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Edward J. Bloustein School of Planning and Public Policy

Center for Energy, Economic and Environmental Policy (CEEEP) http://ceeep.rutgers.edu/

One-Day Workshop

Analyzing the Costs and Benefits of Electric Utility Hardening Efforts in Response to Severe Weather

Oct 21, 2014

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Utility Hardening:
Economic Efficiency and Cost-Benefit Analysis (CBA)

- Integration of CBA with reliability and resiliency analysis
- Dealing with uncertainties during CBA
- Examples of CBA of hardening options
- Data collection challenges and issues

Role of Models

- Models do not completely mimic the world, that is why they are called models
- All models are wrong, some are useful
- If you want to know what to do, ask your mother

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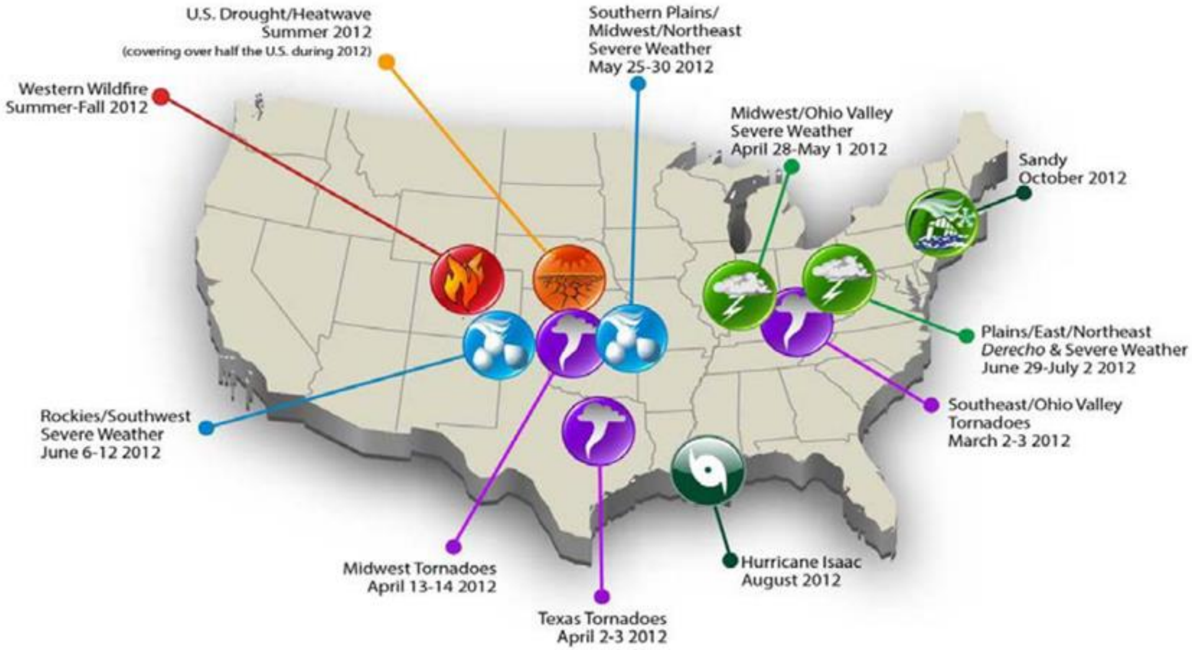
The United States suffered eleven numbers of billion-dollar weather disasters in 2012



Source: National Oceanic and Atmospheric Administration (NOAA)

Between 2003 and 2012, roughly <u>679 power outages</u>, each affecting at least 50,000 customers, occurred due to weather events (U.S. DOE)

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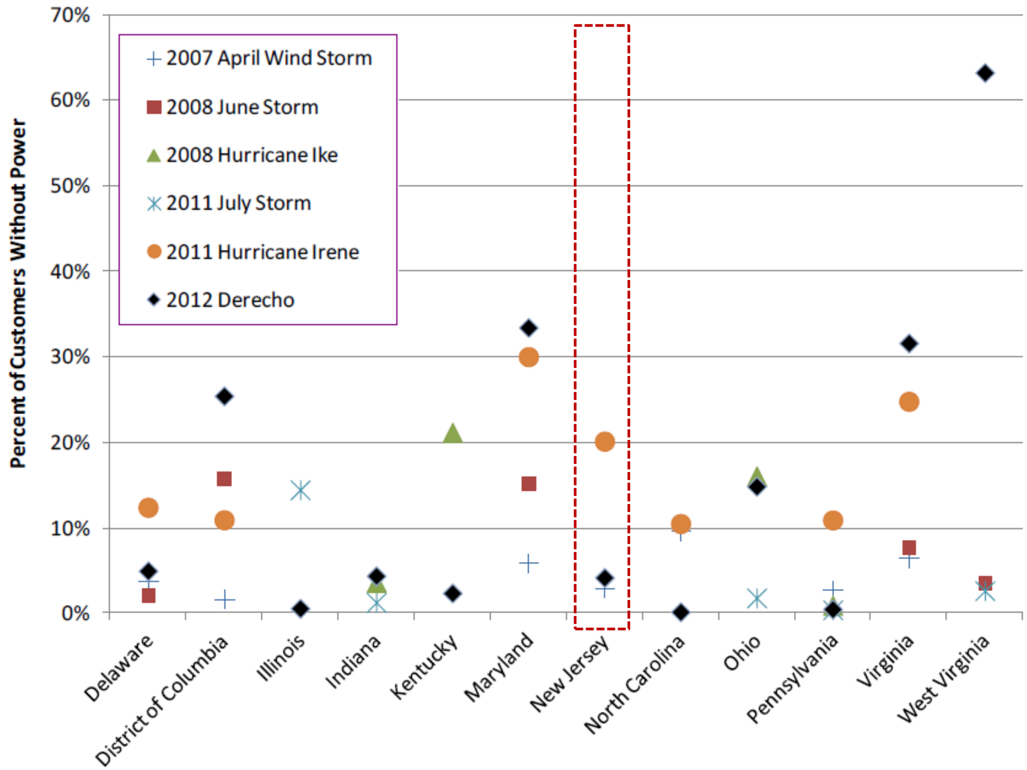
The State of New Jersey has witnessed some of the worst storms in the last few years



Source: OE/ISER Situation Reports and Energy Assurance Daily, A Review of Power Outages and Restoration Following the June 2012 Derecho – U.S. DOE, August 2012

New Jersey electric customers were severely impacted by Hurricane Irene and Superstorm Sandy (U.S. DOE)

The New Jersey Board of Public Utilities asked GE Energy Consulting to assist in reviewing selected areas related to electric distribution hardening

Scope of Work

- Identify and recommend storm hardening initiatives deserving consideration by the New Jersey Electric Distribution Companies (EDCs)
- Evaluate the costs and benefits of implementing various hardening measures by the EDCs
- Perform a review of the submissions by the EDC relating to their Smart Grid and Distribution Automation pilots and plans

Key recommendations proposed by GE Energy Consulting in its final presentation to the BPU on Oct 20, 2014

Event Reporting

- Enhance reporting requirements to enable comparative and quantitative assessment and scorecard-based performance assessments

Distribution Hardening

- Predict associated damage, number of customer interruptions, and restoration time by danger tree
- Segment customers by restoration priority
- Communicate estimates to ratepayers and provide convenient mechanisms for customers to report danger trees (e.g. via twitter feeds)
- Selectively underground most critical feeders and tap lines
- Determine the most cost-effective inspection cycle/method
- Upgrade construction near coast; design for extreme loading
- Insert steel/concrete structures in long straight wood circuits

Substation Hardening

- Add elevation attributes to flood-prone assets and report
- Perform limited failure modes and effects analysis (FMEA)
- FMEA findings, estimate and report hardening costs
- Estimate and report costs of inspection; adjust cycles
- Identify critical communication facilities; estimate hardening costs
- Require quick deployment of mobile subs and backup generators

Smart Grid & Distribution Automation

- Mandate standard EDC SGDAP reporting
- Asses/implement most impactful SG-DA technologies
- Deploy SG-DA technology selectively
- Mandate storm recovery reporting
- Require EDCs to evaluate damage prediction tools
- Assess the value and feasibility of DG and Microgrids

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Questions surrounding the reliability of the grid:

"NY Regulators are building a more Distributed, Reliable, Transactive Grid" Sept 2014

Solar storms add to growing list of pressing issues for reliability, Sept 2014

Repeat Physical attack on California power station, Sept 2014

Strom Arthur Outages, "It took Nova Scotia Power a week to restore service to everyone." Aug 2014

Facing Climate Change, Cities embrace resiliency, Sept 2014

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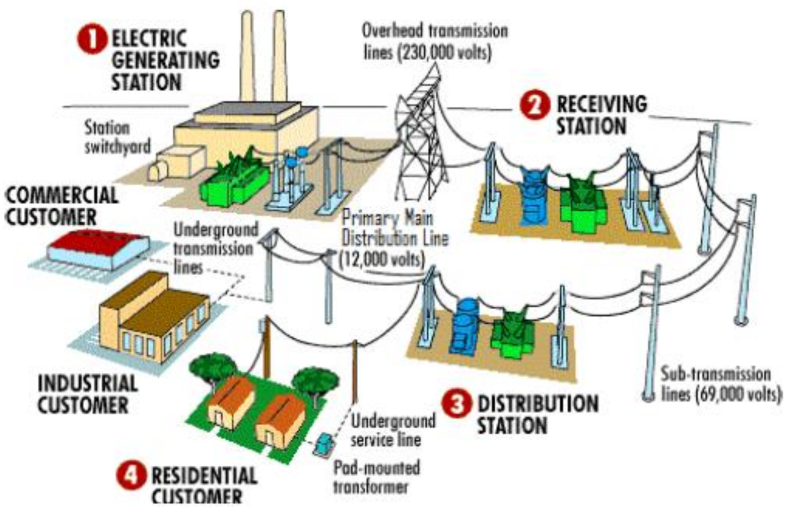
Electric Grid Reliability and Resiliency: in the context of severe weather

- What is an acceptable level of reliability and resiliency in a severe weather event condition?
- What is an acceptable level of investment by the utilities which can ensure that they are able to 'weather the storm'?
- Should utilities be incentivized for their ability (by corollary be penalized for their inability) to improve reliability and harden the grid?
- What are the top 5 / top 10 actions or measures that can achieve maximum impact?

Utility expenses are proposed along the value chain – most notably at the distribution level



Source: SRP

Hardening Activities

- Wind Protection
  - Upgrading damaged poles and structures
  - Strengthening poles with guy wires
  - Burying power lines underground
- Flood Protection
  - Elevating substations/ Control rooms
  - Relocating/ constructing new lines and facilities
- Modernization
  - Installing asset tools and databases
  - Deploying sensors and control technology

Year-Round Readiness Efforts

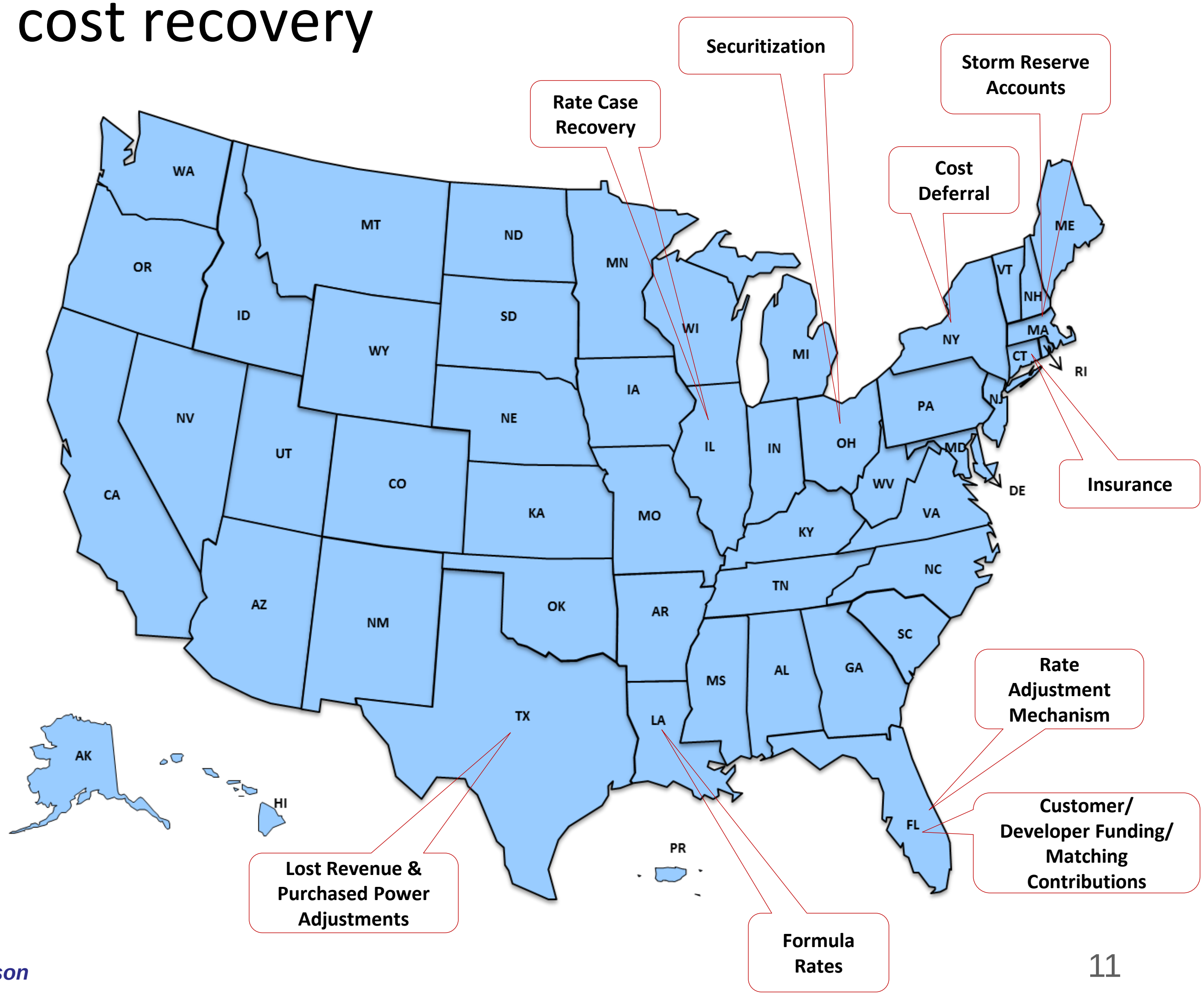
- Managing vegetation
- Complying with inspection protocols
- Procuring spare T&D equipment
- Purchasing or leasing mobile transformers & substations
- Conducting hurricane preparedness planning & training

