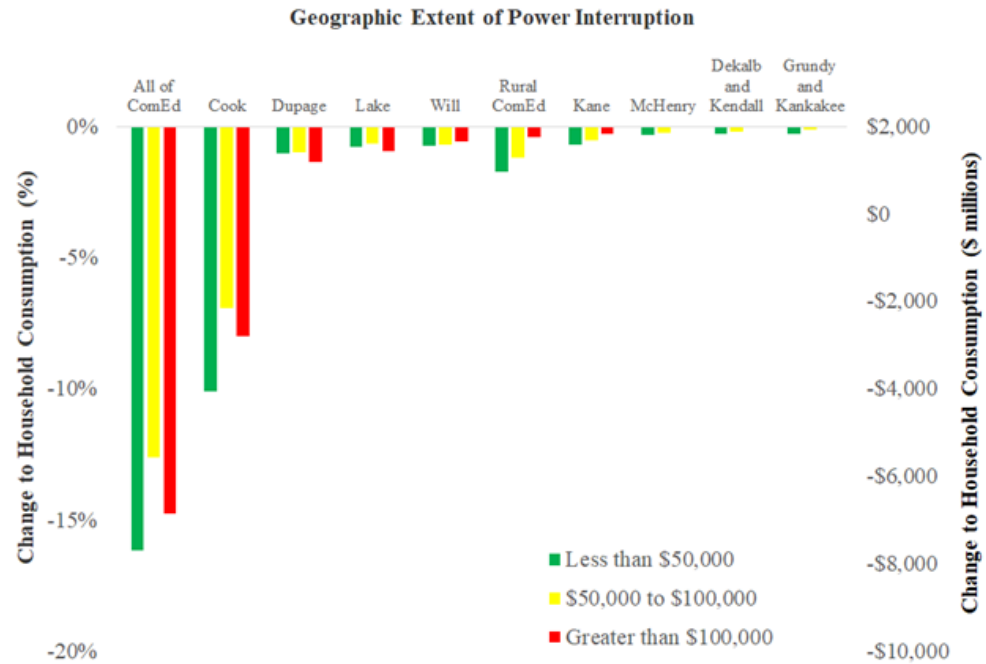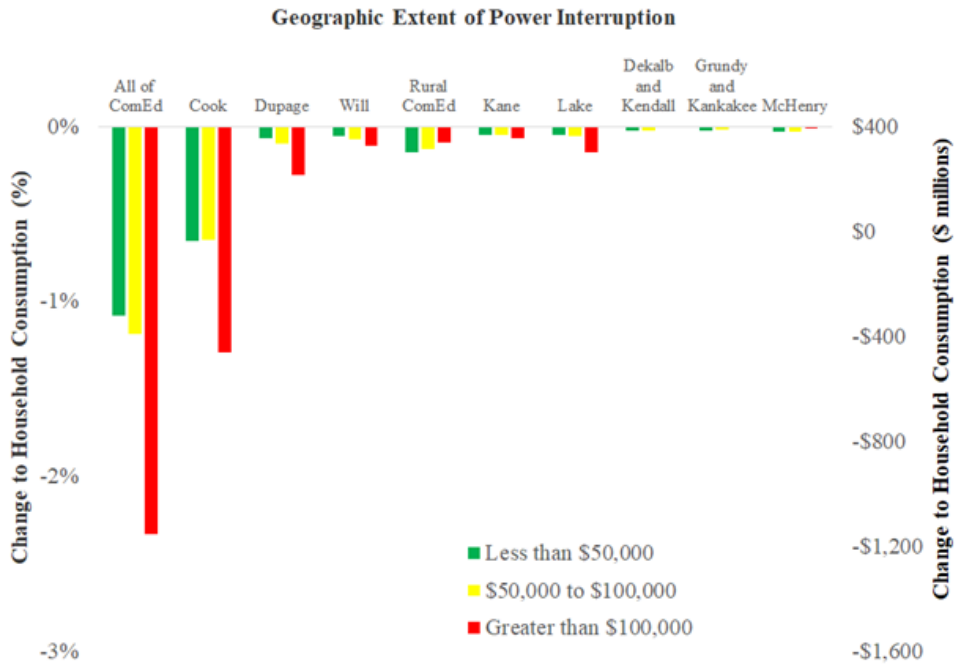
In general, doubling amount of backup generation yields substantial benefits

