Estimating the Costs and Benefits of Undergrounding Power Lines

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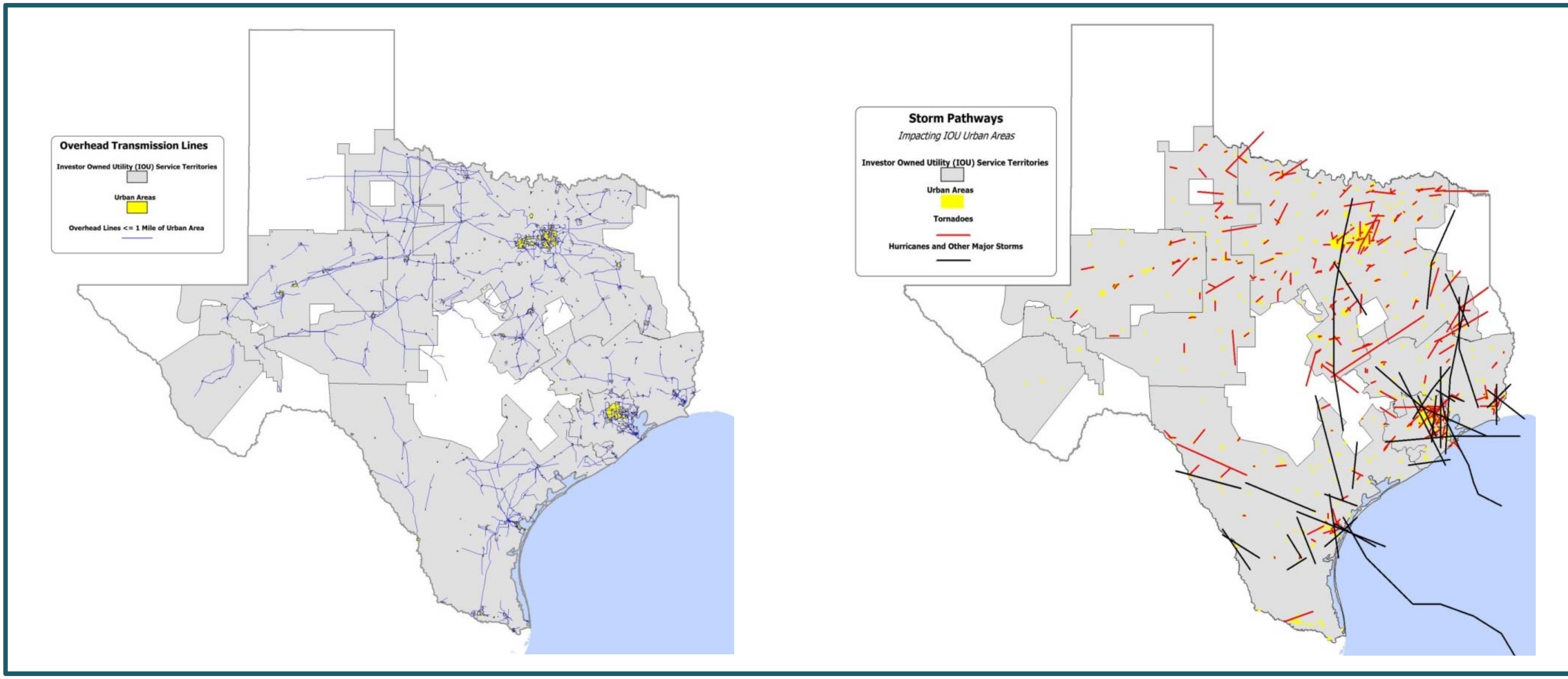

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Background

- No DOE funding was used to conduct this analysis, but it is derivative of a number of DOE-funded projects including:

  (1) LBNL reliability trends report

  (2) LBNL/Nexant ICE Calculator

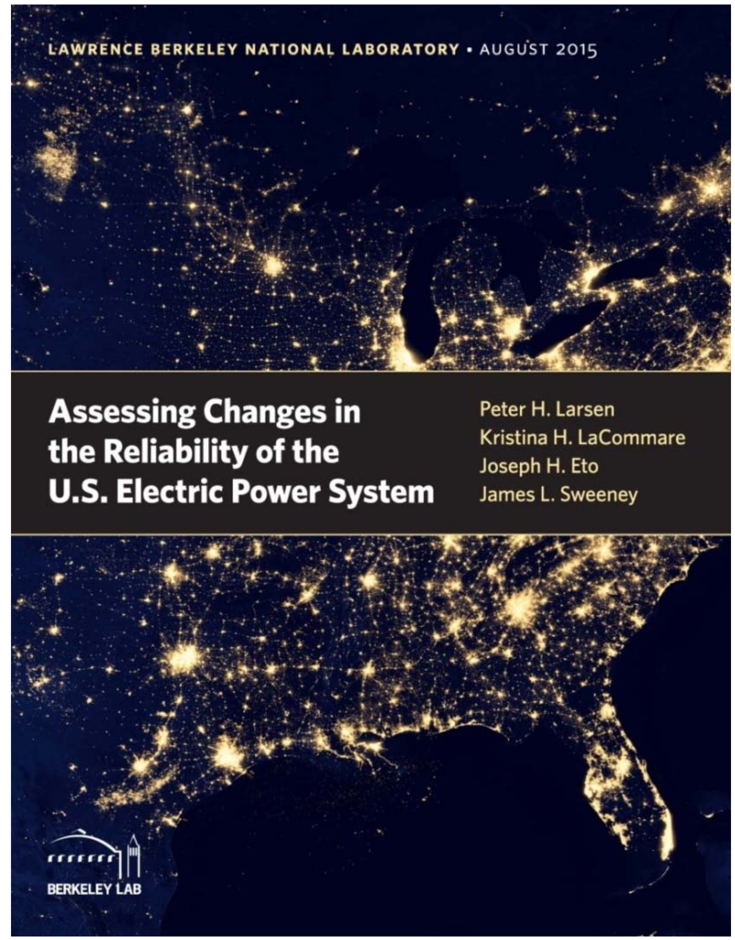
  (3) LBNL/RAP Rural Alaska energy study

- Analysis is part of my Stanford PhD dissertation titled: "Severe Weather, Power Outages, and a Decision to Improve Electric Utility Reliability"

Background

- DOE-NEDD supported study found that weather-related power interruptions are (1) becoming slightly more frequent and (2) strongly correlated with increases in the total minutes customers are without power each year