Source: Hardening and Resiliency U.S. Energy Industry Response to Recent Hurricanes Seasons, DOE, August 2010

Regulators have adopted different approaches for approving utility hardening cost recovery

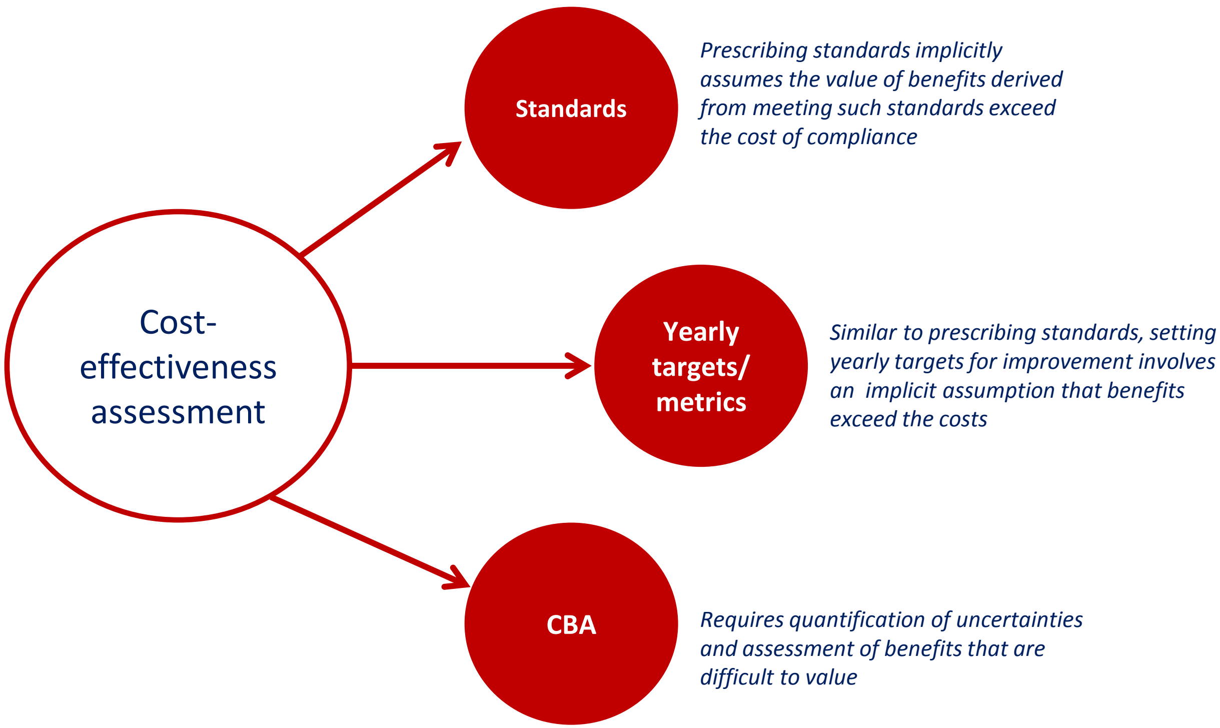
1	Capital Costs
–	incurred in replacing wires, poles, transformers, trucks etc.

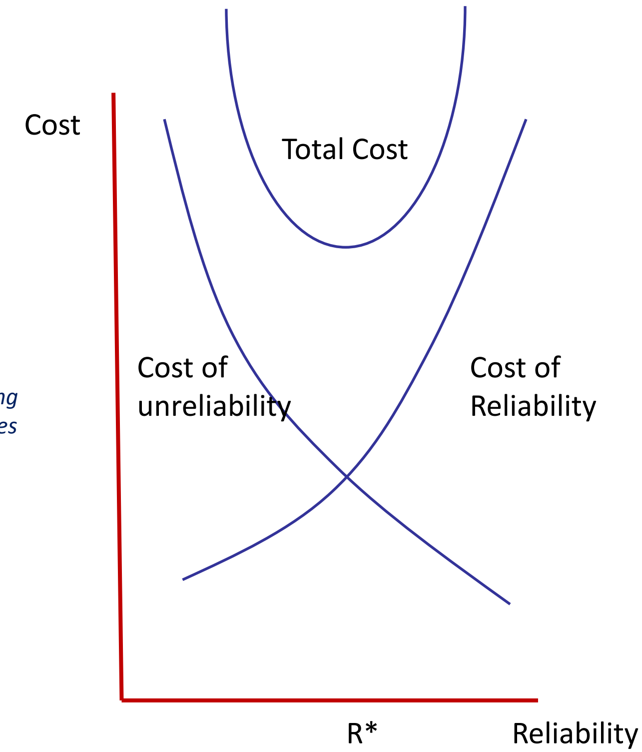
2	O&M Costs
–	Cost of labor and consumables spent in hardening activities



Source: Before and After The Storm, Edison Electric Institute, March 2014

Policy makers and regulators have to deal with the difficult task of evaluating cost-effectiveness of utility hardening investments





=> Cost effectiveness does not mean efficient

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Key considerations before assessing cost-effectiveness

Policy Considerations

- How to measure reliability and resiliency?
- What should be the hierarchy of planning documents for efforts to increase reliability and resiliency?
- How does changes in business environment (microgrid, increased penetration of RE) changes need for reliability and resiliency planning?

Governance Considerations

- Who is responsible for advocating standards for reliability and resiliency?
- Who is responsible for maintaining reliability and resiliency (especially when large-scale events disrupt interdependent infrastructure)?
- Who is responsible for monitoring reliability and resiliency?

Economic Considerations

- What is the optimal cost for maintaining reliability and resiliency at the desired level?
- Who pays for such costs?
- How to avoid/ minimize cost shifting among ratepayers?
- How to measure benefits (individual and society) from investments in increasing and maintaining reliability?

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Cost-benefit analysis (CBA)

- Cost-benefit analysis should be informative not dispositive
- Policy goals should be explicitly decided not implicitly through which cost-benefit results to use
- Cost-benefit analysis provides insights throughout program design and implementation not just a number to justify past decisions
- Cost-benefit analysis can as easily obscure issues as it can enlightened them

=> Easy to use and easy to misuse

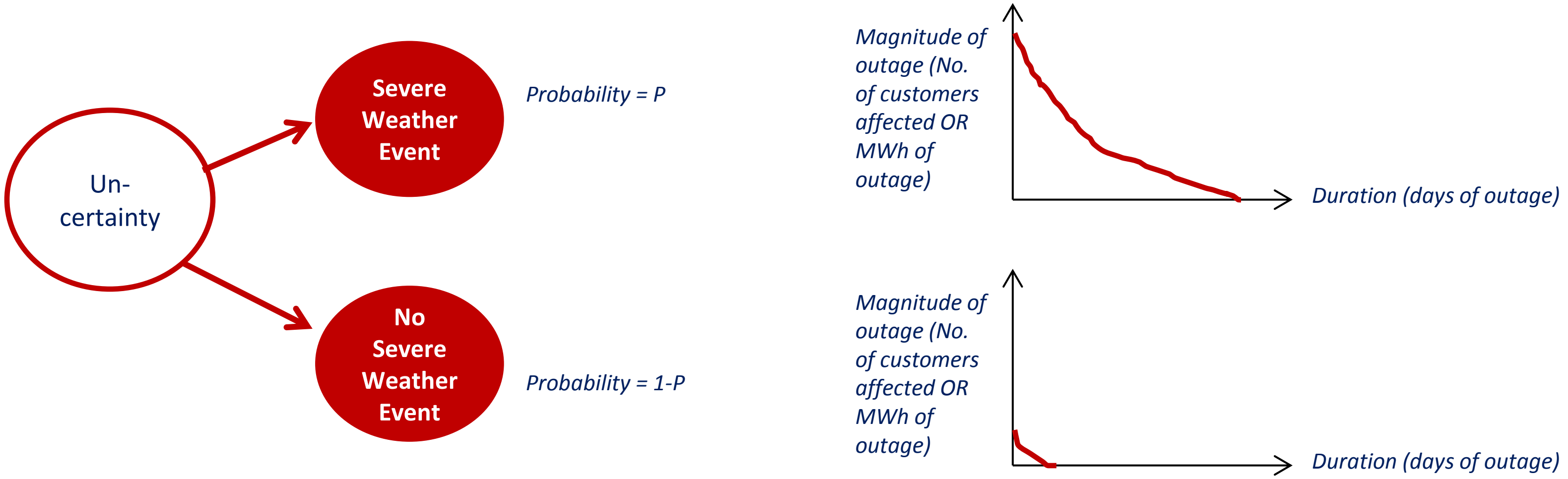
Why Cost-Benefit Analysis of utility hardening measures is a hard problem?

- Formally, it involves decision-making under uncertainty involving low probability, high consequence events
- Standard heuristics that we use do not apply and in fact can lead to poor decisions when applied to these types of decisions
- Data and models are evolving and incomplete
- Understandably, there is public and political calls for immediate action – and much can be done right away – but analysis of the efficacy of costly options is a challenging undertaking
- CBA assumes all benefits can be quantified – such as aesthetics value to a community as a result of undergrounding
- Hardening measures may interact in complex and unforeseen ways

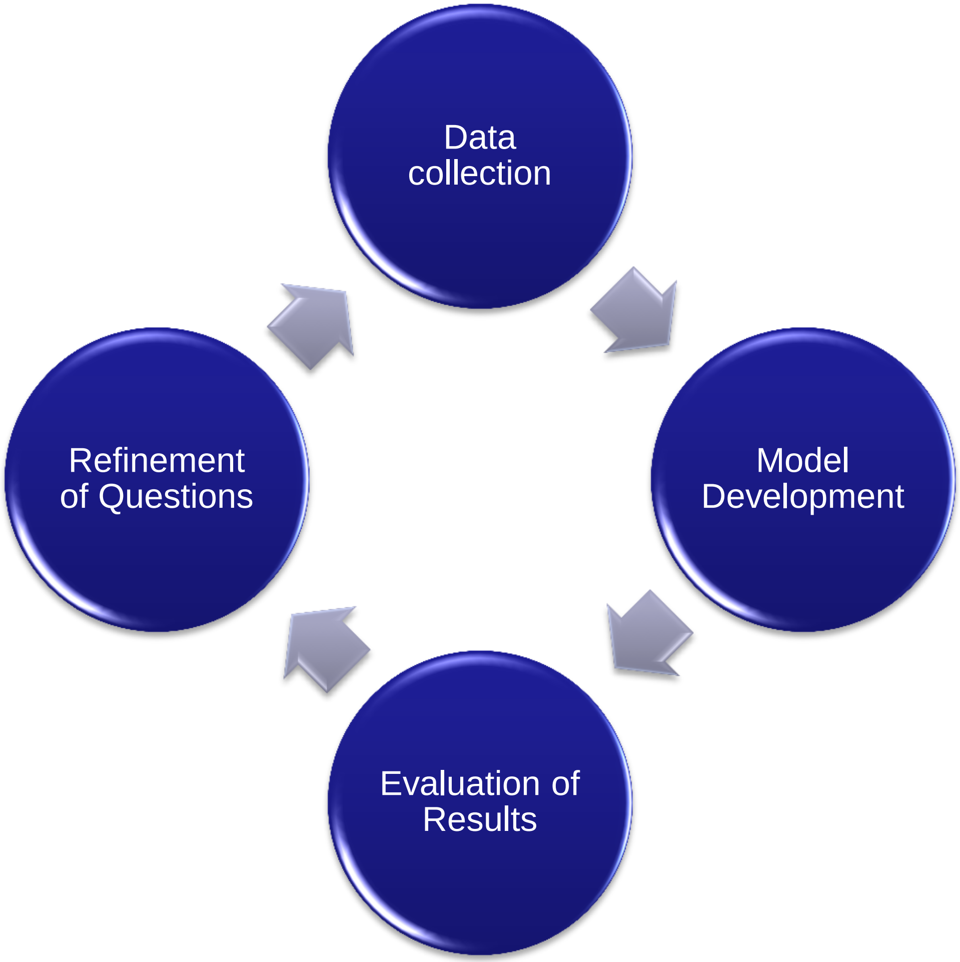
Why Cost-benefit analysis of utility hardening measures is a hard problem? (Con’t)