❑ 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

**Avoided service territory-wide losses due to higher levels of backup generation**

Bar chart: Avoided losses in $ billions, by category (Gross output, GDP, Household consumption) for One day (green), Three days (yellow), 14 days (red). Y-axis from $0.0 to $2.0.
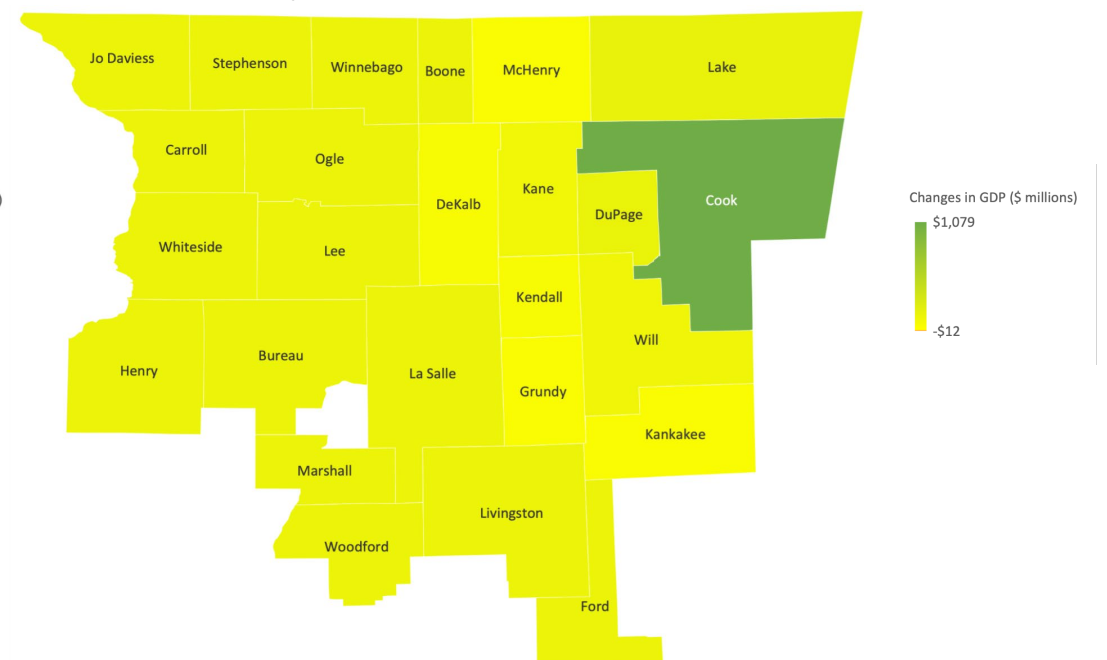
Doubling the amount of backup generation leads to system-wide, positive net benefits to both output and gross domestic product

❑ Left figure: Doubling backup generation–during a 14 day system-wide interruption–leads to net benefits to output across the service-territory (system-wide net benefits to gross output = +$1.2B)

❑ Right figure: Doubling backup generation–during a 14 day system-wide interruption–leads to net benefits to GDP across the service-territory (system-wide net benefits to GDP = +$1.9B)