- **% share of underground line miles is correlated with improved reliability**



**Regression results from the reliability trends study were used in the undergrounding analysis*

Background

- Despite the high costs attributed to power outages, there has been little or no research to quantify both the benefits and costs of improving electric utility reliability—especially within the context of decisions to underground T&D lines (e.g., EEI 2013; Nooij 2011; Brown 2009; Navrud et al. 2008)

- Brown (2009) found that the costs—in general—of undergrounding Texas electric utility transmission and distribution (T&D) infrastructure were "far in excess of the quantifiable storm benefits"

- **Policies specifically targeting urban areas for undergrounding are cost-effective if a number of key criteria are met…**

Analysis framework: Texas IOUs

- **Study perspective:**
  - Individuals who care about maximizing private benefits
- **Key stakeholders with standing:**
  - Investor-owned utilities (IOUs), ratepayers, and all residents within service territory
- **Policy alternatives:**
  - (1) Status quo (i.e., maintain existing underground and overhead line share)
  - (2) Underground all T&D lines (i.e., underground when existing overhead lines reach end of useful lifespan)
- **Why Texas?**
  - Texas IOU service territories were selected due to (1) previous study evaluating costs and (some) benefits of undergrounding; (2) ready access to useful assumptions; and (3) public utility commission showing interest in undergrounding major portions of electrical grid

Analysis framework: Texas IOUs

Key Stakeholders	**Undergrounding Mandate**	
	Selected Costs	**Selected Benefits**
IOUs	• Increased worker fatalities and accidents*	
Utility ratepayers	• Higher installation cost of underground lines***** • Additional administrative, siting, and permitting costs associated with undergrounding* • Increased ecosystem restoration/right-of-way costs**	• Lower operations and maintenance costs for undergrounding*
All residents within service area		• Avoided societal costs due to less frequent power outages*** • Avoided aesthetic costs**

Key: **Minor impact on results → ***** Major impact on results*

Estimating lifecycle costs

Step 1
- Collect information on the total line mileage, lifespan, capital, and operations and maintenance (O&M) costs of T&D infrastructure that is currently overhead and underground for IOUs operating in Texas

Step 2
- Randomly determine the age and length of existing overhead and underground line circuits; project growth in T&D line miles to 2050

Step 3
- Replace lines at end of useful life; calculate the net present capital and O&M costs of T&D lines through 2050 for the status quo and undergrounding mandate

Step 4
- Subtract status quo lifecycle costs from undergrounding lifecycle costs

= net lifecycle cost from undergrounding mandate

Estimating benefits from less frequent outages

Step 1

- Apply econometric model (*i.e., LBNL 2015 reliability trends report*) to estimate the total number of Texas IOU outages—under the status quo—from now until 2050

Step 2

- Estimate the total number of outages—for the undergrounding alternative—by gradually removing the effect of weather on this same econometric model as the share of undergrounded line miles increases each year

Step 3

- Assign a dollar value for the total number of annual customer outages for both alternatives using information from Sullivan et al. (2015) (*i.e., ICE Calculator*)

Step 4

- Discount all costs back to the base year; subtract the outage-related costs for the undergrounding alternative from the outage costs for the status quo

= avoided outage costs from undergrounding mandate

Estimating avoided aesthetic costs

Step 1

- Estimate number of residential, commercial and industrial, and other properties within an "overhead transmission viewing corridor" which is decreasing in size over time

Step 2

- Multiply number of affected properties against the real estate value for each property class and lost property value associated with overhead high-voltage transmission lines (e.g., 12.5%)

Step 3

- Discount the stream of avoided aesthetic costs back to the present using discount rate (e.g., 10%)

= avoided aesthetic costs from undergrounding mandate

Ecosystem-related restoration costs

Step 1
- Estimate the number of acres affected by T&D line growth in the future (using development corridor width and total line miles)—for both alternatives

Step 2
- For both alternatives, multiply total T&D line development corridor acreage against a conservation easement price (e.g., $3,000/acre)

Step 3
- Discount the stream of ecosystem restoration costs back to the present using discount rate

Step 4
- Subtract status quo restoration costs from undergrounding restoration costs

= net ecosystem restoration costs from undergrounding mandate

Conversion-related morbidity and mortality costs

Step 1
- Collect information on total number of IOU employees; utility sector accident rates and costs from relevant injuries; utility sector fatality rates and the value of statistical life (VSL)

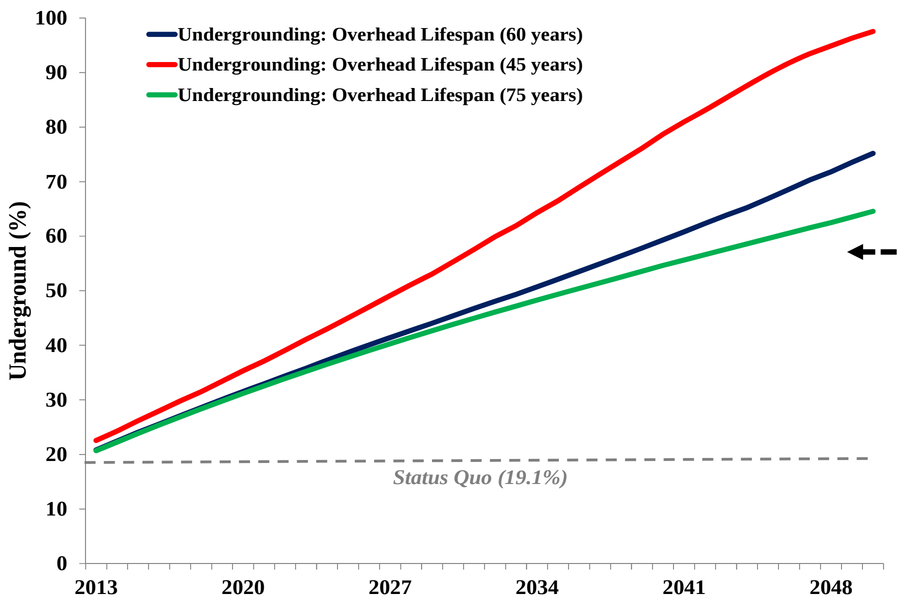
Step 2
- For status quo, multiply fatality and non-fatality incidence rates by VSL and accident costs, respectively, and number of IOU employees

Step 3
- For undergrounding alternative, increase fatal and non-fatal incidence rates proportionally as share of underground line miles increases each year; multiply increased fatality and non-fatality incidence rates by VSL and accident costs, respectively, and number of IOU employees

Step 4
- For both alternatives, discount all costs back to base year; subtract status quo morbidity/mortality costs from undergrounding morbidity/mortality costs