- The quantification of benefits of any proposed response requires determining the **probability, magnitude, and duration** of the electricity outages that were avoided due to that response
- Different responses will have different impacts on the probability, magnitude and duration of outages

A Probability Risk Assessment Model is needed



Data and models needed for a long-term CBA is an iterative process



- Data collection
  - Before storm
  - During storm
  - After storm
- Continuous loop of data analysis and feedback, back to data collection stage

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CBA becomes complex because the "uncertainty itself is uncertain"

- The probabilities, magnitudes and durations of the initiating events (i.e., severe weather) are themselves uncertain
- Overtime (many years), with more data collection, these uncertainties can be updated with new information
- Aleatory vs. epistemic

The costs and benefits of specific hardening efforts can be utility specific and circuit specific within a utility

- Some examples
  - Undergrounding
  - Vegetation management
  - Backup power/distributed generation
  - Hardening distribution facilities
  - Moving substations
  - Redundancy of key facilities
- Having accurate data sets and models involves communication and coordination between the BPU, EDCs, and stakeholders within a regulatory framework

Utility Hardening: Economic Efficiency and CBA

- Integration of CBA with reliability and resiliency analysis
- Dealing with uncertainties during CBA
- Examples of CBA of hardening options
- Data collection challenges and issues

Quantification of benefits is complex

VOLL

for a customer who faces outage

DURATION

of outage

MAGNITUDE

of severe weather event

FREQUENCY

of severe weather event

NJ Storm Events Database Compilation

A. Main sources used by CEEEP for initial database creation

- **National Oceanic and Atmospheric Administration (NOAA) Storm Events Database**
  - Used as a starting point for fields of data to be collected (date, event details, storm 'type', wind speed, precipitation, and number of outages)
- **Bayshore Regional Watershed Council**: ***New Jersey's Most Notable Storms Website***
  - Listed mainly hurricanes and tropical storms to effect NJ; used as a guideline for investigating information on larger storms

  The website has since been revised and the data that was collected originally is no longer available.
- **NOAA Miami Regional Library**: Monthly Weather Review
  - Database with monthly details of storms; provided additional details for most noteworthy storms

NJ Storm Events Database Compilation

B. Limiting Factors

- Use of available electronic resources
  - Events in the database were found through: NOAA, Bayshore Regional Storm events and subsequent outage reporting were found through online databases and archives – thus our own knowledge and findings are limited to the capacity in which these events were recorded.
- Timeline of recorded events
  - We found power outages were reported in more detail since 1980; prior decades have significantly less reports available online or at all.
  - The NOAA Storm Events Database, which provided data for a great number of the events included is limited to the years 1996-2013, and thus skews the data set to show more events in this time period. Thus, we cannot comment on any frequency of events over the entire time period included.

CEEEP's initial efforts need to be reviewed by appropriate subject matter experts for completeness and proper interpretation

NJ Storm Events Database Compilation

C. Terminology (1/2)

- Storms classified into one of 6 categories: Wind/Rain, Winter Weather/Nor'easter, Tornado, Ice Storm, Lightning, Tropical Storms/Hurricanes.
  - Storms were either classified by NOAA or details provided through other electronic sources gave a narrative perspective of each storm that generally included indicators such as wind speeds, precipitation type, as well as other factors.
  - From the data sorted by storm type, the total number of events were tallied, along with the total number of customers that were reported to have lost power for that event type.

NJ Storm Events Database Compilation

C. Terminology (2/2)

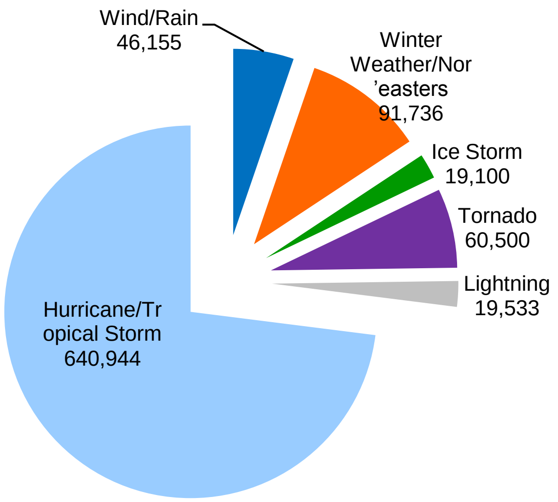
- All of the outages reported are sustained[1] outages.
- Events collected were 1000 or more outages per a weather event.
- "Large-scale" events are labelled as 100,000 or more outages per a weather event.

[1]Sustained outages are characterized by Richard Campbell as "sustained duration outages lasting longer than five minutes (and extending to hours or days) " (Campbell 3)

Outages refer to outage for a meter and not for a customer

NJ Data and preliminary findings

A. Breakdown of Storm Event "Types" and their respective Mean Outages (1985 – 2013)



Mean # of Outages Per Storm Type

	# of Total Events	# of Cumulative Affected Customers	% of reported events	Mean size of customer outages
Wind/Rain	96	4,430,900	67.1	46,155
Winter Weather/Nor'easters	22	2,018,200	15.4	91,736
Ice Storm	5	95,500	3.5	19,100
Tornado	2	121,000	1.4	60,500
Lightning	9	175,800	6.3	19,533
Hurricane/Tropical Storm	9	5,768,500	6.3	640,944
Totals	**143**	**12,609,900**		

Table 1: Database storm event totals and proportion of storm types/mean outages; from CEEEP Storm Events Database)

Data and Findings

B. Breakdown of Storm Event "Types" and their respective Mean Outages (1985 – 2013)

All Storms – Outages: 1985 - 1995

Storm Type	Total # of Storms	Total # Outages
Hurricane/ Tropical Storm	2	277,000
Winter Weather/ Nor'easter	2	140,000
Wind/Rain	Not Reported	Not Reported
Ice Storm	Not Reported	Not Reported
Tornado	Not Reported	Not Reported
Lightning	Not Reported	Not Reported
Total	**4**	**417,000**

All Storms – Outages: 1996 - 2013

Storm Type	Total # of Storms	Total # Outages
Hurricane/ Tropical Storm	7	5,491,500
Winter Weather/ Nor'easter	20	1,878,200
Wind/Rain	96	4,430,900
Ice Storm	5	95,500
Tornado	2	121,000
Lightning	9	175,800
Total	**139**	**12,192,900**

No consistent data available over long period in the way that storms have been reported. The reporting of outages for more types of storms is apparent in these two year brackets.

NJ Data and preliminary findings

C. "Large-scale" events 1985 – 2013: 100,000 + outages reported per event

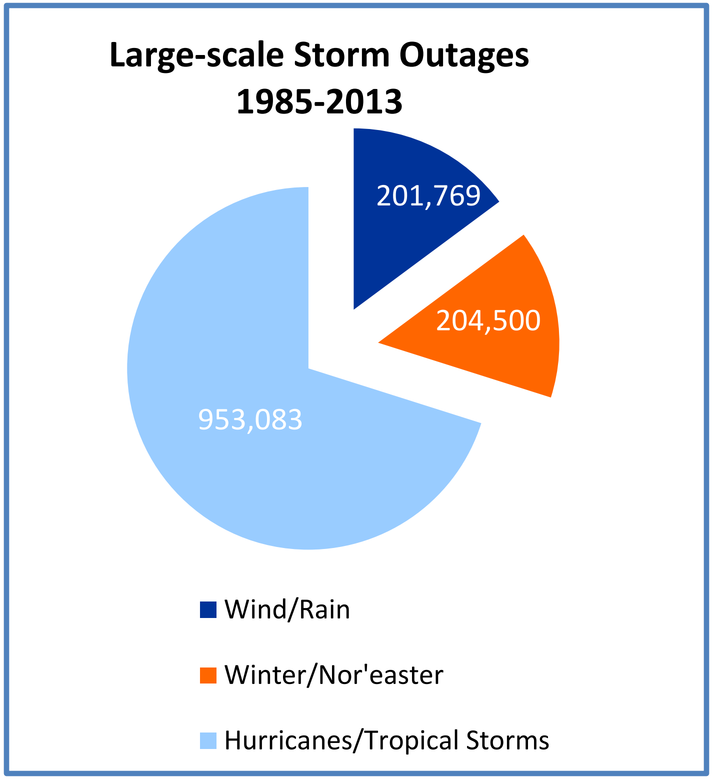
"Large-scale" events in the database are labeled as 100,000 or more outages per weather event.

Of the total database, 27 events were classified as "large-scale" by their respective outages.

By classifying these outages according to the magnitude of customers that lost power, we could see the types of storms that most affected distribution.

NJ Data and preliminary findings

D. “Large-scale Storms” 1985 – 2013: 100,000 + outages reported per event



	# of Large-scale Storms	# of Cumulative Affected Customers	% of Major events	Mean size of customer outages
Wind/Rain	13	2,623,000	48.2	201,769
Winter Weather/Nor’easters	8	1,636,000	29.6	204,500
Hurricane/Tropical Storm	6	5,718,500	22.2	953,083
Totals	**27**	**9,977,500**		

Table 2: “Large-scale” Storms and their outages (by totals, proportion, and mean outages); from CEEEP Storm Events Database)

NJ Data and preliminary findings

E. Hurricanes/ Tropical Storms in NJ

- Despite accounting for only a relatively small percentage of the types of weather-related events that have caused power outages in the state since 1985, hurricanes and tropical storms show a considerable number of mean customer outages (as seen in the previous charts).
- Using data retrieved from the Bayshore Regional Watershed Council online resource entitled "List of New Jersey's Most Notable Storms" and additional online sources*, we have cited **36 hurricanes and tropical storms** that have affected New Jersey in various capacities – as remnants of the storm to high levels of precipitation and winds - **since 1985 to present day**, an average of 1.3 hurricanes or tropical storms per year over that span of time.

**Number based on data/observations by Bayshore Regional Watershed Council up to 2007, along with United States National Oceanic and Atmospheric Administration's National Weather Service, National Climatic Data Center, and the National Weather Service Weather Prediction Center.*

NJ Data and preliminary findings

F. Hurricanes/ Tropical Storms in NJ

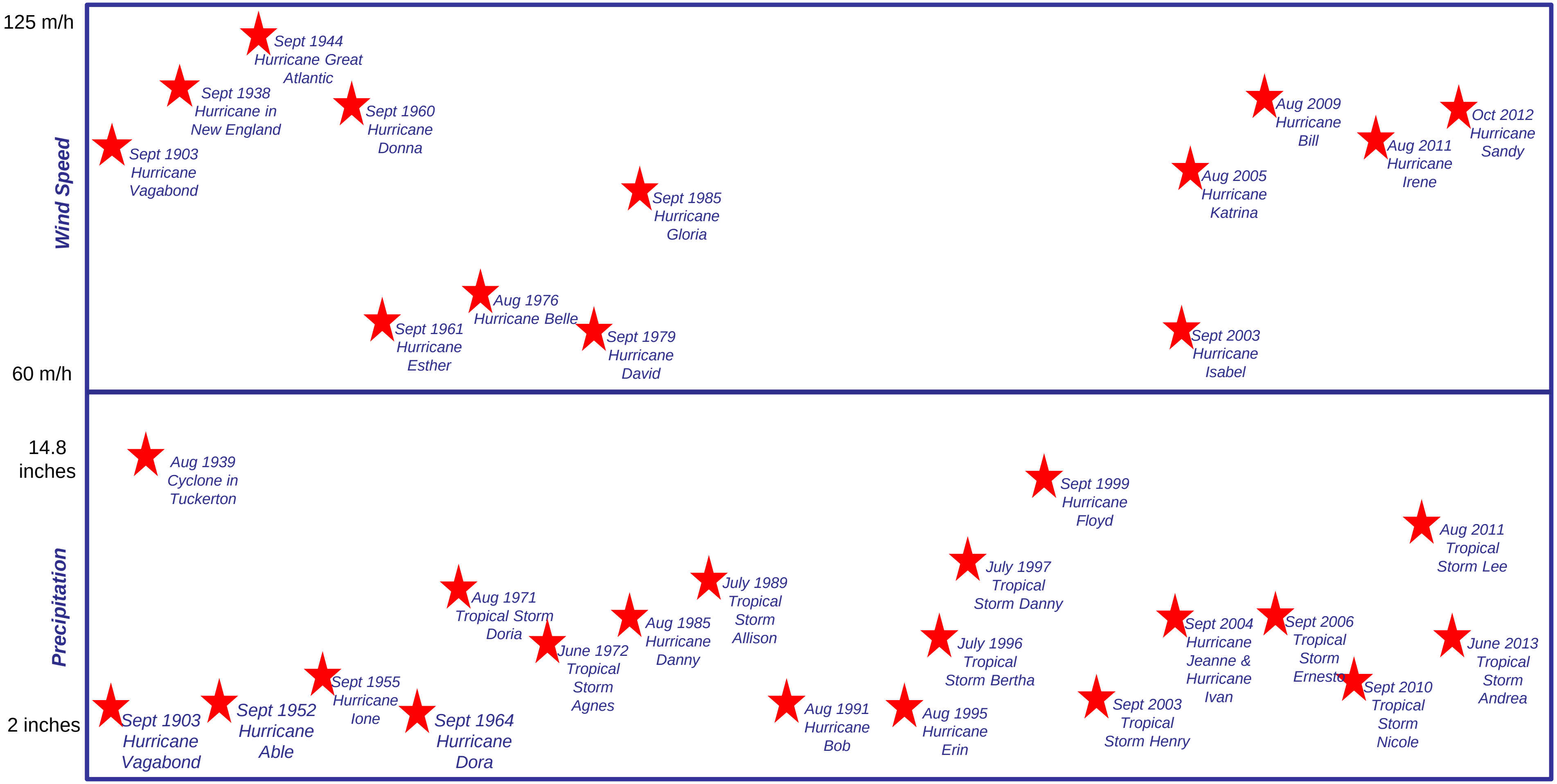
- While some of these 36 hurricanes/tropical storms reported minor electricity distribution impact - including little to no major power loss to customers - our database compilation included **9 total with reported power outages at 1000 or more**, and classified **6 as "large-scale" with over 100,000 outages** (many of the 6 exceeding this number).