Net benefits to system-wide gross output of doubling backup generation: a 14 day system-wide interruption
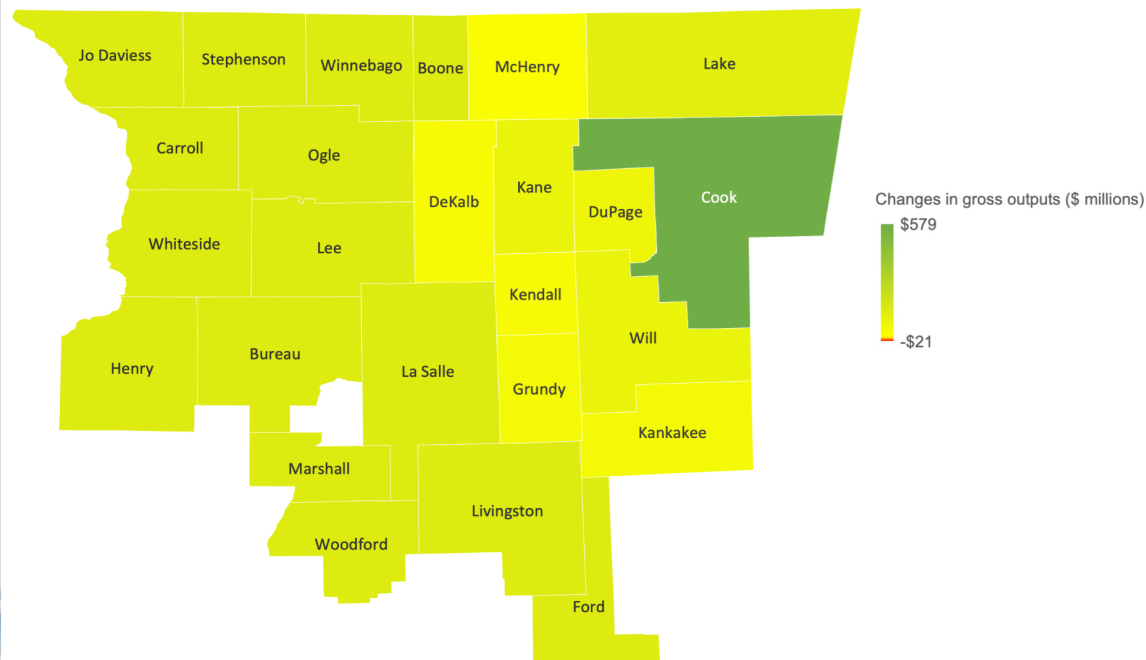
Net benefits to system-wide GDP of doubling backup generation: a 14 day system-wide interruption

Doubling backup generation reduces system-wide household consumption losses across all income levels, durations, and geographic extents of interruption

❑ Doubling the amount of backup generation will lead to avoided, system-wide losses to household consumption across all income levels, durations, geographic extents of interruption (system-wide net benefits to output = +$1.2B)

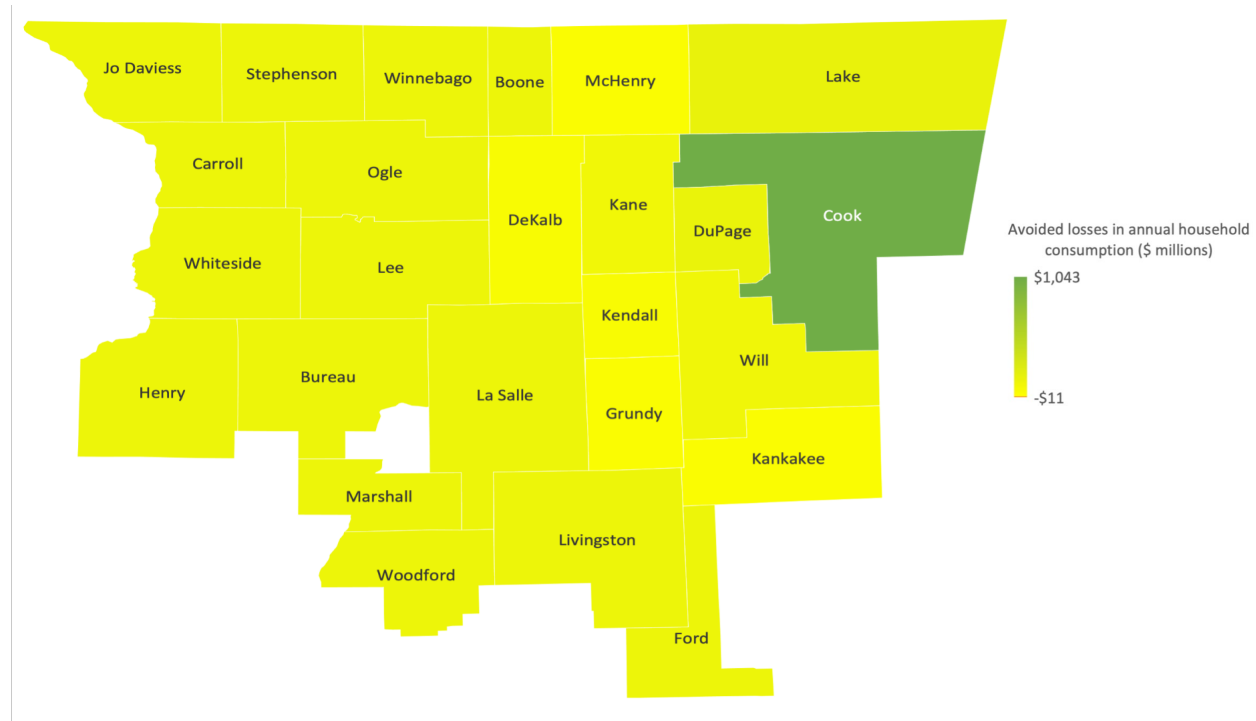Net benefits to system-wide household consumption of doubling backup generation: a 14 day system-wide interruption