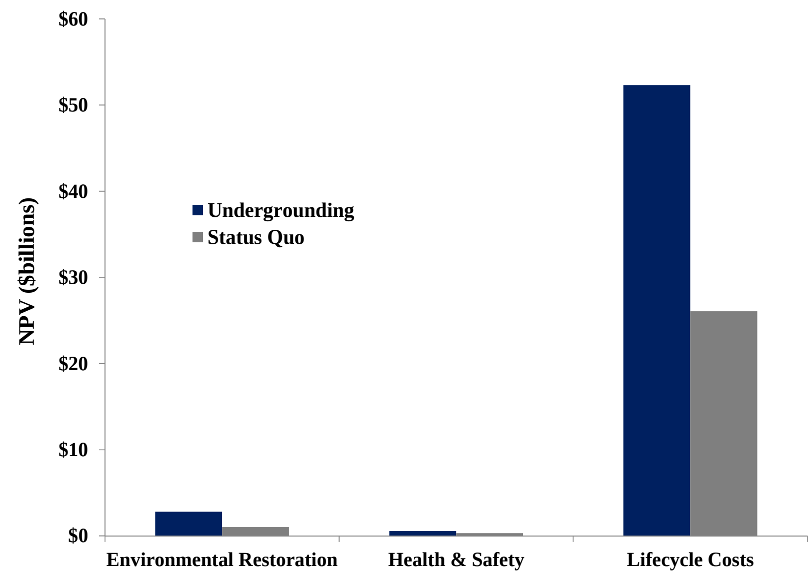
= net morbidity and mortality costs from undergrounding mandate

Estimated costs

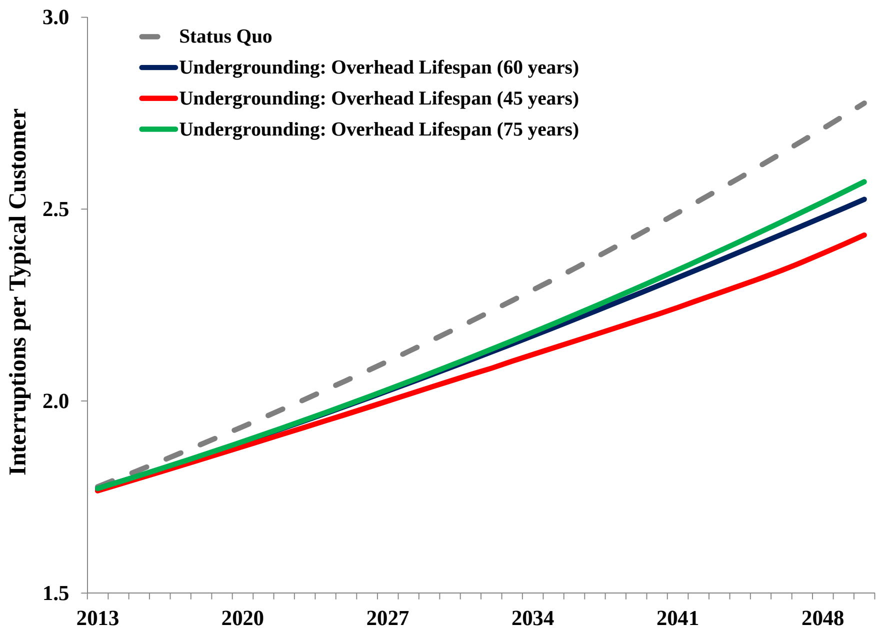


Underground mileage share increasing over time under alternative overhead lifespan assumptions

NPV of undergrounding and status quo costs ($2012)

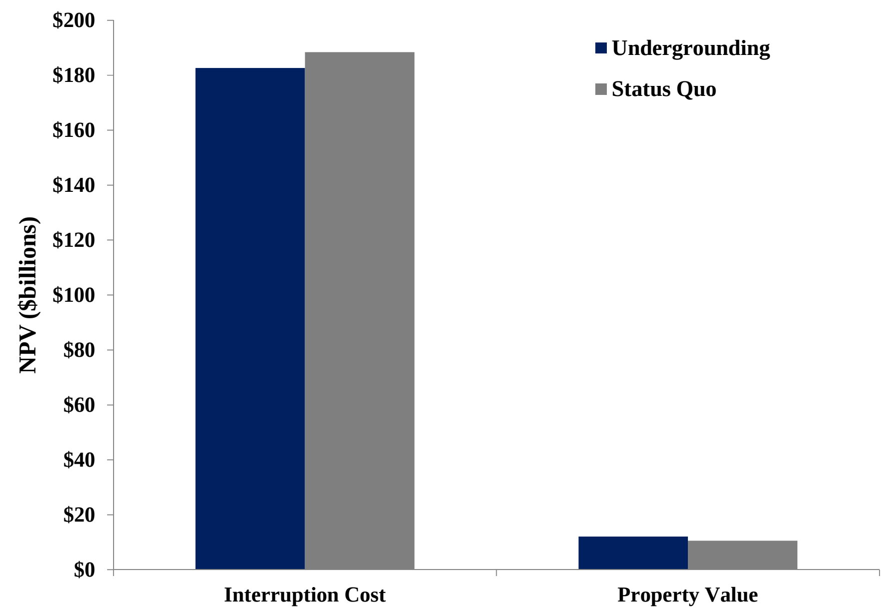


Estimated benefits



Projected power outages over time under alternative overhead lifespan assumptions