- Thus major hurricanes/tropical storms average at .21 per year over the 28 year span of 1985-2013.

- These **6 major storms** accounted for an estimated total of **5,717,800** reported outages over the course of 1985-2013, **averaging to 952,966 outages per storm**.

Data and Findings

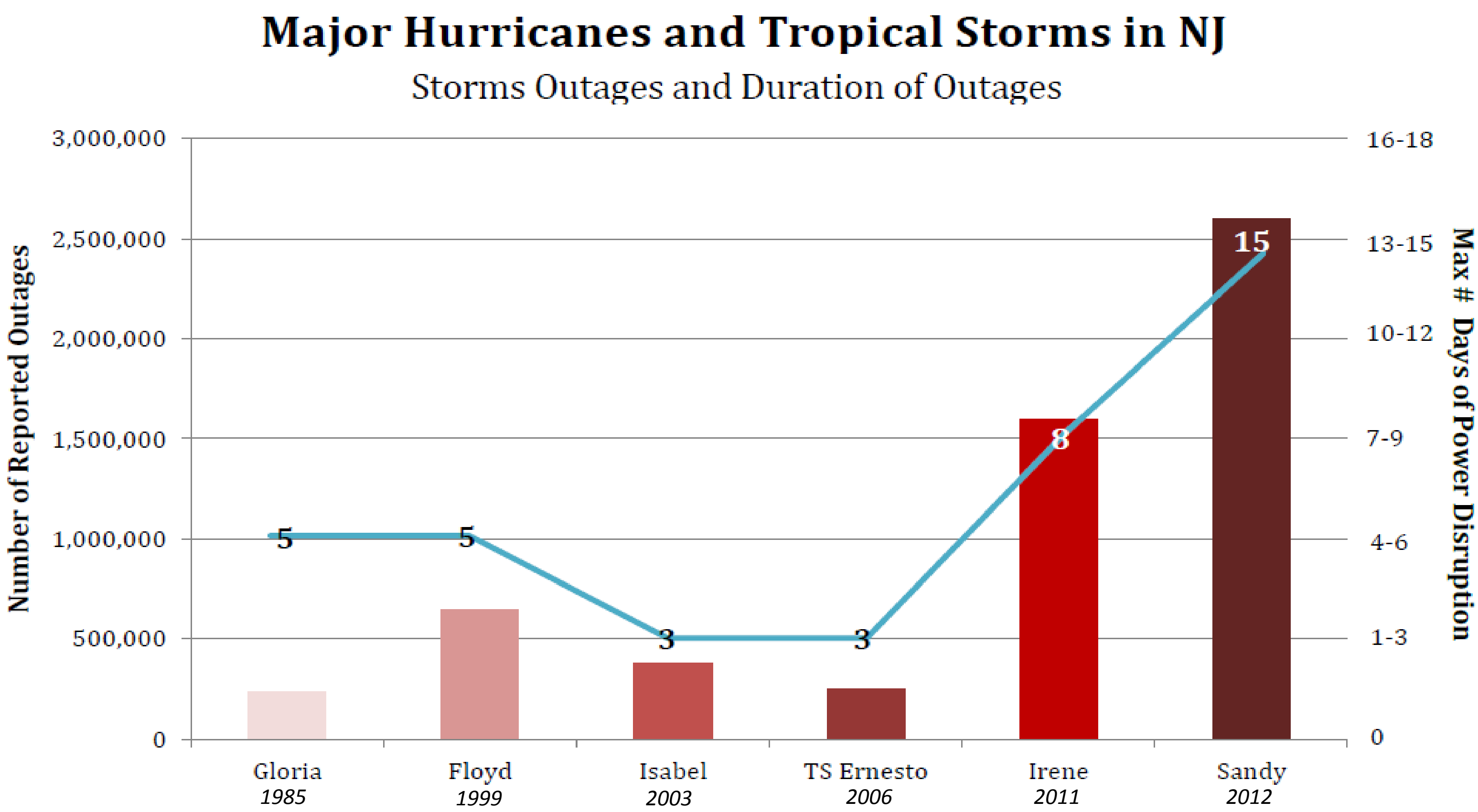
G. Hurricanes/ Tropical Storms in Northeast region



Graph not to scale and does not list all hurricanes/ tropical storms during the depicted period

NJ Data and preliminary findings

H. Comparing Hurricanes/ Tropical Storms Outages and Duration



Predictions of future severe weather from other studies

WRF control simulation 2012
Observed 2012 (National Hurricane Center (NHC))
WRF simulation 2050

Figure 14. Comparison of observed (2012), modelled (2012) and simulated 2050 track of Superstorm Sandy (Base map: © 2014 OpenStreetMap Data CC-By-SA)

Source: DNV GL: Adaptation to a changing climate, Hovik, 2014

What is the 'Value' of uninterrupted and quality power supply to a consumer?

VOLL (Value of Lost Load)

- "the value an average consumer puts on an unsupplied MWh of energy" (Cramton and Lien, 2000)
- 'reliability worth', 'willingness to pay/accept', 'value of electric service'

- $1 bn, voltage disturbance blakouts of 1996 in California (Douglas, 2000)
- $6 bn, 2003 US Northeast blackout (Graves and Wood, 2003)
- VOLL entire economy in US (2007) $/kWh (Welle and Zwaan, 2007)
  - » Developed Countries 4 to 40
  - » Developing Countries 1 to 10

Estimate of Total VOLL Value
PSE&G System-Wide Hypothetical 1 Day Outage

Customer Class	Number of Customers	Unserved kWhs	VOLL ($ per Unserved kWh)	Total VOLL
Residential	1,871,700	37,106,134	$0.92	$34,107,816
Commercial	273,499	64,487,493	$49.17	$3,170,909,519
Industrial	9,219	11,564,795	$11.29	$130,581,186
TOTAL	2,154,418	113,158,422	$29.48	$3,335,598,521

Source: Analysis of Benefits: PSE&G's Energy Strong Program, The Brattle Group, Oct 7, 2013

There exists no market for interruptions of energy supply – quantifying VOLL remains a challenge

VOLL depends upon various factors notably the type of facility

Factors affecting VOLL

Location densely populated areas and areas with a high concentration of industry are most affected

Duration longer outages are more disruptive overall, but also have a lower per unit cost

Customer Type residential, commercial or industrial

Amount of Notification loss can be lowered by advance notice

Season some industries may face greater loss from outages during certain seasons

Time of Week & Time of Day weekday outages are most costly for firms; for residential weekend outages are more costly; Afternoon interruptions are more costly for firms; morning outages are more costly for residents

What methodologies can be adopted to quantify VOLL?

Approach	Description	Strength	Weakness
Revealed preference (market behavior)	Use of surveys to determine expenditures customers incur to ensure reliable generation (i.e., back-up generators and interruptible contracts) to estimate VOLL	•Uses actual customer data that is generally reliable	•Only relevant if customers actually invest in back-up generation •Limited consideration of duration and/or timing of outages •Difficult for residential customers to quantify expenses
Stated choice (contingent valuation and conjoint analysis)	Use of surveys and interviews to infer a customer's willingness-to-pay, willingness-to-accept and trade-off preferences	•More directly incorporates customer preferences •Includes some indirect costs •Considers duration and/or timing of outages	•Experiment and survey design is time-consuming and effort intensive •Need to manage for potential biases •Residential customers may give unreliable answers due to lack of experience
Macroeconomic (production function)	Uses macroeconomic data and other observable expenditures to estimate VOLL (e.g. GDP/electric consumption)	•Few variables •Easy to obtain data •GDP reasonable proxy for business VOLL	•Does not consider linkages between sectors, productive activities •Proxies for cost of residential outages may be arbitrary or bias
Case Study	Examines actual outages to determine VOLL	•Uses actual, generally reliable data	•Costly to gather data •Available case studies may not be representative of other outages/ jurisdictions

Source: Estimating the Value of Lost Load, London Economics, June 2013

Outage costs studies are not new and have been attempted after major blackout events

Cost of the New York City blackout - 1977				
Impact Areas	**Direct Costs ($M)**		**Indirect Costs ($M)**	
Business	Food Spoilage Wages Lost Securities Industry Banking Industry	1.0 5.0 15.0 13.0	Small Businesses Private Emergency Aid	155.4 5.0
Government			Federal Assistance Programs New York Assistance Programs	11.5 1.0
Consolidated Edison	Restoration Costs Overtime Payments	10.0 2.0	New Capital Equipment	65.0
Insurance			Federal Crime Insurance Fire Insurance Private Property Insurance	3.5 19.5 10.5
Public Health Services			Public Hospitals – Overtime, Emergency Room Charges	1.5
Other Public Service	MTA – Revenue Losses MTA – Overtime and Labor	2.6 6.5	MTA Vandalism MTA Capital Equipment Red Cross Fire Department Police Department State Courts Prosecution and Correction	0.2 11.0 0.01 0.5 4.4 0.5 1.1
Westchester County	Equipment Damage Overtime Payments	0.25 0.19		
TOTAL		$55.54		$290.16

Source: Electrical Power Interruption Cost, Estimates for Individual Industries, Sectors, and U.S. Economy, PNNL, 2002

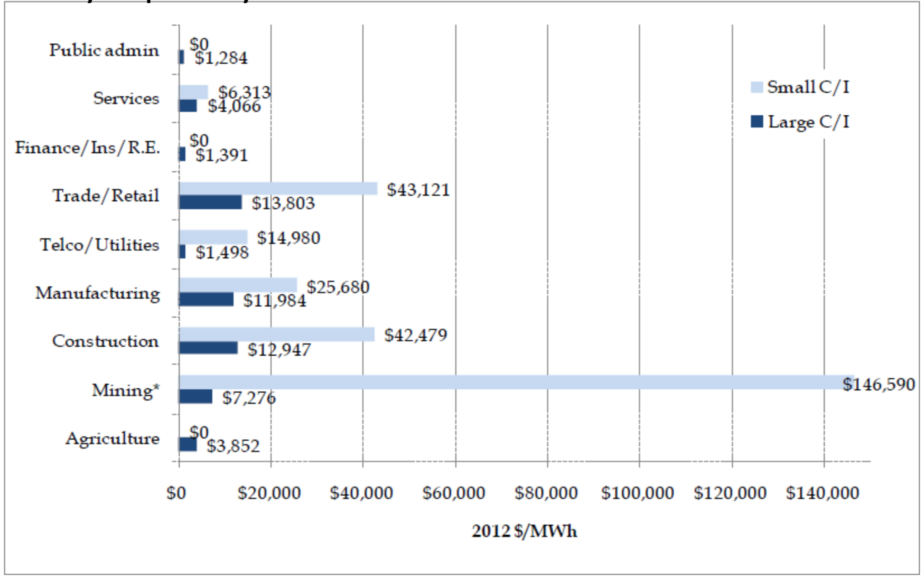
More recent estimates of VOLL from various national and regional studies

Costs per Avg. kWhr of a 1 hour interruption for Medium & Large C&I (2008$)	
Interruption Characteristics	**Mean (Ratio)**
Season	
Winter	$13.8
Summer	$22.8
Day	
Weekend	$30.6
Weekday	$21.4
Region	
Midwest	$19.8
Northwest	$19.9
Southeast	$18.2
Southwest	$37.0
West	$28.5

Costs per Avg. kWhr of a 1 hour interruption for Medium & Large C&I (2008$)		Costs per event – 1 hour interruption duration Medium & Large C&I (Summer Weekday Afternoon) (2008$)
Interruption Characteristics	**Mean (Ratio)**	
Industry		
Agriculture	$43.6	$8,049
Mining	$7.6	$16,366
Construction	$62.9	$46,733
Manufacturing	$22.0	$37,238
Telco. & Utilities	$19.0	$20,015
Trade & Retail	$34.2	$13,025
Fin., Ins. & RE	$32.7	$30,834
Services	$18.7	$14,793
Public Admin	$14.8	$16,601