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

❏ Targeted resilience interventions towards the sectors with the greatest impact on gross output:
  ❏ Wholesale trade (avoided losses range from $0.6B to $2.9B)
  ❏ Transportation (avoided losses range from $0.4B to $1.8B)

❏ Targeted resilience interventions toward the income groups with highest losses to household consumption:
  ❏ Higher income households for shorter duration power interruptions
  ❏ Lower income households for longer duration power interruptions

❏ Based on all three economic impact metrics, increasing deployment of backup generation may be most beneficial in specific counties:
  ❏ For example, avoided losses to GDP during a 14 day power interruption are extremely high relative to total GDP in Dekalb and Kendall counties
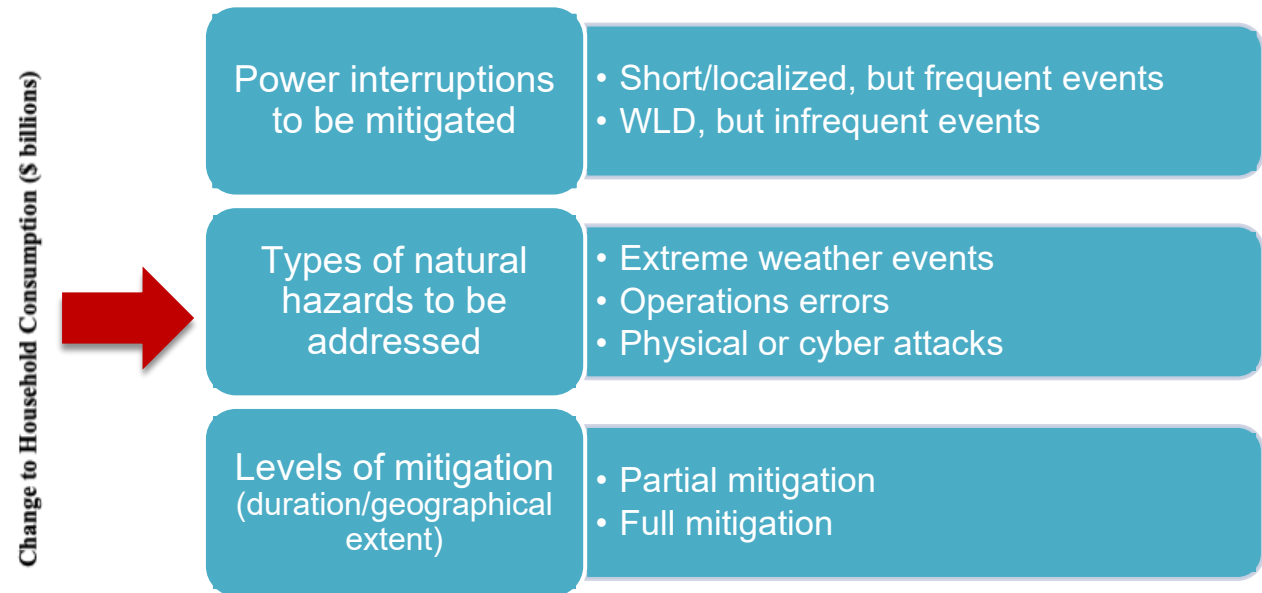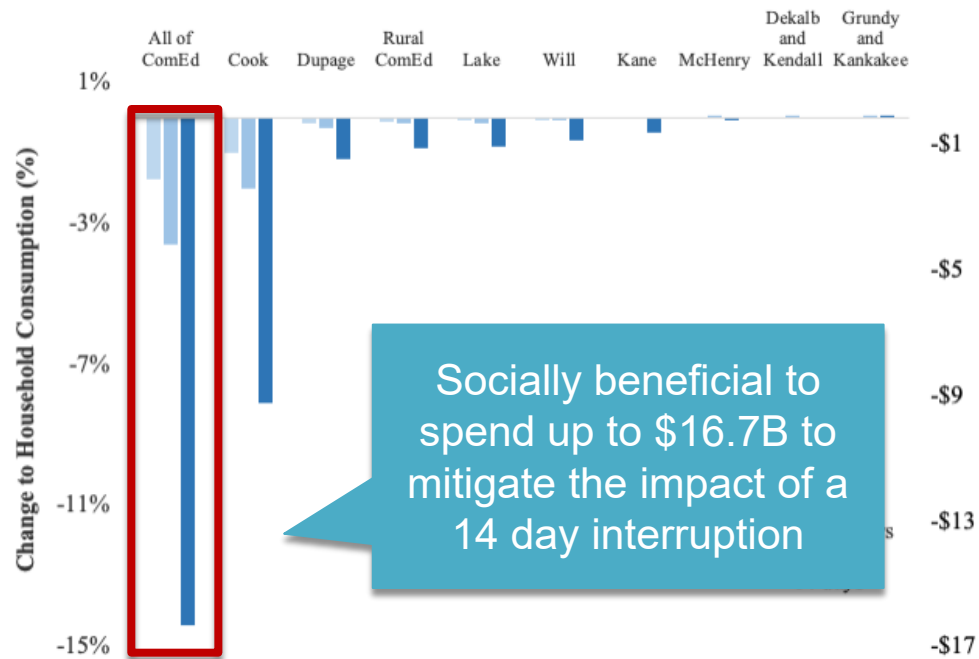
How can the results be used to evaluate investments in resilience within a traditional cost-benefit framework?

