Case Studies of the Economic Impacts of Power Interruptions and Damage to Electricity System Infrastructure from Extreme Events

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This work was funded by the U.S. Department of Energy Office of Electricity, under Contract No. DE-AC02-05CH11231.

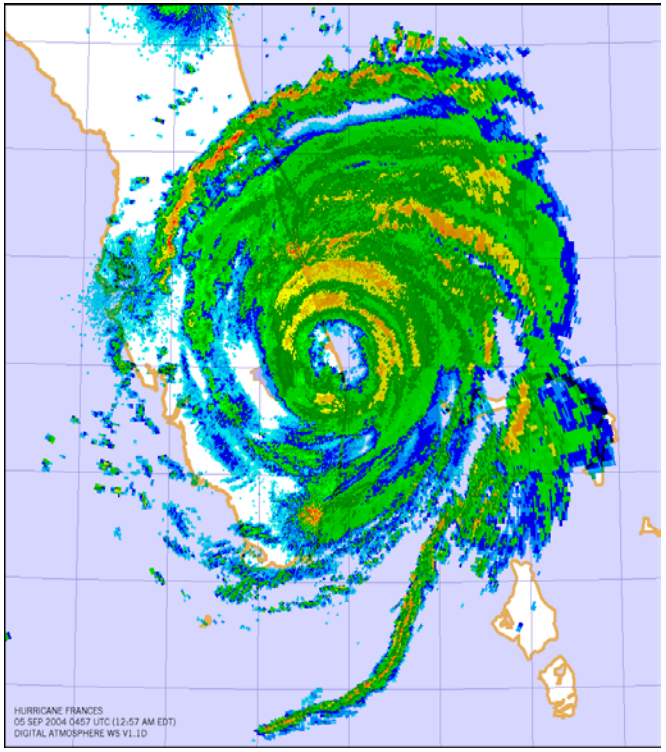
Study Motivation

- *Long-duration, widespread power interruptions* (LDWIs) are those lasting days, weeks or longer, and affecting entire utility service territories or larger regions—often caused by extreme weather.

- There is a growing need on the part of utilities and regulators for information on the:

1. Economic impacts of LDWIs

2. Costs and benefits of investments to mitigate such impacts



Research Questions

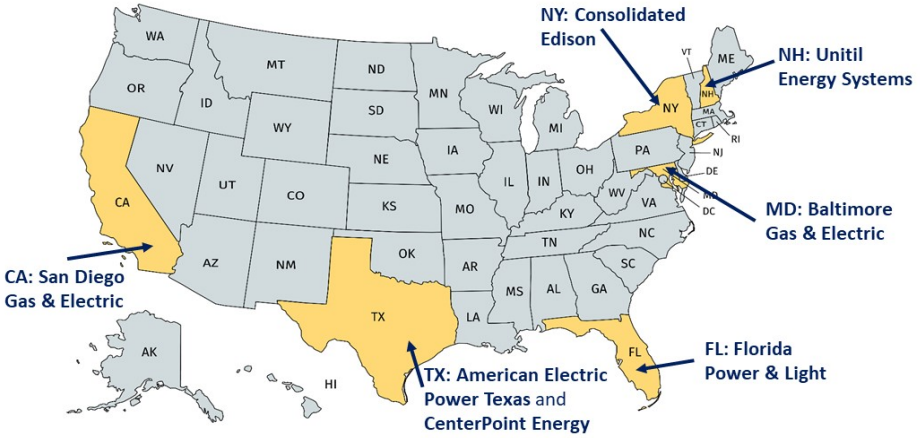
We investigated the following questions:

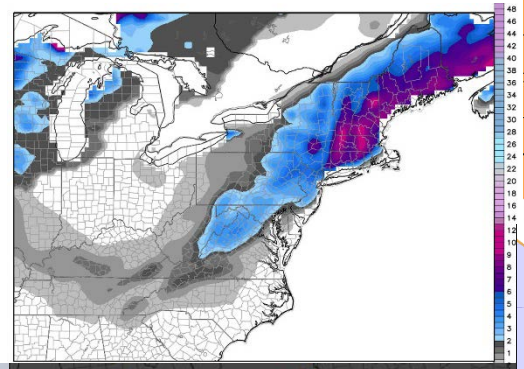
- *How do utilities…*
  1. *Assess the costs of system damage caused by extreme weather and the costs of recovering from this damage?*
  2. *Estimate customer costs of past power interruptions?*
  3. *Estimate the costs and benefits of investments to reduce power system vulnerabilities to future extreme weather events?*
  4. *Use the concept of "resilience" when making economic assessments of extreme weather impacts and the value of preventive investments?*