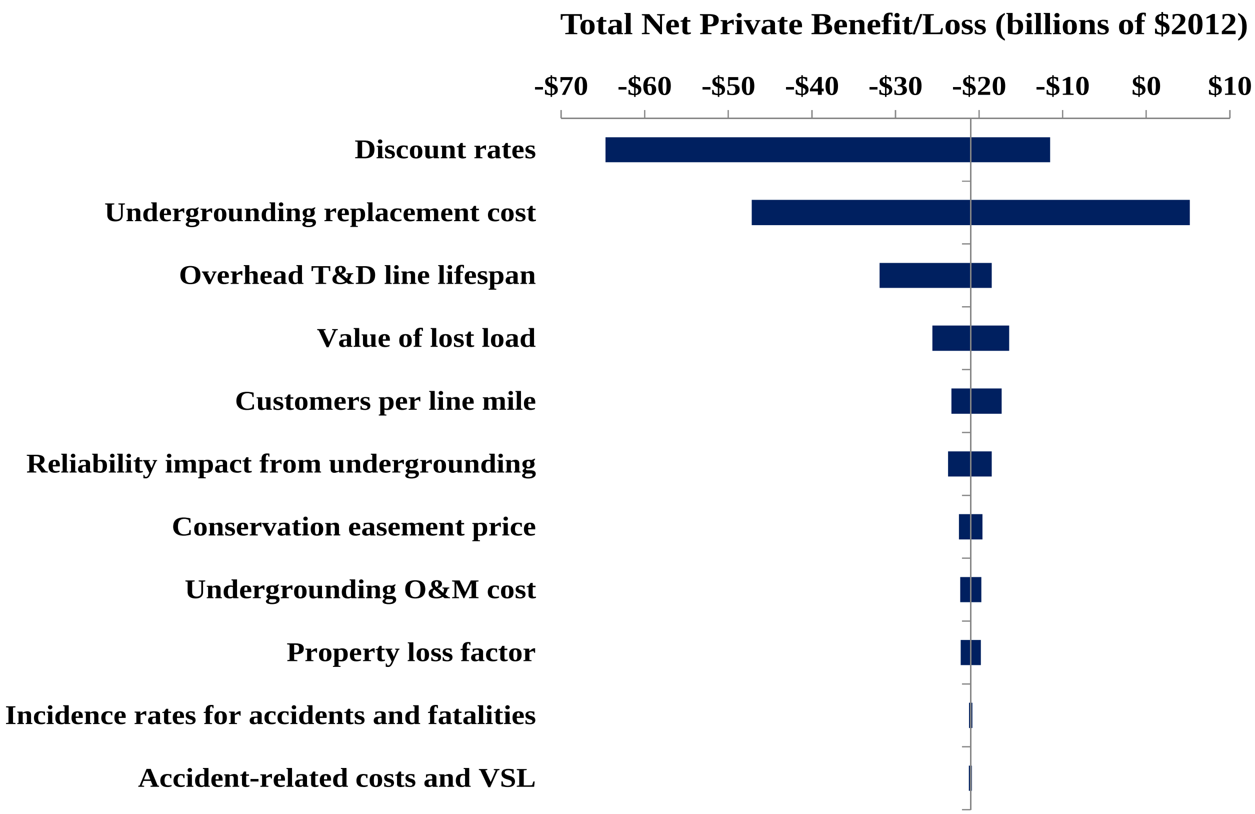
NPV of undergrounding and status quo benefits/avoided costs ($2012)



Net private loss

Impact Category	Undergrounding	Status Quo	Net Cost ($billions)
Environmental restoration	$2.8	$1.0	$1.8
Health & safety	$0.56	$0.31	$0.2
Lifecycle costs	$52.3	$26.1	$26.3
Total net costs (Undergrounding)			$28.3
Impact Category	**Undergrounding**	**Status Quo**	**Net Benefit ($billions)**
Interruption cost	$182.7	$188.4	$5.8
Avoided aesthetic costs	$12.1	$10.6	$1.5
Total net benefits (Undergrounding)			$7.3
Net Private Loss (Undergrounding)			
Net private loss (billions of $2012)			**-$21.0**
Benefit-cost ratio			**0.3**

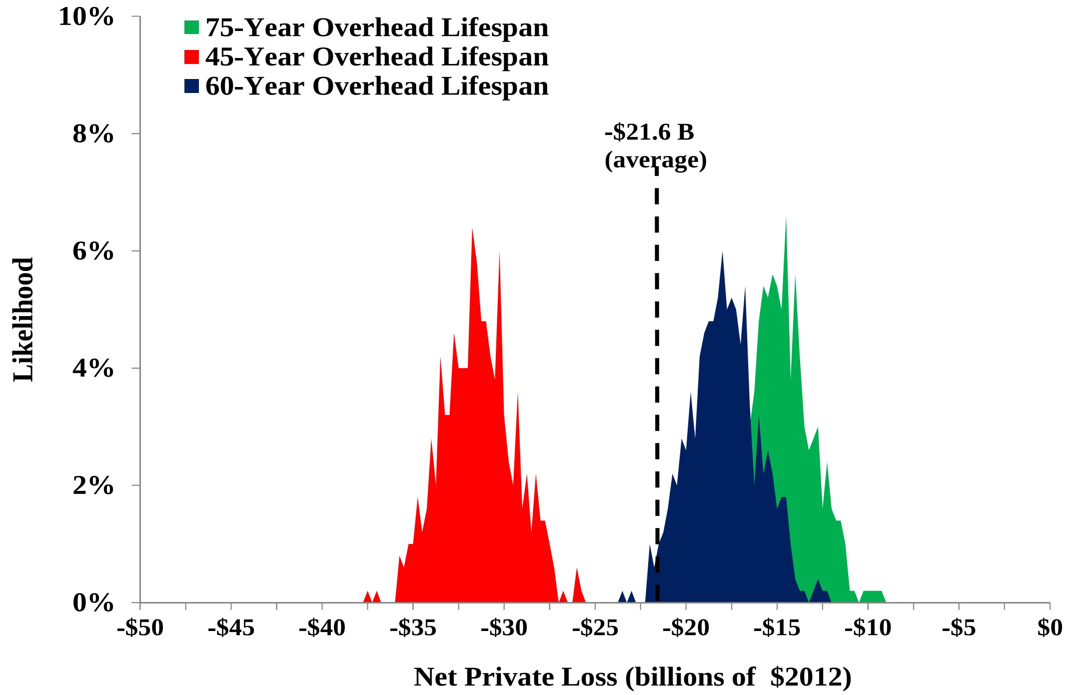
Sensitivity analysis



Note: Results generated by using 10th (90th) percentile value for individual assumption while holding all other assumptions constant at median value.

- Net benefit (loss) calculation is most sensitive to the choice of (1) discount rates; (2) undergrounding replacement cost; (3) overhead T&D lifespan; (4) value of lost load; and (5) customers per line mile (population density)