❑ **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

❏ The POET model demonstrated here does 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

Socially beneficial to spend up to $16.7B to mitigate the impact of a 14 day interruption

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)

Acknowledgements

❑ The authors would like to first and foremost thank **Susanna Aguilar** from Commonwealth Edison. We would also like to acknowledge other anonymous reviewers at Commonwealth Edison for providing constructive feedback on the report

❑ 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

Contact Information

Peter Larsen

Leader, Electricity Markets and Policy

Lawrence Berkeley National Lab

phlarsen@lbl.gov

Appendix

Survey design

❏ Samples of ComEd customers were presented with hypothetical scenarios of long-duration interruption scenarios lasting 24 hours, three days, and two weeks

❏ The interruptions were described as a complete loss of power affecting all homes and businesses within a 20-mile radius of the respondent's location

❏ Each interruption was said to occur suddenly and without warning, but the customer would be notified by their utility within a few hours of the onset how long it would take for power to be restored

❏ Approximately half of the customers were questioned about interruptions occurring in the summer and the other half about interruptions occurring in the winter

Information collected from surveys used for POET calibration

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

Survey design, sampling, and administration

❑ The general survey was administered between April 20, 2022 and June 21, 2022
  - ❑ The residential survey was administered using an online platform and respondents were compensated with a $5 pre-incentive payment
  - ❑ The SMB and LCI surveys were conducted via phone-based interviews and respondents were compensated by $50 to $100 (SMB) and $150 (LCI)

❑ Study team had a goal of receiving 600 completed surveys for residential, 200 for SMB, and 80 for LCI