Source: Estimated Value of Service Reliability for Electric Utility Customers in the United States, Lawrence Berkeley National Laboratory (LBNL), 2009

Estimated VOLLs by sector (median value, $/MWh) – based on the LBNL 2009 study – reported by London Economics

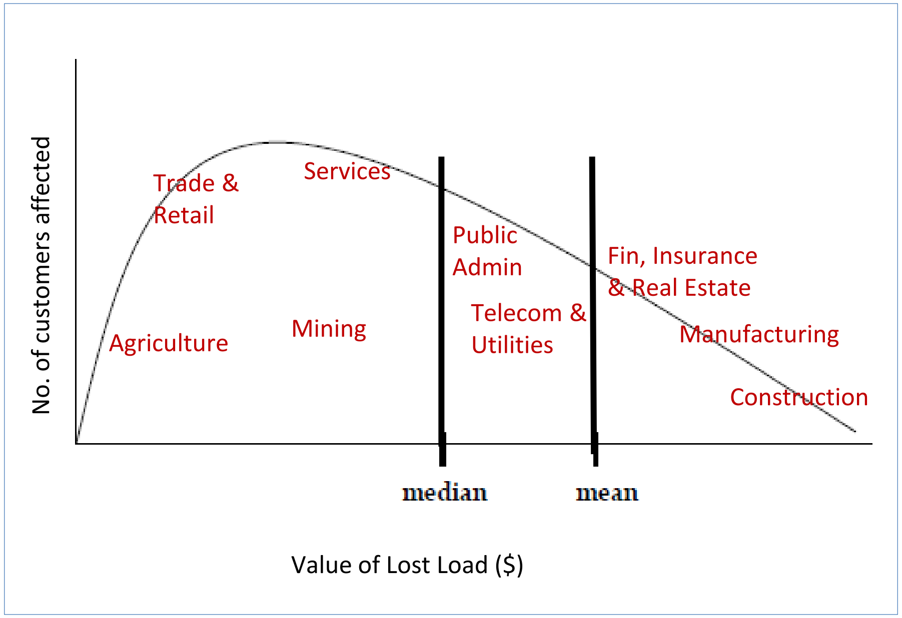


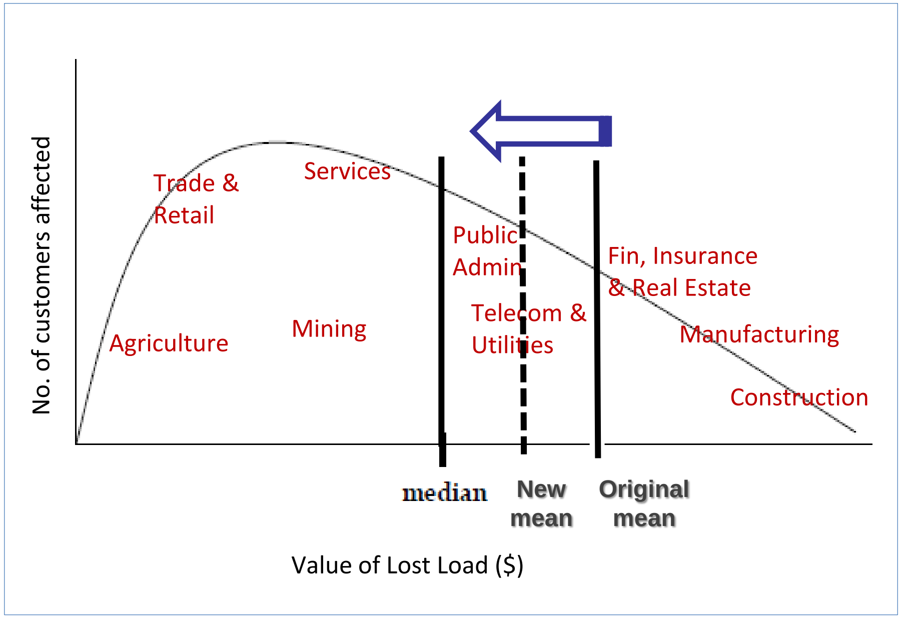
Source: Estimating the Value of Lost Load, London Economics, 2013

Caveats:

- *LBNL does **not** report median VOLL*
- *LBNL does **not** report NJ specific or Northeast specific VOLL*
- *London Economics does not study NJ specific or Northeast specific VOLL*
- *London Economics quotes a 2003 Northeast specific study by ICF ("The Economic Cost of the Blackout" which uses an assumed VOLL (as a multiple of retail electricity price) to calculate total economic cost of outage*

VOLL also depends upon whether any existing backup arrangements are present



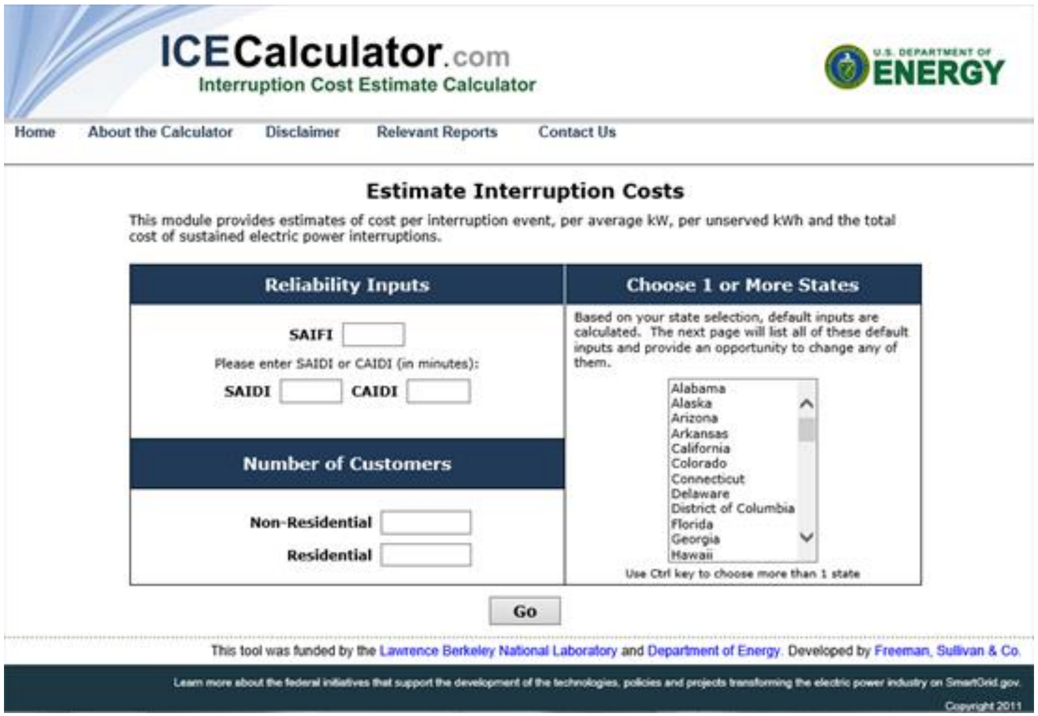


Source:

- *Estimated Value of Service Reliability for Electric Utility Customers in the United States, Lawrence Berkeley National Laboratory, 2009*
- *Estimating the Value of Lost Load, London Economics, 2013*

Possibly customers with high VOLL shall have some back up arrangements; thereby shifting the mean towards left

Cost of interruptions calculation using U.S. DOE "Interruption Cost Estimate Calculator"



Name of Utility	Results	
ACE, NJ	No. of Customers	483,508
	Total Cost of Sustained Interruptions (2011$)	$171,476,718
	Cost per Unserved kWh (2011$)	$39.4
JCP&L, NJ	No. of Customers	969,179
	Total Cost of Sustained Interruptions (2011$)	$147,771,603
	Cost per Unserved kWh (2011$)	$37.5
PSE&G, NJ	No. of Customers	1,998,822
	Total Cost of Sustained Interruptions (2011$)	$183,709,186
	Cost per Unserved kWh (2011$)	$42.6
RECO, NJ	No. of Customers	133,400
	Total Cost of Sustained Interruptions (2011$)	$107,943,705
	Cost per Unserved kWh (2011$)	$59.4

Results for NJ utilities using utility-specific reliability & customer data and DOE's Interruption Cost Estimate Calculator

Utility Hardening: Economic Efficiency and CBA

- Integration of CBA with reliability and resiliency analysis
- Dealing with uncertainties during CBA
- Examples of CBA of hardening options
- Data collection challenges and issues

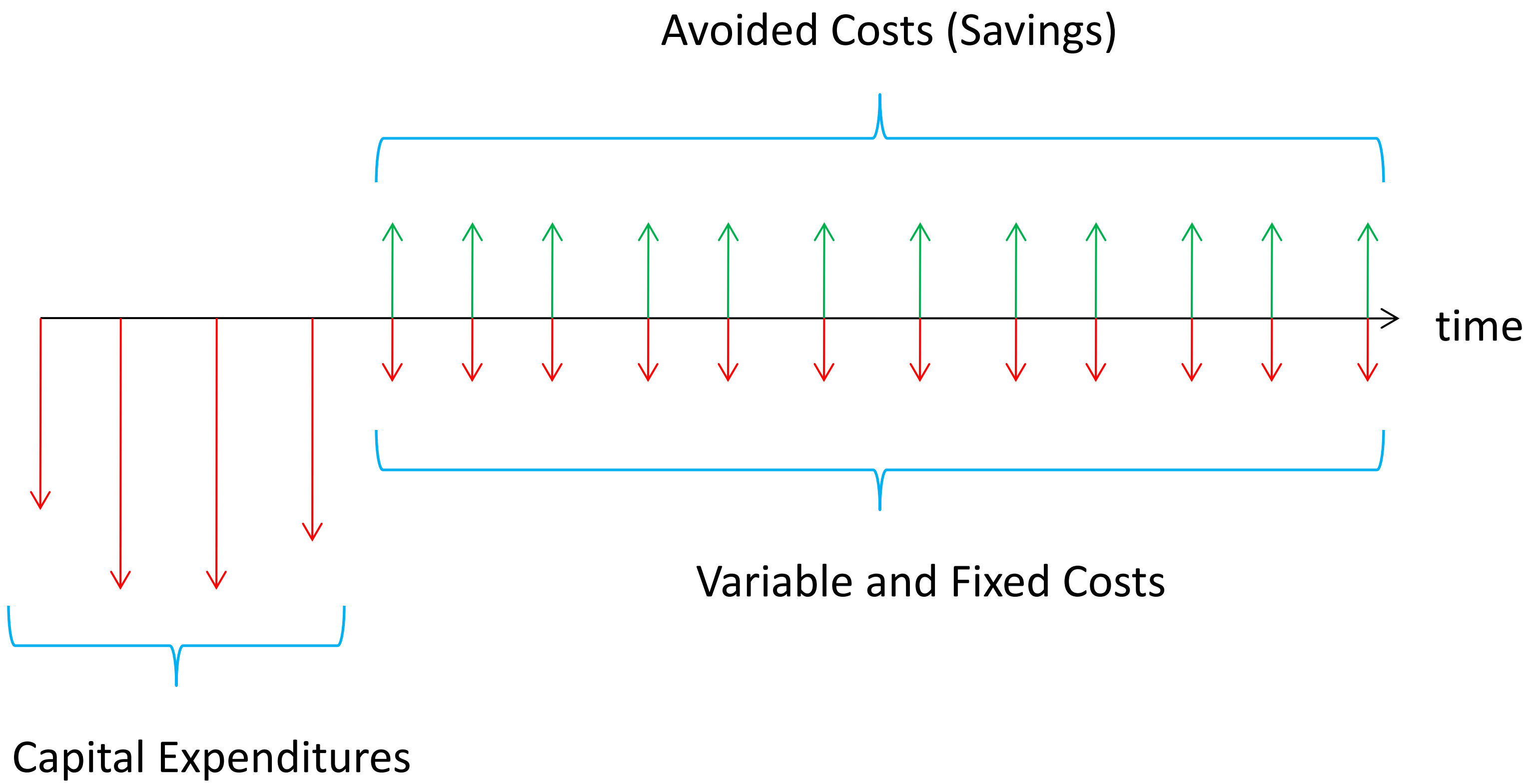
Expressing the results of cost-benefit analysis

- Benefit/Cost Ratio
- Cost/Benefit Ratio
- Net Present Value (NPV)
- Internal Rate of Return (IRR - not commonly used in this context)
- Absolute vs. relative metrics

Net Benefits (Difference)	Net Benefits_a (dollars)	=	$\text{NPV} \sum \text{benefits}_a \text{ (dollars)} - \text{NPV} \sum \text{costs}_a \text{ (dollars)}$
Benefit-Cost Ratio	$\text{Benefit-Cost Ratio}_a$	=	$\dfrac{\text{NPV} \sum \text{benefits}_a \text{ (dollars)}}{\text{NPV} \sum \text{costs}_a \text{ (dollars)}}$