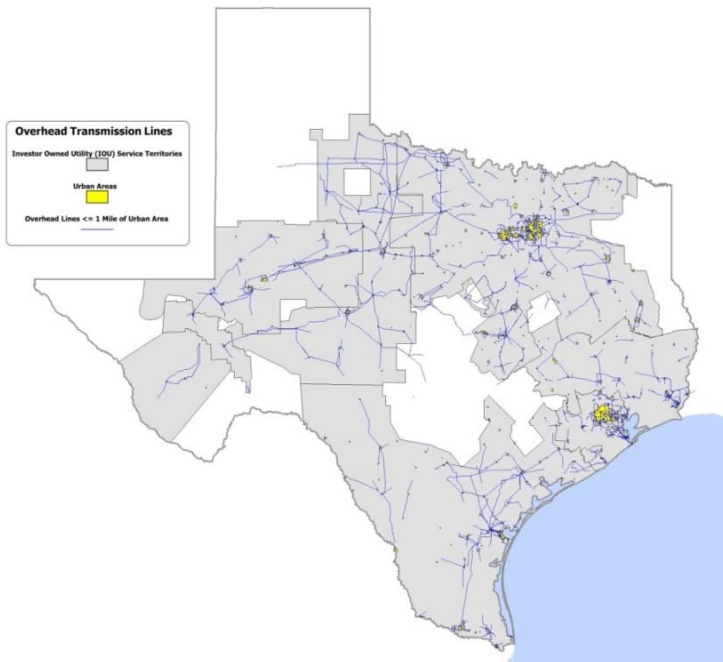
Sensitivity analysis

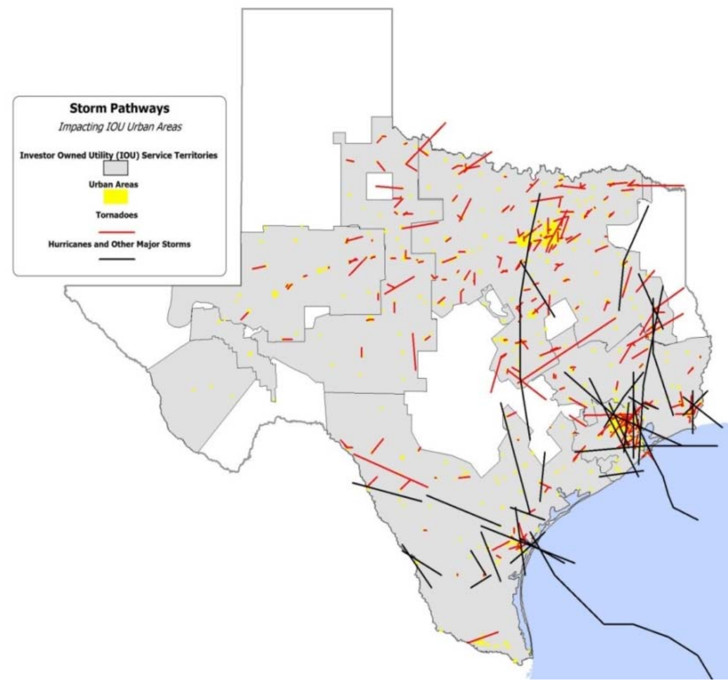


- A Monte-Carlo simulation was conducted by sampling all of the key input assumptions from uniform distributions—bounded by the minimum and maximum values reported earlier— simultaneously
- Varying all key parameters simultaneously leads to consistently negative net private losses

Possibility of net benefits

- Based on the initial configuration of this model, the Texas public utility commission should not consider broadly mandating undergrounding when overhead T&D lines have reached the end of their useful life

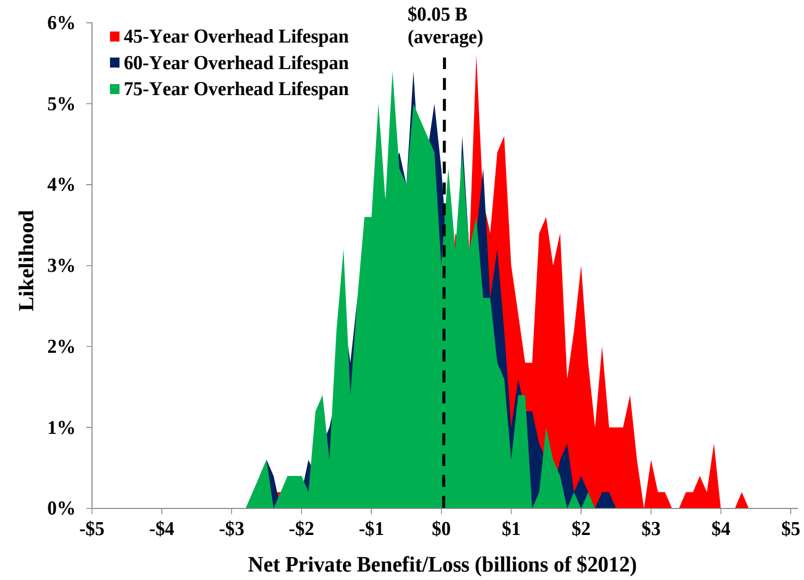




- What are minimum conditions necessary for a targeted undergrounding initiative to have positive net benefits?

Possibility of net benefits

Texas policymakers <u>should</u> consider requiring that all T&D lines be undergrounded in places where:



- *there are a large number of customers per line mile* (e.g., greater than 75 customers per T&D line mile)
- *there is an expected vulnerability to frequent and intense storms*
- *there is the potential for underground T&D line installation economies-of-scale* (e.g., ~2% decrease in annual installation costs expected per year)
- *overhead T&D line utility easements (i.e., rights-of-way) are larger than underground T&D utility easements*

(Under)ground-truthing: Cordova, Alaska

Author (May 2015)

Analysis framework: Cordova case

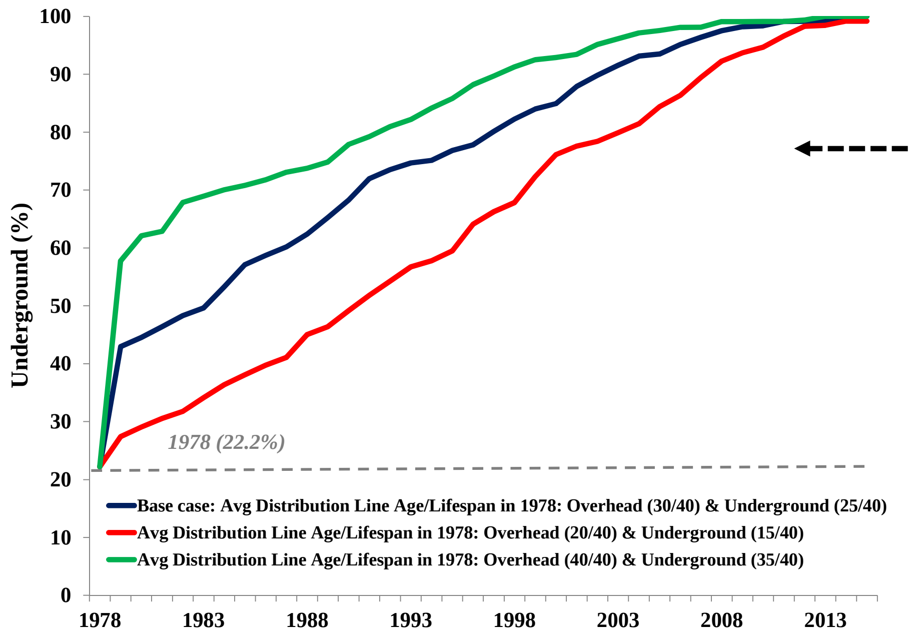
- **Study perspective:**
  - CEO who cares about maximizing private benefits
- **Key stakeholders with standing:**
  - Cordova Electric Cooperative, ratepayers, and all residents within service territory
- **Policy alternatives:**
  - (1) 1978 status quo (i.e., maintain existing underground and overhead line share)
  - (2) Underground all T&D lines (i.e., underground when existing overhead lines reach end of useful lifespan)
- **Why Cordova?**
  - Cordova selected due to (1) community recently completing undergrounding initiative; (2) CEO showing great interest in this analysis and willingness to provide assumptions; (3) fishing industry extremely sensitive to power interruptions; and (4) extreme weather conditions.