❑ After survey pre-testing, it was determined that an additional sample of non-residential customers needed to be drawn and incentive payments were increased for SMB respondents
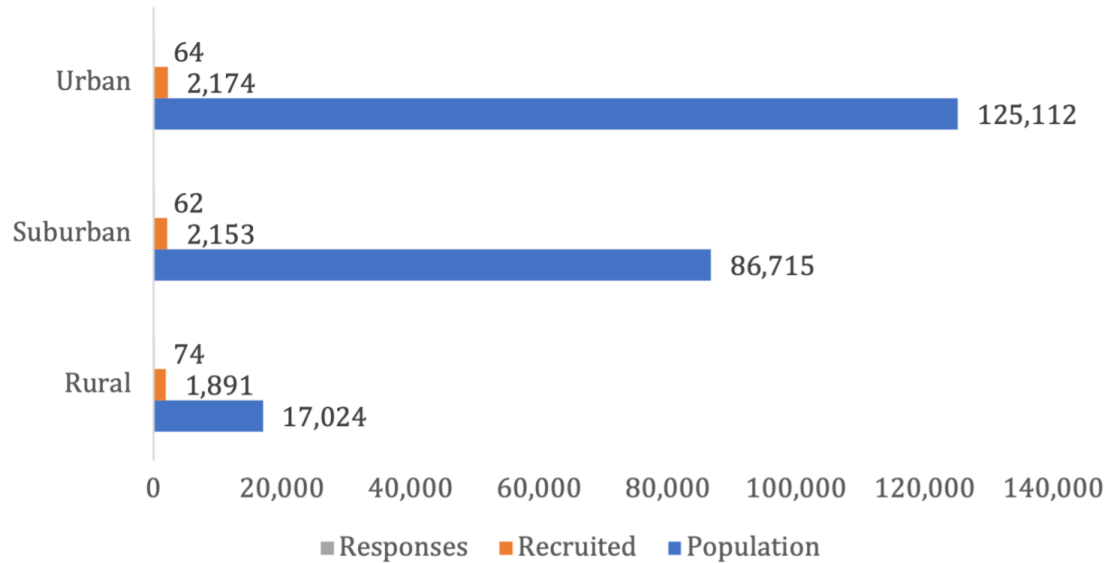
Population, sample, and respondents

❑ Residential, SMB, and LCI customers were recruited from samples drawn in each geographic area and industry sector

❑ Sample sizes were determined using a pretest

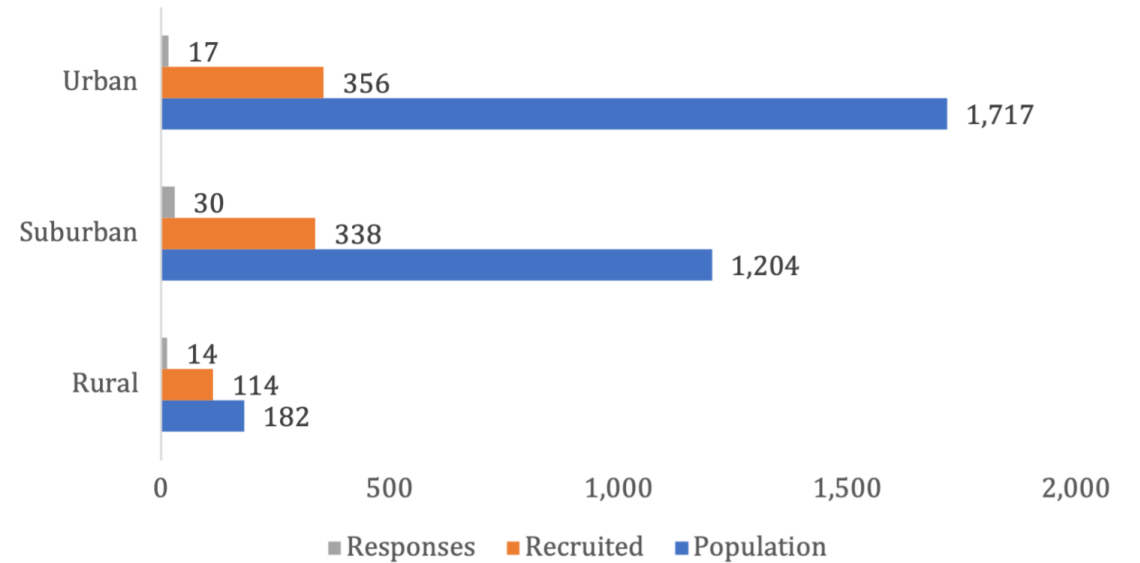|	Population	Sample	Responses received	Response rate
Residential	3,530,984	6,330	829	13%
Small/medium business (SMB)	228,851	6,218	200	3%
Large commercial & industrial (LCI)	3,103	808	61	8%