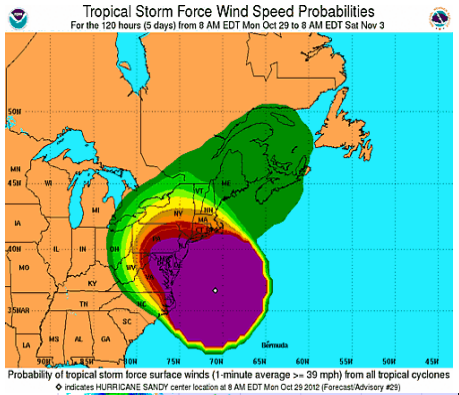
- *How do regulatory processes influence utilities' economic analyses related to power interruptions?*

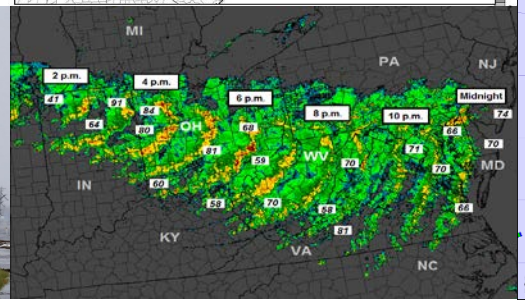
Approach and Scope

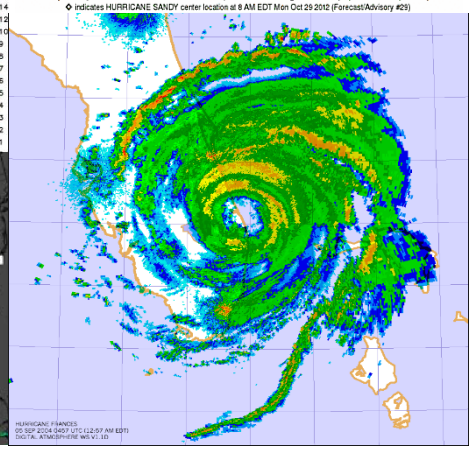
- We conducted case studies of investor-owned utilities and regulatory processes in six jurisdictions—selected for geographic, regulatory, utility-practice, and extreme event-type variation.











Method

Jurisdiction	Precipitating event
Florida	Hurricanes of 2004-2005
New York	Tropical Storm Sandy, 2012
Texas	Hurricanes of 2005, 2008, 2017
California	2007 Southern California wildfires
New Hampshire	Severe fall and winter storms in 2008, 2011, and 2014
Maryland	Derecho (severe wind event) in 2012

- Primary source of information was state public utilities commissions' online regulatory archives
- Secondary sources included reports by other state government agencies and academic literature

Method (cont.)

Availability of information on categories of economic impacts summarized in tables…	
Symbol	Key
●	Extensive publicly-available documentation
◒	Moderate amount of publicly-available documentation
○	Little/no publicly-available documentation

- Economic information related to ***cost recovery*** including:

1. Transmission system costs
2. Distribution system costs
3. Generation system costs
4. Increased customer service costs
5. Other costs

- Economic information related to ***mitigating future impacts*** including:

1. Avoided customer interruption costs
2. Avoided regional economic impacts
3. Other avoided societal impacts
4. Other
5. Cost-effectiveness or cost-benefit analysis conducted?

Florida, Hurricanes

- Hurricanes Katrina and Wilma caused unprecedented impacts on Florida Power & Light (FPL) and its customers
  - Storm damaged power plants, transmission lines, substations, and distribution facilities
  - Power interrupted to more than 3 million customers (75%) across 21 counties
  - Power was restored to most customers within several days, but full restoration > two weeks
  - Costs from these hurricanes exceeded FPL's storm impact insurance reserves
  - At the time, Wilma was the most damaging storm in FPL's history

Availability of economic information related to cost recovery…

Utility	Precipitating Event	Trans. System Costs	Dist. System Costs	Gen. System Costs	Increased Customer Service Costs	Other Costs	Comments
Florida Power & Light (FL)	Hurricanes of 2004-2005	●	●	●	●	●	"Other" costs include utility internal management and other expenses in support of recovery and restoration activities.