Analysis framework: Cordova case

Key Stakeholders	1978 Decision to Underground 100% of Distribution System	
	Selected Costs	**Selected Benefits**
Cordova Electric Cooperative	• Increased chance of worker accidents*	
Cordova ratepayers	• Additional administrative, siting, and permitting costs associated with undergrounding* • Increased capital costs for undergrounding***	• Lower operations and maintenance costs for undergrounding* • Decreased ecosystem restoration/right-of-way costs*
All residents/businesses within service area		• Avoided societal costs due to less frequent power outages***** • Avoided aesthetic costs*** • Decreased chance of community fatalities and accidents[NA]

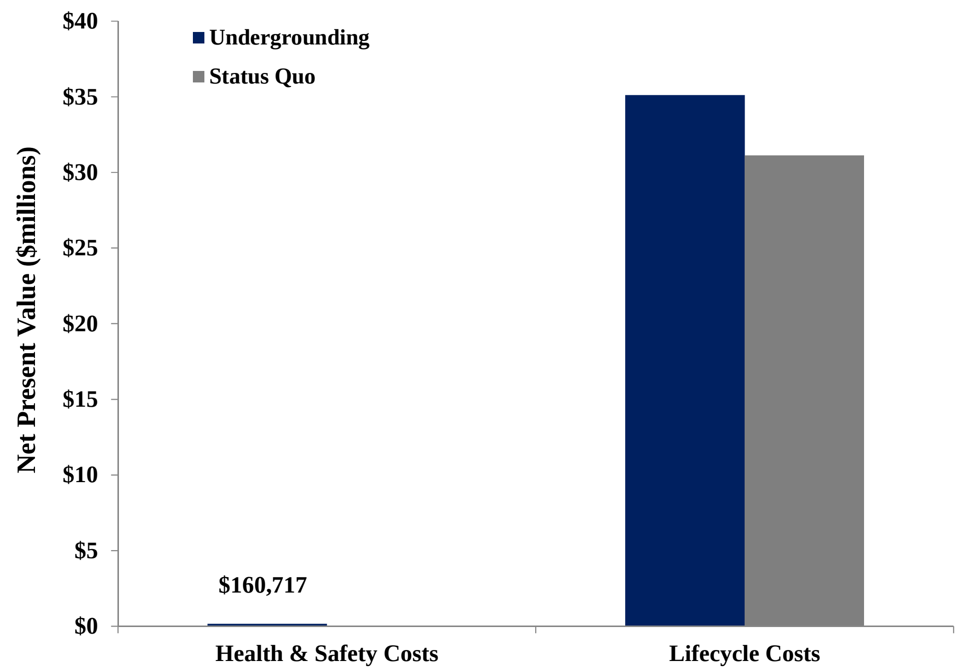
*Key: *Minor impact on results → ***** Major impact on results*

Estimated costs



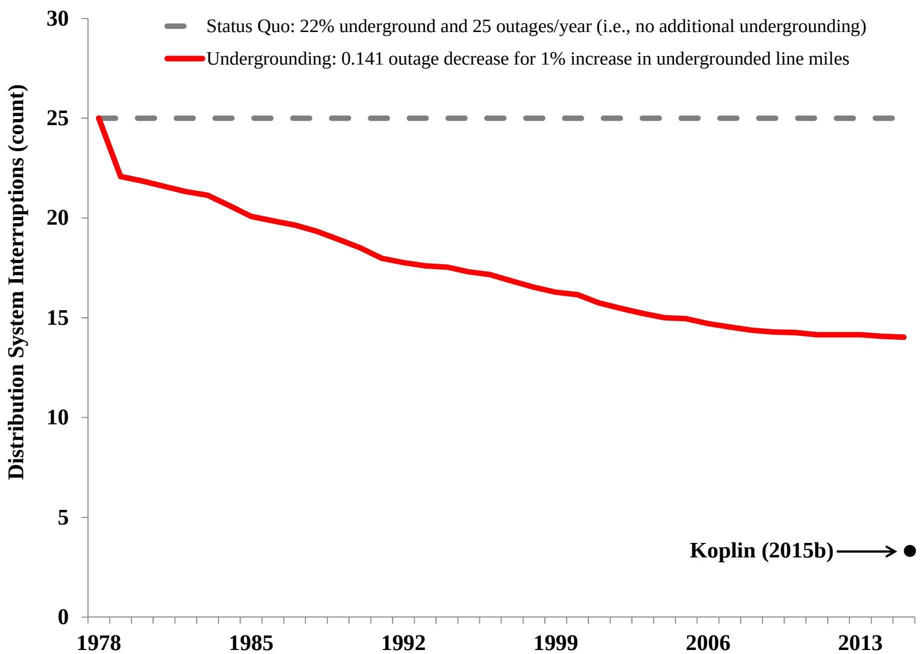
Underground mileage share increasing over time

NPV of undergrounding and status quo costs ($2015)