Population, sample, and responses received by geographic area (SMB/LCI)

Population, sample, and response received by region (SMB)

Region	Responses	Recruited	Population
Urban	64	2,174	125,112
Suburban	62	2,153	86,715
Rural	74	1,891	17,024

Population, sample, and response received by region (LCI)

Region	Responses	Recruited	Population
Urban	17	356	1,717
Suburban	30	338	1,204
Rural	14	114	182

Population, sample, and responses received by industry sector (SMB/LCI)

Number of responses collected by industry sector
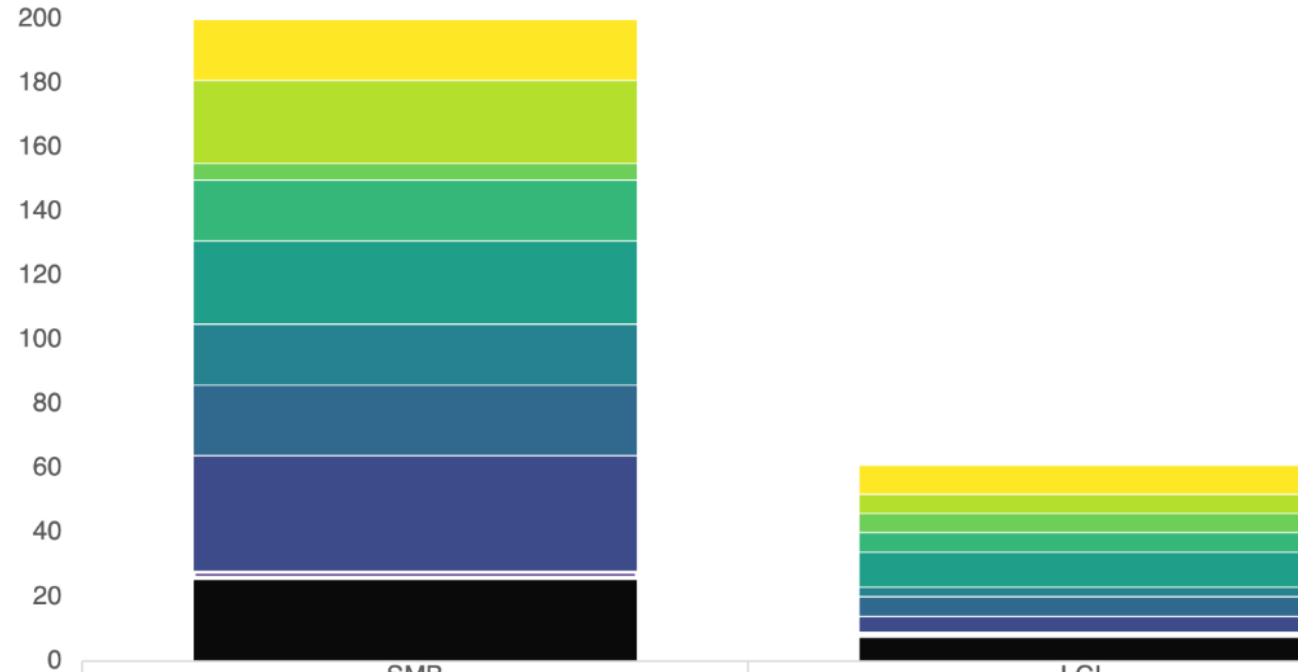
	SMB	LCI
■ Government	19	9
■ Restaurants, entertainment, other services	26	6
■ Hospitals and healthcare	5	6
■ Education	19	6
■ Telecommunications, finance, data processing	26	11
■ Retail	19	3
■ Wholesale trade, transportation	22	6
■ Manufacturing	36	5
■ Electric distribution, nat. gas, and water	2	1
■ Agricultural, construction, and mining	26	8