Florida, Hurricanes (cont.)

Availability of economic information related to mitigating future customer and regional impacts…								
Organization	**Precipitating Event**	**Avoided Customer Interruption Costs**	**Avoided Regional Economic Impacts**	**Other Avoided Societal Impacts**	**Other**	**Cost-Effectiveness Analysis?**	**Cost-Benefit Analysis?**	**Comments**
Florida Power & Light (FL)	Hurricanes of 2004-2005	○	○	○	○	Yes	No	"Other" category includes utility estimates of net present value of restoration cost savings per mile of hardened feeder; little or no documentation available on method to estimate the restoration cost savings.

- ***Economic analysis***
  - State law requires that storm hardening investments and measures be cost-effective, and that utility plans include estimates of their costs and benefits *to the utility.*
  - FPL has quantitatively estimated its own future restoration cost savings from storm hardening, but to-date, over several planning cycles, has only reported qualitative benefits to customers, stating that avoided cost information is unavailable.
- ***Regulatory factors and resilience***
  - FPL's economic analysis practices fully reflect the laws and regulations to which it is subject.
  - "Resilience" is not used either conceptually or operationally by the utility or the regulator.

New York, Tropical Storm Sandy

- In 2012, Hurricane Sandy was downgraded to a tropical storm before making landfall on the Eastern Seaboard, but several factors—including coincidence with high tide—made it unusually damaging.

- Sandy caused more than 2 million customers to lose power within the Consolidated Edison (Con Ed) service territory.
  - 50% were restored within three days, but full restoration took > 2 weeks

Availability of economic information related to cost recovery…

Utility	Precipitating Event	Trans. System Costs	Dist. System Costs	Gen. System Costs	Increased Customer Service Costs	Other Costs	Comments
Consolidated Edison (NY)	Tropical Storm Sandy	●	●	●	●	●	"Other" category includes employee expenses and equipment rentals.

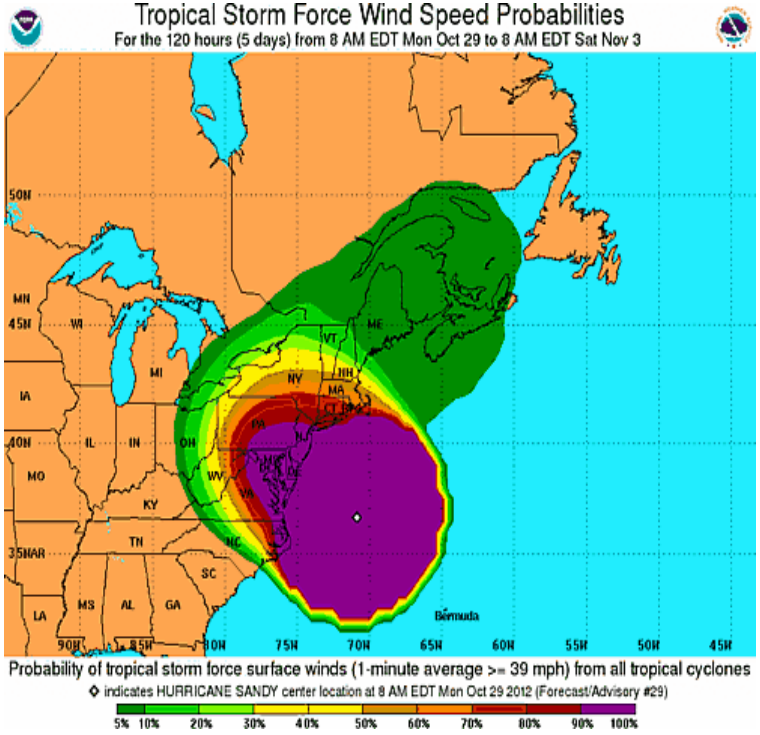
New York, Tropical Storm Sandy (cont.)