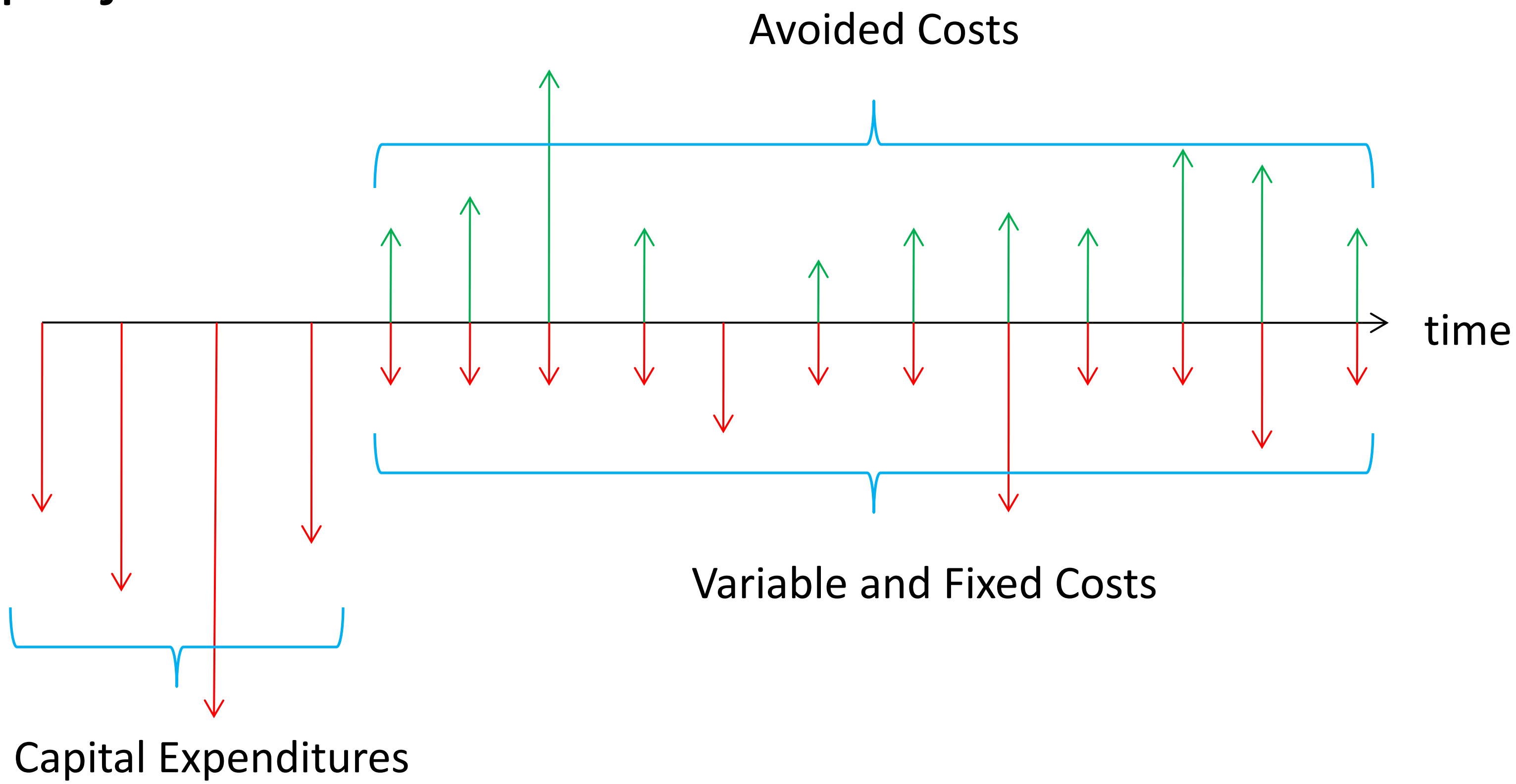
Source: California Standard Practice Manual: Economic Analysis of Demand-Side Programs and Projects, 1983

Assumed project cash flows



- Given the time value of money, do the future revenues exceed the immediate capital expenditures and on-going costs?
- Need to be consistent in comparing costs and benefits (in the context of attribution)
  - Incremental costs vs. incremental benefits
  - Total costs vs. total benefits

Actual project cash flows



- How to address uncertainty?
- Different benefits and costs have different levels of uncertainty

Importance of the discount rate

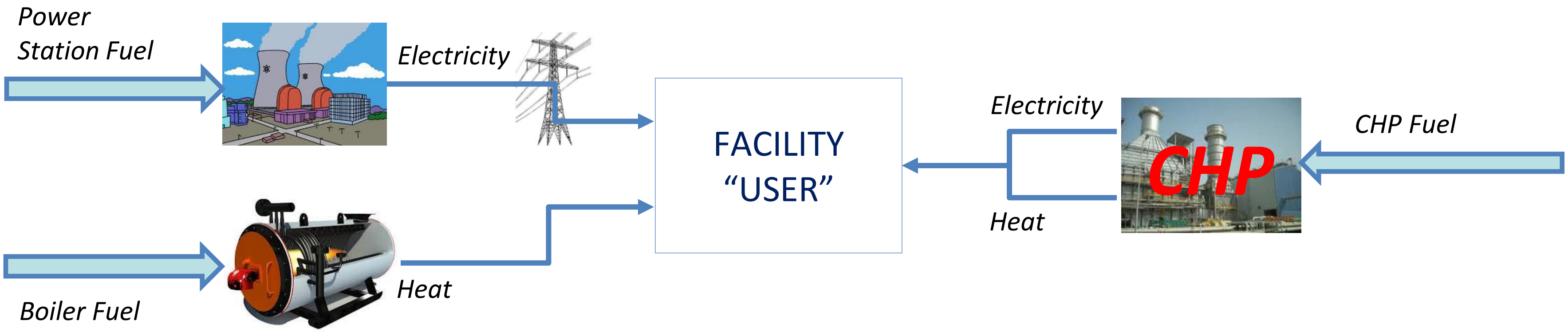
- The discount rate is an important determinate of the results
- The discount rate consists of two aspects:
  - Impatience
  - Non-diversifiable risk
- A lower discount rate makes investments more attractive; a higher discount rate makes them less attractive

$$\text{NPV} = \sum_{t=0}^{n} \frac{(\text{Benefits} - \text{Costs})_t}{(1 + r)^t}$$

where:
r = discount rate
t = year
n = analytic horizon (in years)

Cost-effectiveness analysis centers around five major perspectives

Conceptualizing Costs & Benefits of a CHP



SOCIETY

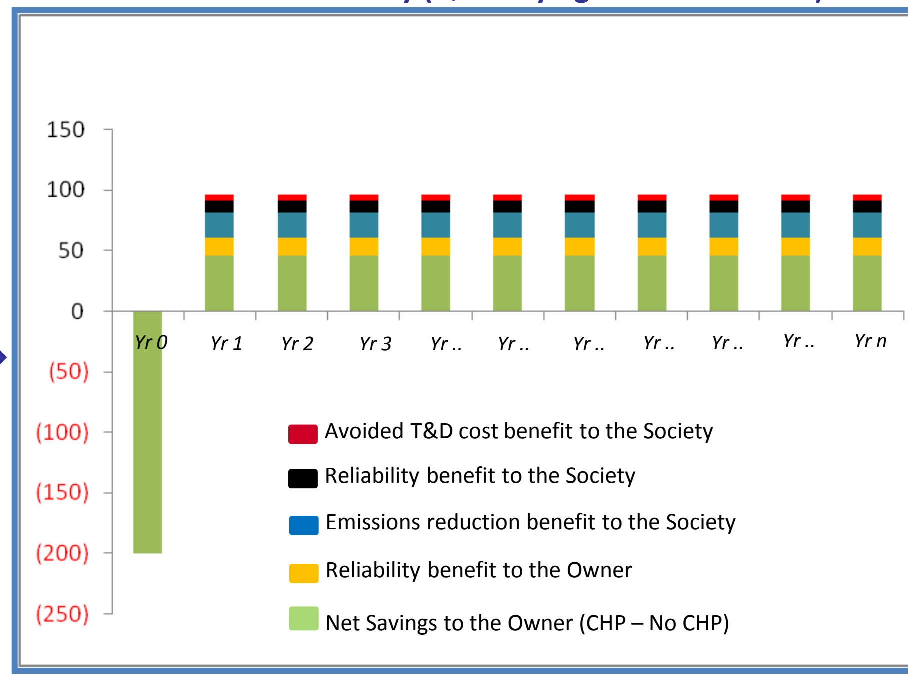
COSTS	BENEFITS
✓ CHP Incentives ✓ Gas T&D costs (for additional supply of gas to CHP)	✓ Increased Reliability resulting in community benefits such as storm shelter etc. ✓ Avoided electric T&D costs ✓ Reduction in air emissions

OWNER

COSTS	BENEFITS
✓ Capital Costs ✓ Fuel Costs ✓ O&M Costs	✓ Increased Reliability ✓ Savings on electricity supply bills (after paying for standby charges)

There could be some macroeconomic effects (such as job growth) which could be positive or negative

Net Benefits to Society (Quantifying Costs & Benefits)



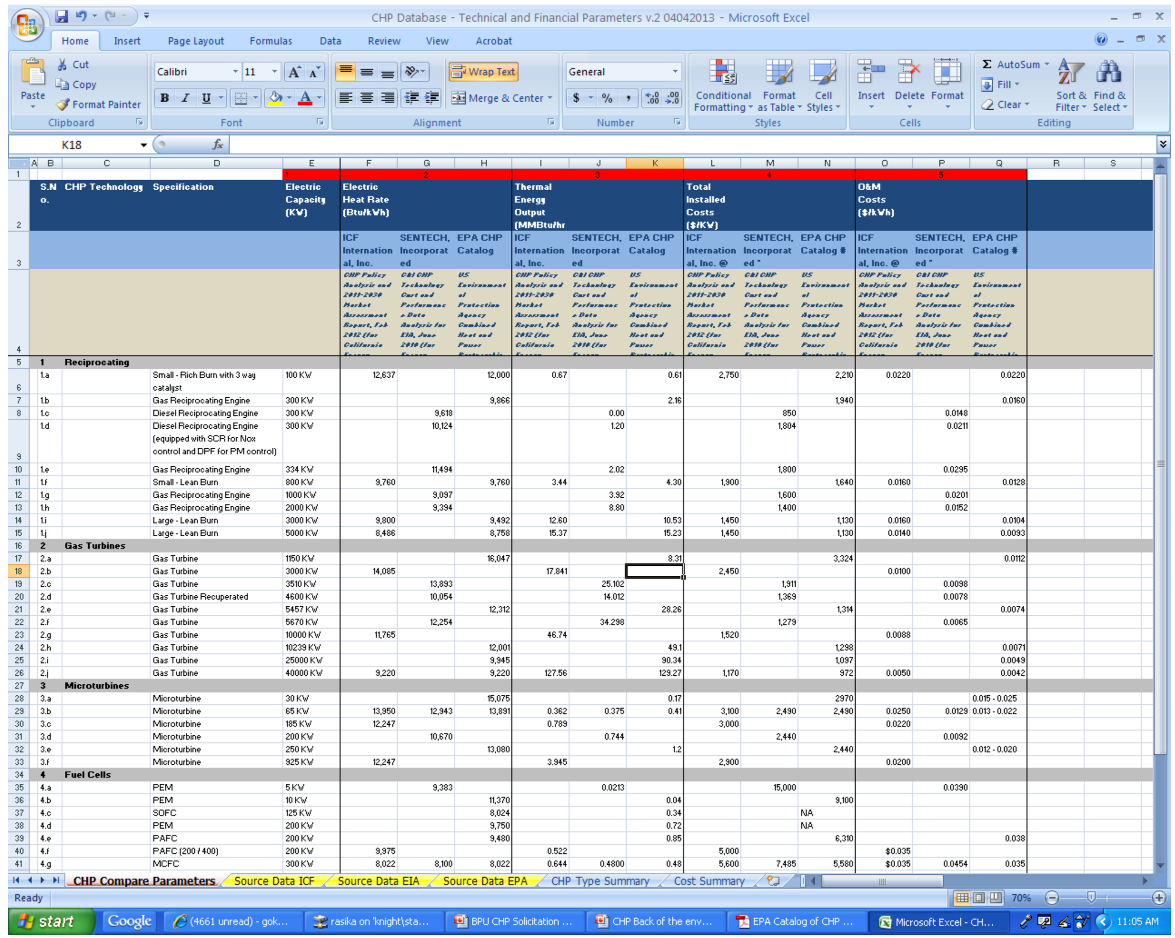
Key inputs into the CBA Model – Financial and Technical depending upon CHP plant configuration (1/5)