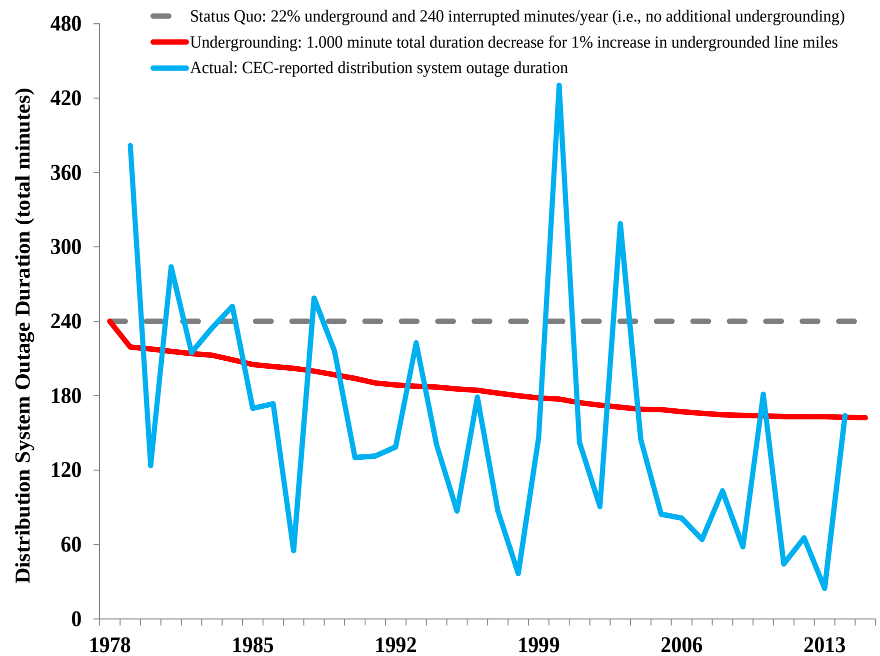


Estimated benefits

Customer interruptions



Interruption minutes

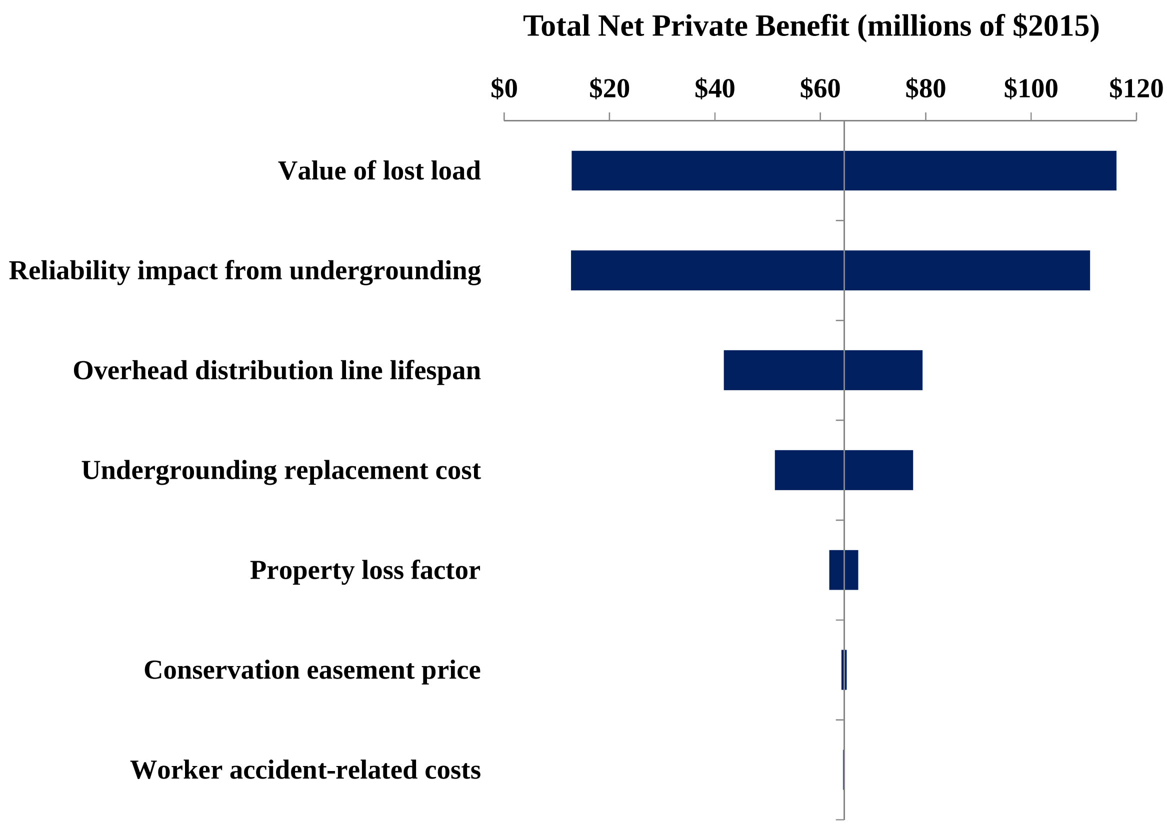


Net private benefit

Impact Category	100% Underground	Status Quo	Net Cost ($millions)
Health & safety costs	$0.2	$0	$0.2
Lifecycle costs	$35.3	$31.1	$4.1
Total net costs (Undergrounding)			$4.3
Impact Category	**100% Underground**	**Status Quo**	**Net Avoided Costs ($millions)**
Interruption costs	$130.1	$194.7	$64.6
Aesthetic costs	$27.9	$24.4	$3.5
Enviro. restoration costs	$2.4	$3.1	$0.6
Total net benefits (Undergrounding)			$68.7
Net Private Benefit (Undergrounding)			
Net private benefit (millions of $2015)			**$64.5**
Benefit-cost ratio			**16.1**

- Reliability benefits, although large, are not necessary for cost-effectiveness.