Availability of economic information related to mitigating future customer and regional impacts…

Organization	Precipitating Event	Avoided Customer Interruption Costs	Avoided Regional Economic Impacts	Other Avoided Societal Impacts	Other	Cost-Effectiveness Analysis?	Cost-Benefit Analysis?	Comments
Consolidated Edison (NY)	Tropical Storm Sandy	●	○	○	○	Yes	Yes	Extensive documentation is available in NYPSC online regulatory archives; consultant report on applying the VOLL estimates was not publicly available.
City of New York (NY)	Tropical Storm Sandy	○	◒	○	○	Yes	Yes	The city's indirect impact estimation method and results were reported in regulatory documents in Con Ed rate case proceedings.

New York, Tropical Storm Sandy (cont.)

- ***Economic analysis***
  - Con Ed developed a risk assessment and cost-benefit tool to assess potential storm hardening projects.
  - Berkeley Lab's ICE Calculator was used to estimate customer interruption costs, but extrapolated for outages lasting up to 12 days.
  - City of New York (through a consultant) conducted simple Gross City Product-based analysis of economic impacts of severe storms.
- ***Regulatory factors and resilience***
  - The NY regulatory environment, processes, and procedures strongly influence what types of economic analysis Con Ed applies to storm hardening projects.
    - The utility proposes particular methods and studies, but these must be approved with multi-stakeholder support.
  - Resilience concept is widely used in Con Ed's and NYPSC's processes for storm hardening planning and implementation.



Texas, Hurricanes

- Hurricane Harvey made landfall on the central Gulf Coast in August 2017 as a Category 4 hurricane—it was rated as the most severe U.S. tropical cyclone in terms of scope and peak rainfall since the late 19th century.
- Power to about 300,000 Texas electricity customers was interrupted:
  - American Electric Power (AEP) restoration times were 5 days for roughly 50% of its customers; 10% of AEP customers did not have power for > 2 weeks
  - CenterPoint Energy restored power to most of its customers in ~1 week

Availability of economic information related to cost recovery…

Utility	Precipitating Event	Trans. System Costs	Dist. System Costs	Gen. System Costs	Increased Customer Service Costs	Other Costs	Comments
AEP Texas (TX)	Hurricanes of 2005, 2008, and 2017	●	●	N/A	◒	●	"Other" category includes expenses for required activities in support of restoration work, such as charges for land rights and settlement of damage claims incurred from transmission construction activities.

Texas, Hurricanes (cont.)

Availability of economic information related to mitigating future customer and regional impacts…								
Organization	**Precipitating Event**	**Avoided Customer Interruption Costs**	**Avoided Regional Economic Impacts**	**Other Avoided Societal Impacts**	**Other**	**Cost-Effectiveness Analysis?**	**Cost-Benefit Analysis?**	**Comments**
CenterPoint Energy (TX)	Hurricanes of 2005, 2008, and 2017	◒	○	○	○	Yes	Yes	Utility—in partnership with EPRI—conducted a cost-benefit analysis of the Intelligent Grid Project.

- ***Economic analysis***
  - Texas law requires electric utility storm hardening plans, including cost-effective strategies for reducing vulnerabilities.
  - No evidence was found of either utility using avoided cost information.
    - However, a 2013 consultant study for the Electric Reliability Council of Texas (ERCOT) did report such information.
    - CenterPoint did conduct a cost-benefit analysis, but not for storm hardening investments.
- ***Regulatory factors and resilience***
  - Utilities' use of cost-effectiveness, but not cost-benefit, analysis reflects state law. Documentation does refer to resilience, though not extensively; utility reports did not define this term.

California, Wildfires

- Over many decades, fires at the “wildfire-urban interface” in California have increased in both frequency and severity.
- Catastrophic fires occurred in 2007 across Southern California, including the service territory of San Diego Gas & Electric (SDG&E)—several of which were determined to have been caused by faulty power lines.
- Unlike the other case studies, this case focused not on power interruptions, but rather on damages caused by a utility’s infrastructure.
  - For the first time in the state’s history, these damages exceeded the utility’s insurance liability coverage.

Availability of economic information related to cost recovery…							
Utility	**Precipitating Event**	**Trans. System Costs**	**Dist. System Costs**	**Gen. System Costs**	**Increased Customer Service Costs**	**Other Costs**	**Comments**
San Diego Gas & Electric (CA)	2007 Southern California wildfires	○	○	○	○	○	The costs submitted to the CPUC for recovery were primarily associated with the utility’s legal costs.

California, Wildfires (cont.)