Financial Parameters

- *Capital Cost ($/ kW) → Configuration & Site Conditions*
- *O&M Cost ($/ kWh)*

Technical Parameters

- *Heat Rate → Fuel Usage (MMBtu/kWh)*
- *Thermal Energy Output (MMBtu/hr)*



S.No.	CHP Technology	Specification	Electric Capacity (KW)	Electric Heat Rate (Btu/kWh) – ICF International, Inc.	Electric Heat Rate (Btu/kWh) – SENTECH, Incorporated	Electric Heat Rate (Btu/kWh) – EPA CHP Catalog	Thermal Energy Output (MMBtu/hr) – ICF International, Inc.	Thermal Energy Output (MMBtu/hr) – SENTECH, Incorporated	Thermal Energy Output (MMBtu/hr) – EPA CHP Catalog	Total Installed Costs ($/KW) – ICF International, Inc. @	Total Installed Costs ($/KW) – SENTECH, Incorporated "	Total Installed Costs ($/KW) – EPA CHP Catalog #	O&M Costs ($/kWh) – ICF International, Inc. @	O&M Costs ($/kWh) – SENTECH, Incorporated "	O&M Costs ($/kWh) – EPA CHP Catalog #
			1	2			3			4			5		
				CHP Policy Analysis and 2011-2030 Market Assessment Report, Feb 2012 (for California	C&I CHP Technology Cost and Performance Data Analysis for EIA, June 2010 (for	US Environmental Protection Agency Combined Heat and Power	CHP Policy Analysis and 2011-2030 Market Assessment Report, Feb 2012 (for California	C&I CHP Technology Cost and Performance Data Analysis for EIA, June 2010 (for	US Environmental Protection Agency Combined Heat and Power	CHP Policy Analysis and 2011-2030 Market Assessment Report, Feb 2012 (for California	C&I CHP Technology Cost and Performance Data Analysis for EIA, June 2010 (for	US Environmental Protection Agency Combined Heat and Power	CHP Policy Analysis and 2011-2030 Market Assessment Report, Feb 2012 (for California	C&I CHP Technology Cost and Performance Data Analysis for EIA, June 2010 (for	US Environmental Protection Agency Combined Heat and Power
1	**Reciprocating**														
1.a		Small - Rich Burn with 3 way catalyst	100 KW	12,637		12,000	0.67		0.61	2,750		2,210	0.0220		0.0220
1.b		Gas Reciprocating Engine	300 KW			9,866			2.16			1,940			0.0160
1.c		Diesel Reciprocating Engine	300 KW		9,618			0.00			850			0.0148	
1.d		Diesel Reciprocating Engine (equipped with SCR for Nox control and DPF for PM control)	300 KW		10,124			1.20			1,804			0.0211	
1.e		Gas Reciprocating Engine	334 KW		11,494			2.02			1,800			0.0295	
1.f		Small - Lean Burn	800 KW	9,760		9,760	3.44		4.30	1,900		1,640	0.0160		0.0128
1.g		Gas Reciprocating Engine	1000 KW		9,097			3.92			1,600			0.0201	
1.h		Gas Reciprocating Engine	2000 KW		9,394			8.80			1,400			0.0152	
1.i		Large - Lean Burn	3000 KW	9,800		9,492	12.60		10.53	1,450		1,130	0.0160		0.0104
1.j		Large - Lean Burn	5000 KW	8,486		8,758	15.37		15.23	1,450		1,130	0.0140		0.0093
2	**Gas Turbines**														
2.a		Gas Turbine	1150 KW			16,047			8.31			3,324			0.0112
2.b		Gas Turbine	3000 KW	14,085			17.841			2,450			0.0100		
2.c		Gas Turbine	3510 KW		13,893			25.102			1,911			0.0098	
2.d		Gas Turbine Recuperated	4600 KW		10,054			14.012			1,369			0.0078	
2.e		Gas Turbine	5457 KW			12,312			28.26			1,314			0.0074
2.f		Gas Turbine	5670 KW		12,254			34.298			1,279			0.0065	
2.g		Gas Turbine	10000 KW	11,765			46.74			1,520			0.0088		
2.h		Gas Turbine	10239 KW			12,001			49.1			1,298			0.0071
2.i		Gas Turbine	25000 KW			9,945			90.34			1,097			0.0049
2.j		Gas Turbine	40000 KW	9,220		9,220	127.56		129.27	1,170		972	0.0050		0.0042
3	**Microturbines**														
3.a		Microturbine	30 KW			15,075			0.17			2970			0.015 - 0.025
3.b		Microturbine	65 KW	13,950	12,943	13,891	0.362	0.375	0.41	3,100	2,490	2,490	0.0250	0.0129	0.013 - 0.022
3.c		Microturbine	185 KW	12,247			0.789			3,000			0.0220		
3.d		Microturbine	200 KW		10,670			0.744			2,440			0.0092	
3.e		Microturbine	250 KW			13,080			1.2			2,440			0.012 - 0.020
3.f		Microturbine	925 KW	12,247			3.945			2,900			0.0200		
4	**Fuel Cells**														
4.a		PEM	5 KW		9,383			0.0213			15,000			0.0390	
4.b		PEM	10 KW			11,370			0.04			9,100			
4.c		SOFC	125 KW			8,024			0.34			NA			
4.d		PEM	200 KW			9,750			0.72			NA			
4.e		PAFC	200 KW			9,480			0.85			6,310			0.038
4.f		PAFC (200 / 400)	200 KW	9,975			0.522			5,000			$0.035		
4.g		MCFC	300 KW	8,022	8,100	8,022	0.644	0.4800	0.48	5,600	7,485	5,580	$0.035	0.0454	0.035

Key inputs into the CBA Model – an example (2/5)

CHP Project Level Assumptions	Units	
CHP Technology Type		Gas Turbine
CHP System rated Electric Capacity	kW	1,150
CHP Electric Capacity	kW	1,070
CHP System Availability	%	95%
CHP Hours of Operation	Hrs	8,322
CHP Capacity Factor	%	95%
CHP Economic Life	yrs	20
Project Construction Period	mths	12
CHP Electric Heat Rate	Btu/ kWh	16,047
CHP Thermal Energy Output	MMBtu/ hr	8.31
CHP Capital Cost	$/kW	3,324
CHP O&M Costs	$/kWh	0.01
CHP O&M Cost escalation per year	% per yr	2.20%
CHP Incentive	$/kW	550

Capital Structure, Tax Treatment & Returns		
Equity Usage	%	20%
Cost of Equity	%	16%
Debt Usage	%	80%
Cost of Debt	%	10%
Corporate Tax Rate (Marginal)	%	45%
WACC	%	8%
Federal Investment Tax Credit	%	10%

Utility Standby Charges		
Electric Standby Charge (all months)	$/ kW/ mth	3.52
Electric Standby Charge (summer months)	$/ kW/ mth	8.38
CHP Outage (in summer month in a year)	days/ yr	1

Electric & Natural Gas Usage - NO CHP		
Facility Annual Peak Demand	kW	2,300
Facility Load Factor	%	60%
Annual Electricity Consumption	MWh/ yr	12,089
Annual Thermal Energy Output from Boiler	MMBtu/ yr	62,240
Boiler Efficiency (No-CHP)	%	80%
Annual Thermal Energy Input (in the Boiler)	MMBtu/ yr	77,800
Electricity Tariff (Commodity + T&D)	$/ kWh	0.13
Natural Gas Tariff (Commodity + T&D)	$/ MMBtu	7.91
Natural Gas Tariff (Commodity + T&D) - to CHP (no SUT charged)	$/ MMBtu	7.39
Electric Tariff escalation (Commodity + T&D)	% per yr	1.98%
NG Tariff escalation (Commodity + T&D)	% per yr	3.20%

Black Start & Islanding Capacbility Assumptions	Units	
Capital Cost Black Start Equip + islanding	$/ kW	120
Equity Usage	%	20%
Cost of Equity	%	16%
Debt Usage	%	80%
Cost of Debt	%	10%
Corporate Tax Rate (Marginal)	%	45%
Average Grid Outage Period	Days/ yr	1
Value of Loss Load	$/ MWh	5000
Hours of operation	hrs/ day	24
Reliability Benefit share of the Owner	%	100%
Discount Rate	%	8%

Key Inputs into the CBA Model – quantification of "Reliability Benefits" (3/5)

Annual Expected Net Benefits of B/S and Islanding Capability = **Benefits**

- *Annual Probability of Outage*
  x
- *Duration of Outage (hrs)*
  x
- *CHP System Size (MW)*
  x
- *VOLL ($/MWh)*

- **Costs**

- *Annual Cost of Black Start & islanding ($/MW)*
- *Annual Variable Costs (Fuel + O&M) ($/MWh)*

NPV of this annual expected net benefit can be allocated to CHP owner and society

Epistemic Uncertainty (uncertainty in our knowledge)

Probability of Outage - Range **x** Duration of Outage - Range **x** CHP Size **x** CHP Availability **x** VOLL - Range

Aleatory Uncertainty (uncertainty in measurement)

- Cost

Fixed + Variable (includes B/S & islanding costs)

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Key inputs into the CBA Model – illustration of calculations (4/5)

Cash Flows

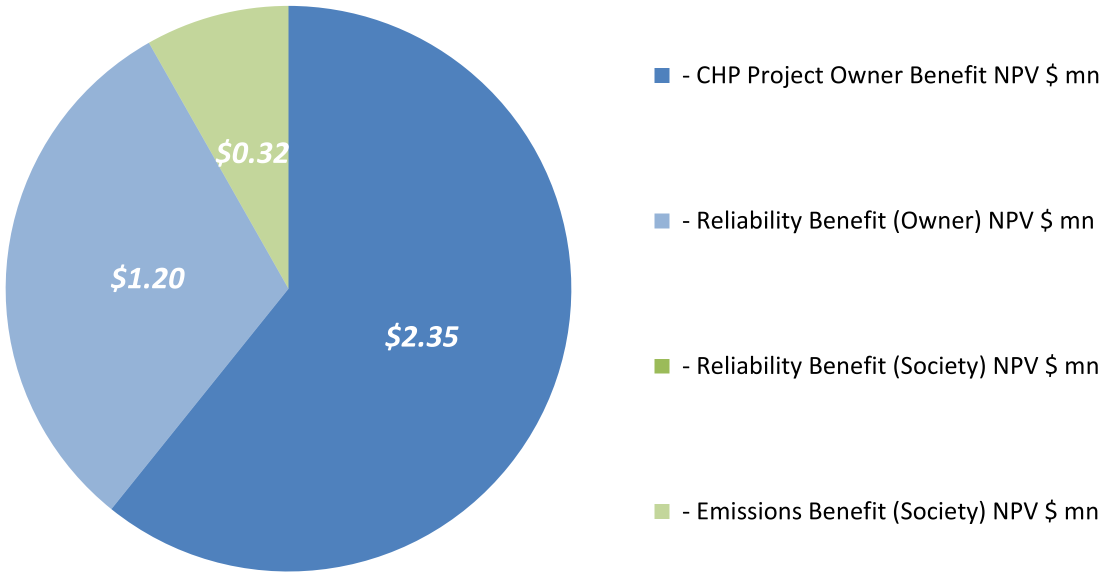
		INSTL.	OPERATING YEAR			
Cash Flows (No-CHP)		*Yr 0*	*Yr 1*	*Yr 2*	*Yr 3*	*Yr n*
Electricity Bill (Commodity + T&D)	$ mn	(1.57)	(1.60)	(1.63)	(1.67)	
Gas Bill (Commodity + T&D)	$ mn	(0.62)	(0.64)	(0.66)	(0.68)	
Total	$ mn	(2.19)	(2.24)	(2.29)	(2.34)	

Cash Flows (CHP)						
Installed Capital Cost without Incentive	$ mn	(3.82)				
CHP Incentive	$ mn	0.59				
Installed Capital Cost with Incentive	$ mn	(3.23)				
Electricity Bill (for purchase from grid) (Commodity + T&D)	$ mn	(1.57)	(0.42)	(0.43)	(0.44)	
Gas Bill (Commodity + T&D)	$ mn	(0.62)	(1.09)	(1.12)	(1.16)	
CHP O&M Expenses	$ mn	0.00	(0.10)	(0.10)	(0.11)	
Electric Standby Charges	$ mn	0.00	(0.11)	(0.11)	(0.11)	
Total	$ mn	(5.42)	(1.72)	(1.77)	(1.82)	
Federal Investment Tax Credit	$ mn	0.32				
Net Savings (due to CHP) to the Owner	$ mn	**(3.23)**	**0.68**	**0.68**	**0.52**	

Reliability Benefits						
Capital Costs	$,000	138.00				
Outage Period	Days	1	1	1	1	
Loss of Load	MWh	25.67	25.67	25.67	25.67	
Value of Loss Load	$,000	128.34	128.34	128.34	128.34	
Net Benefit: Black Start Equip + islanding	$,000	(9.66)	128.34	128.34	128.34	

Emissions Reduction Benefits						
Avoided Electricity Purchase (at Generation level)	MWh	-	9,632	9,632	9,632	
Avoided Electric Emissions – CO2	Lbs	-	17,878,568	17,878,568	17,878,568	
Avoided Thermal Emissions – CO2 (Boiler)	Lbs	-	3,550,862	3,550,862	3,550,862	
CHP Emissions – CO2	Lbs	-	16,706,011	16,706,011	16,706,011	
Net Emissions Benefit – due to CHP (reduced CO2)	$ mn	-	0.09	0.09	0.10	

Key inputs into the CBA Model – illustration of results (5/5)



Total Societal Benefit	$ mn	**$3.86**	
- CHP Project Owner Benefit NPV	$ mn	**$2.35**	**61%**
- Reliability Benefit (Owner) NPV	$ mn	**$1.20**	**31%**
- Reliability Benefit (Society) NPV	$ mn	**0**	**0%**
- Emissions Benefit (Society) NPV	$ mn	**$0.32**	**8%**

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Prioritizing between multiple projects/ options for hardening proposed by a given utility

Project 1	C	B	ΔB/ΔC	Project 3	C	B	ΔB/ΔC
→ 1.1 Do Nothing	0	0	-	→ 1.1 Do Nothing	0	0	-
1.2 Cheap	20	40	2.00	1.2 Cheap	10	25	2.50
1.3 Moderate	25	48	1.92	1.3 Moderate	12	40	3.33
1.4 Expensive	30	55	1.83	1.4 Expensive	20	45	2.25

Best Option (Project 3, 1.3 Moderate)

Project 2	C	B	ΔB/ΔC	Project 4	C	B	ΔB/ΔC
→ 1.1 Do Nothing	0	0	-	1.1 Do Nothing	0	0	-
1.2 Cheap	50	150	3.00	→ 1.2 Cheap	50	120	-
1.3 Moderate	60	165	2.75	1.3 Moderate	60	130	1.00
1.4 Expensive	70	175	2.50	1.4 Expensive	65	150	2.00

→ *Set point of each project*

C *Cost*
B *Benefit*
ΔB/ ΔC *Marginal Benefit to Cost*

Source: Electric Power Distribution Reliability, Second Edition, Richard E. Brown, CRC Press

- Marginal Benefit-to-Cost Analysis (MBCA) optimization involves selecting those projects which maximizes the net benefit
- Set point for each project is a “do nothing” option which is assigned zero cost and zero benefit; under some circumstances a project needs to be performed for safety reasons and in that case the set point is the next least expensive option

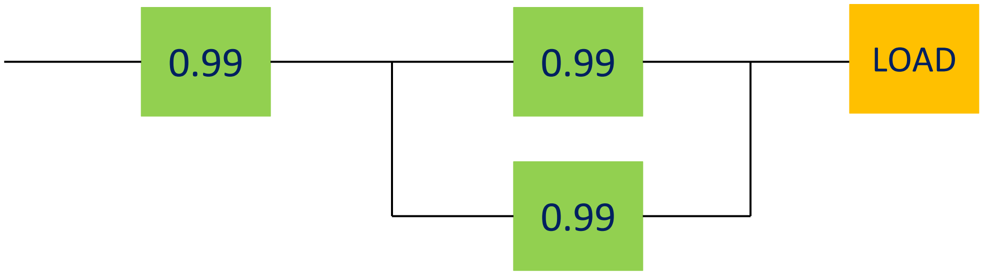
Prioritizing between multiple projects/ options for hardening proposed by different utilities

Reliability Improvement Project	B/C Ratio (No. of customers x Minutes improvement in SAIDI ÷ dollars)		
	Utility A	Utility B	Utility C
Tree Trimming Modifications	-	-	142.9
Faulted Circuit Indicators	100.0	76.9	100.0
SCADA with Breaker Control	20.0	-	20.0
Infrared Feeder Inspection	1.5	1.5	1.5
URD Cable Replacement	1.5	-	0.7
Reclosers and Sectionalizers	1.1	1.0	-
Lightning Protection	0.8	0.8	0.8
Sectionalizing Switches	-	0.5	-
Feeder Automation	-	0.2	-

Source: Electric Power Distribution Reliability, Second Edition, Richard E. Brown, CRC Press

Measure and compare ‘Incremental Costs’ versus ‘Incremental Benefits’

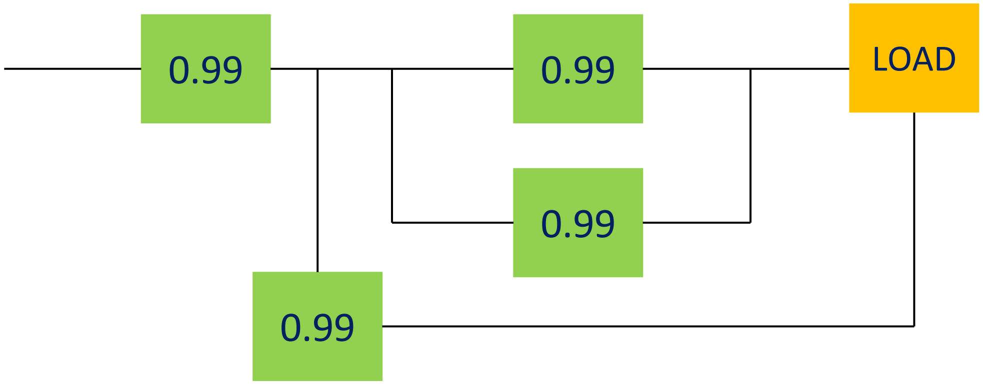
Old Configuration



$R_o = 1 – (1\text{-}0.99)^2$

$= 0.9999$

New Configuration



$R_N = 1 – (1\text{-}0.99)^3$

$= 0.999999$

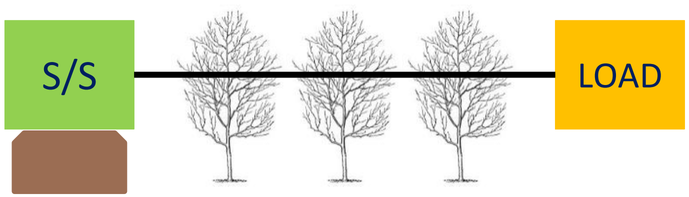
Incremental Benefit Calculation

Inc. Benefit = Change in Reliability (R_N - R_O) x Interruption Minutes x No. of Customers x VOLL ($)

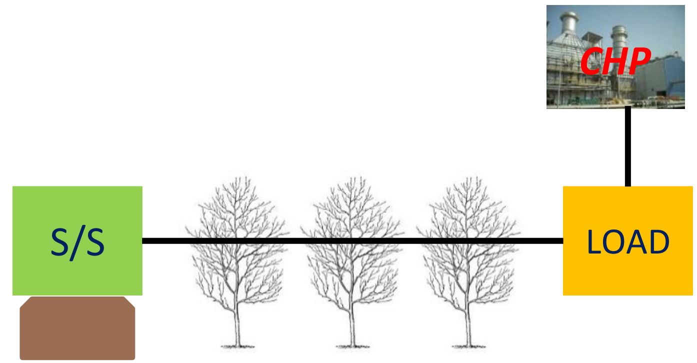
Change in Reliability (R_N - R_O) = 0.0001

Measures may be ‘complementary’ or ‘competitive’ actions

Complementary Action
Substation elevation coupled with tree trimming on a radial line



Supplementary Action
Adding CHP near to load (increase redundancy)?



Utility Hardening: Economic Efficiency and CBA

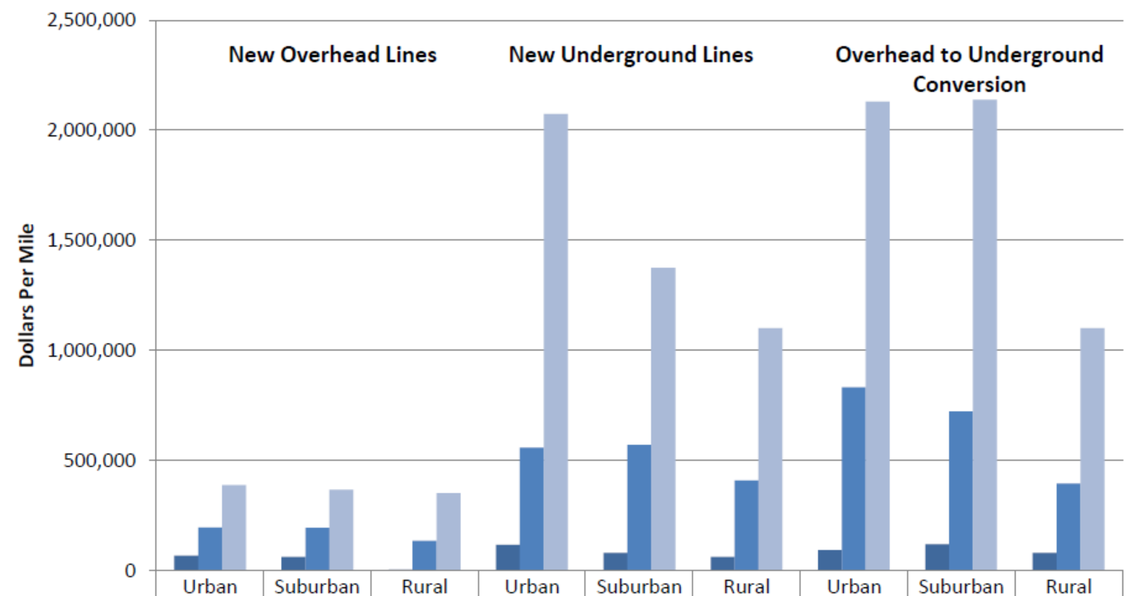
- Integration of CBA with reliability and resiliency analysis
- Dealing with uncertainties during CBA
- Examples of CBA of hardening options
- Data collection challenges and issues

Key questions

- What data sets are available?
- Should each utility prepare hardening plan individually or should a region (PJM) or state (NJ) have an integrated plan?
- When should the planning take place and for how long in future?
- Can all benefits be quantified (for e.g. increased aesthetics of a community as a result of undergrounding of wires)?

Hardening costs vary widely even for a given measure

Figure 16 - Cost of Distribution Power Lines (Dollars per Mile)



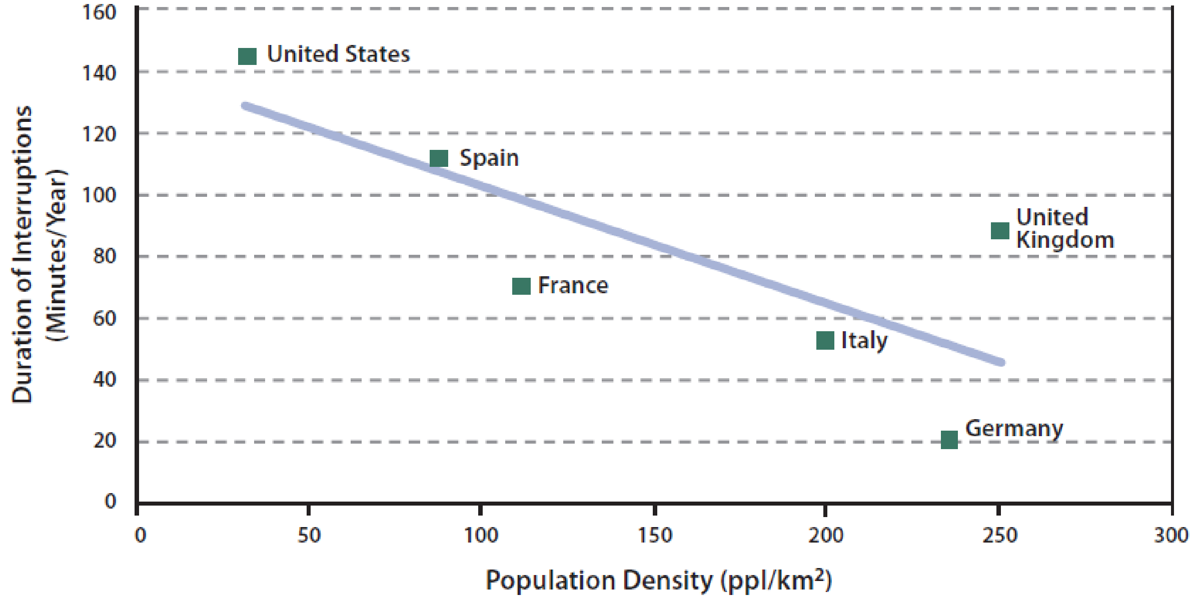
	Urban	Suburban	Rural	Urban	Suburban	Rural	Urban	Suburban	Rural
Minimum	67,892	63,000	5,300	117,000	80,000	63,000	93,202	120,000	80,000
Average	196,628	193,850	135,307	559,293	571,400	408,532	832,383	723,692	395,874
Maximum	388,600	367,000	351,000	2,074,000	1,375,000	1,100,000	2,130,000	2,138,400	1,100,000

Source: Edison Electric Institute, *Out of Sight, Out of Mind Revisited*, December 2009

Source: Edison Electric Institute, Out of Sight, Out of Mind Revisited, December 2009

Data interpretation is equally important as is data availability

Figure 1.6 Average Duration of Interruptions for Selected Countries, 2006



Source: United States Reliability Data: J.H. Eto and K.H. Lacommare, *Tracking the Reliability of the U.S. Electric Power System: An Assessment of Publicly Available Information Reported to State Public Utility Commissions* (Berkleley, CA: Lawrence Berkeley National Laboratory, 2008); European Reliability Data: Council of European Energy Regulators, *4th Benchmarking Report on Quality of Electricity Supply 2008* (Brussels, Belgium, 2008); Population Density: World Bank Development Indicators.

Source: The Future of the Electric Grid, MIT, 2011

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Summary

- Need more data
- Need better models
- Need better integration of engineering and economic models
- Need to formally treat uncertainty
- Nonetheless, CBA provides useful but not dispositive analysis
- Reliability and resiliency is a long-term, iterative process