Availability of economic information related to mitigating future customer and regional impacts…								
Organization	**Precipitating Event**	**Avoided Customer Interruption Costs**	**Avoided Regional Economic Impacts**	**Other Avoided Societal Impacts**	**Other**	**Cost-Effectiveness Analysis?**	**Cost-Benefit Analysis?**	**Comments**
San Diego Gas & Electric (CA)	2007 Southern California wildfires	◒	○	○	○	Yes	No	Risk-management framework has been developed that draws on Berkeley Lab avoided cost estimates; regulatory staff considered economic benefits of fire prevention measures to be unquantifiable.

- ***Economic analysis***
  - SDG&E and other utilities now conduct risk analysis of wildfires and measures to prevent their causation by electric power infrastructure. However, the CPUC has judged cost-benefit analysis to be currently infeasible for this problem due to the lack of a generally-accepted cost-avoidance model.
- ***Regulatory factors and resilience***
  - The CPUC and other agencies have been deeply involved in addressing the wildfire risk problem; “resilience” is very seldom mentioned in regulatory records and other documents.

New Hampshire, Severe Storms

- Severe ice, wind, and snow storms impacted the state in 2008, 2011, and 2014, respectively.

- The 2011 storm left more than 300,000 Unitil Energy Systems (UES) customers without power; more than 230,000 customers were without power in 2014.

Availability of economic information related to cost recovery…							
Utility	**Precipitating Event**	**Trans. System Costs**	**Dist. System Costs**	**Gen. System Costs**	**Increased Customer Service Costs**	**Other Costs**	**Comments**
Unitil Energy Systems (NH)	Severe fall and winter storms	N/A	●	N/A	○	○	

New Hampshire, Severe Storms (cont.)

Availability of economic information related to mitigating future customer and regional impacts…								
Organization	**Precipitating Event**	**Avoided Customer Interruption Costs**	**Avoided Regional Economic Impacts**	**Other Avoided Societal Impacts**	**Other**	**Cost-Effectiveness Analysis?**	**Cost-Benefit Analysis?**	**Comments**
Unitil Energy Systems (NH)	Severe fall and winter storms	○	○	○	○	Yes	No	

- ***Economic analysis***
  - UES uses metrics such as SAIDI to quantify the potential benefits of its reliability and vegetation management projects and investments, but does not conduct either cost-effectiveness or cost-benefit analysis with costs and benefits monetized.
- ***Regulatory factors and resilience***
  - The NHPSC does not require specific types of economic analysis for investments to reduce the state power system's vulnerability to storms, and this is reflected in UES's practices.
  - Resilience is not mentioned in New Hampshire's regulations for electric utilities. UES does mention "resiliency" in its reports, but this term is not defined.

Maryland, Derecho

- A derecho is a storm with sustained wind speeds greater than 58 mph, traveling in one direction along a relatively straight path; gusts can exceed 100 mph.
- A June 2012 derecho impacted an area spanning 10 Mid-Atlantic states including Maryland, interrupting power to more than 4 million customers.
- The average Baltimore Gas & Electric (BGE) outage was almost 40 hours; restoration took more than one week for many customers.

Availability of economic information related to cost recovery…							
Utility	**Precipitating Event**	**Trans. System Costs**	**Dist. System Costs**	**Gen. System Costs**	**Increased Customer Service Costs**	**Other Costs**	**Comments**
Baltimore Gas & Electric (MD)	June 2012 Derecho	●	●	●	○	○	

Maryland, Derecho (cont.)

Availability of economic information related to mitigating future customer and regional impacts…								
Organization	**Precipitating Event**	**Avoided Customer Interruption Costs**	**Avoided Regional Economic Impacts**	**Other Avoided Societal Impacts**	**Other**	**Cost-Effectiveness Analysis?**	**Cost-Benefit Analysis?**	**Comments**
Grid Resiliency Task Force (MD)	June 2012 Derecho	●	○	○	○	Yes	Yes	

- ***Economic analysis***
  - The Grid Resiliency Task Force used Berkeley Lab's ICE Calculator to estimate customer costs of the derecho.
  - Among its recommendations was that Maryland utilities should determine cost-effective levels of investment in resiliency.
    - BGE has used the ICE Calculator for this purpose in subsequent rate cases.
  - The National Oceanic and Atmospheric Administration conducted an analysis of the regional (multi-state) economic impacts of the derecho, but did not explain details of the approach.
- ***Regulatory factors and resilience***
  - The Maryland regulatory environment, processes, and procedures strongly influence what types of economic analysis, and what tools, BGE and other utilities apply to storm hardening projects.
  - The resilience concept is also widely used in the Maryland Public Service Commission's and BGE's processes for planning and implementation of projects.

Summary of Available Information, Cost Recovery

Availability of economic information related to cost recovery…						
Utility	**Precipitating Event**	**Trans. System Costs**	**Dist. System Costs**	**Gen. System Costs**	**Increased Customer Service Costs**	**Other Costs**
Florida Power & Light (FL)	Hurricanes of 2004-2005	●	●	●	●	●
Consolidated Edison (NY)	Tropical Storm Sandy	●	●	●	●	●
AEP Texas (TX)	Hurricanes of 2005, 2008, and 2017	●	●	N/A	◒	●
San Diego Gas and Electric (CA)	2007 Southern California wildfires	○	○	○	○	○
Unitil Energy Systems (NH)	Severe fall and winter storms	N/A	●	N/A	○	○
Baltimore Gas & Electric (MD)	June 2012 Derecho	●	●	●	○	○

Summary of Available Information, Mitigating Future Impacts

Availability of economic information related to mitigating future customer and regional impacts…

Organization	Precipitating Event	Avoided Customer Interruption Costs	Avoided Regional Economic Impacts	Other Avoided Societal Impacts	Other	Cost-Effectiveness Analysis?	Cost-Benefit Analysis?
Florida Power & Light (FL)	Hurricanes of 2004-2005	○	○	○	○	Yes	No
Consolidated Edison (NY)	Tropical Storm Sandy	●	○	○	○	Yes	Yes
City of New York (NY)	Tropical Storm Sandy	○	◒	○	○	Yes	Yes
CenterPoint Energy (TX)	Hurricanes of 2005, 2008, and 2017	◒	○	○	○	Yes	Yes
San Diego Gas and Electric (CA)	2007 Southern California wildfires	◒	○	○	○	Yes	No
Unitil Energy Systems (NH)	Severe fall and winter storms	○	○	○	○	Yes	No
Grid Resiliency Task Force (MD)	June 2012 Derecho	●	○	○	○	Yes	Yes

Summary of Key Findings

- ***How do utilities assess the costs of system damage caused by extreme weather and the costs of recovering from this damage?***
  - Utilities conduct detailed physical and engineering assessments of damages
  - They estimate costs of replacement and repair as well as response and recovery operations

- ***How do utilities estimate customer costs of past power interruptions?***
  - Utilities often report statistics, including the counts, locations, and durations of customers without power, but generally did not monetize these customer impacts

- ***How do utilities or others estimate the costs and benefits of investments to reduce power system vulnerabilities to future extreme weather events?***
  - Costs of preventive investments can be estimated with reasonable accuracy, but the economic benefits are very uncertain
  - Cost-effectiveness analysis is the most common method
  - Berkeley Lab's ICE Calculator was used, but there was no evidence of avoided cost information being developed specifically for LDWI applications
  - No utility or regulator used regional economic modeling to estimate either direct or indirect costs of power interruptions

Summary of Key Findings (cont.)

- ***How do utilities and regulators use the concept of resilience in economic assessments of extreme weather impacts and the value of preventive investments?***
  - Utilities and regulators referred to "resilience" extensively in two of the case studies, a moderate amount in two others, and very little in the remaining two
  - "Resilience investments" were typically related to traditional storm hardening, for example, but at greater scale and cost
  - The challenge is not what "resilience metrics" should be used, but rather how to value proposed investments using these metrics within a cost-benefit framework
- ***How do regulatory processes influence utilities' economic analysis related to power interruptions?***
  - Laws, regulations, and regulatory practices can significantly influence utilities' preparation for, and response to, long-duration widespread power interruptions
  - New economic tools and methods are usually developed and/or adopted through collective decision-making involving utilities as well as other stakeholders, rather than unilaterally by utilities

Key Recommendations

1. ***Investigate the value of consistently collecting information on past extreme events***

2. ***Improve economic analysis of avoided costs associated with preventing long-duration, widespread power interruptions***

3. ***Determine factors that influence regulatory/utility willingness to incorporate, into planning and other processes, economic information and methods for analyzing long-duration, widespread power interruptions***

Report can be downloaded by visiting:

https://emp.lbl.gov/

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