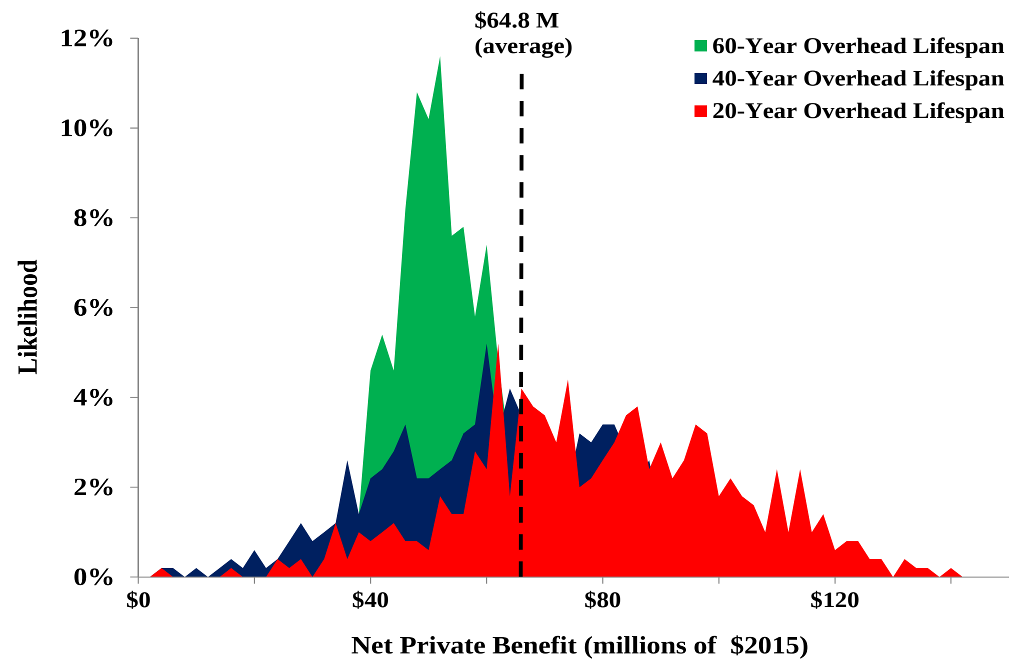
Sensitivity analysis



- Cordova's net benefit calculation is most sensitive to the choice of (1) value of lost load; (2) reliability impact from undergrounding; and (3) overhead distribution line lifespan.

Sensitivity analysis

- A Monte-Carlo simulation was conducted by sampling all of the key input assumptions from uniform distributions—bounded by the minimum and maximum values reported earlier—simultaneously



- Varying all of the key parameters simultaneously leads to consistently positive net benefits

Overall conclusion

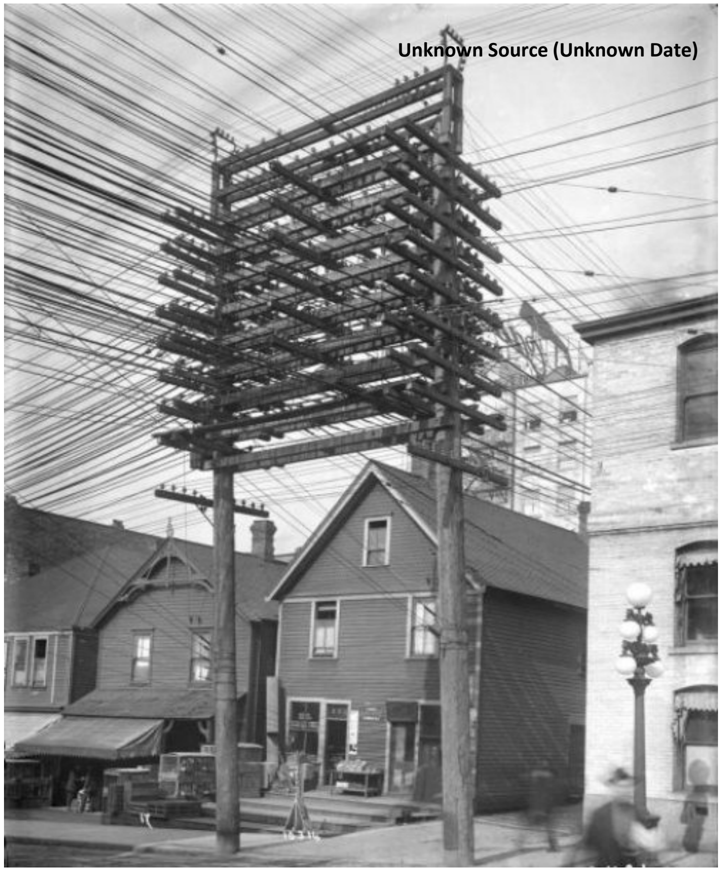
- Generally assumed that the costs of undergrounding transmission and distribution lines far exceed the benefits from avoided outages

- Undergrounding power system infrastructure can improve reliability and that comprehensive benefits of this strategy can, in some cases, exceed the all-in costs

- Cost-effectiveness depends on (1) the age/lifespan of existing overhead infrastructure; (2) whether economies of scale can be achieved; (3) the vulnerability of locations to increasingly severe and frequent storms; and (4) the number of customers per line mile.

- Analysis framework could be adapted to evaluate economics of other strategies to improve grid resiliency and reliability (e.g., grid hardening activities)

Thank you



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Key assumptions: Texas IOUs

		Range			Impact Category				
#	Sensitivity/ scenario analysis	Minimum value (10th %)	Base case value (50th %)	Maximum value (90th %)	Lifecycle assessment (cost)	Avoided outages (benefit)	Aesthetics (benefit)	Health and safety (cost)	Ecosystem restoration (cost)
1	Alternative replacement cost of undergrounding T&D lines ($ per mile)	$71,400 (dist.) $336,000 (trans.)	$357,000 (dist.) $1,680,000 (trans.)	$642,600 (dist.) $3,024,000 (trans.)	*	*			
2	Alternative values of lost load for each customer class ($ per event)	$0.5 (residential) $87 (other) $1,843.4 (C&I)	$2.7 (residential) $435 (other) $9,217 (C&I)	$4.9 (residential) $783 (other) $16,590.6 (C&I)		*			
3	Alternative discount rates (%)	2%	10%	18%	*	*	*	*	*
4	Alternative aesthetic-related property loss factors (% of property value)	2.5%	12.5%	22.5%			*		
5	Alternative incidence rates for accidents and fatalities (per 100,000 employees)	420 (non-fatal) 3 (fatal)	2,100 (non-fatal) 15 (fatal)	3,780 (non-fatal) 27 (fatal)				*	
6	Alternative accident costs and VSL ($ per accident/$ per life)	$26,131.6 $1,380,000 (VSL)	$130,658 $6,900,000 (VSL)	$235,184.4 $12,420,000 (VSL)				*	
7	Alternative conservation easement prices ($/acre)	$600	$3,000	$5,400					*
8	Alternative lifespan assumptions for overhead T&D infrastructure (years)	45	60	75	*	*	*	*	*
9	Share of underground line miles impact on reliability	-0.0002	-0.001	-0.0018		*			
10	Number of customers per line mile	15	75.0	135		*			
11	Annual O&M cost expressed as % of replacement cost: underground T&D lines	1% (trans.) 0.1% (dist.)	5% (trans.) 0.5% (dist.)	9% (trans.) 0.9% (dist.)	*				

Key assumptions: Cordova Electric Coop.

For the base case, it is assumed that half of all distribution-related reductions in the frequency and total minutes customers were without power are a result of the Cordova's decision to underground lines…

		Range			Impact Category				
#	**Sensitivity/ scenario analysis**	**Minimum value (10^{th} %)**	**Base case value (50^{th} %)**	**Maximum value (90^{th} %)**	**Lifecycle assessment (cost)**	**Avoided outages (benefit)**	**Aesthetics (benefit)**	**Worker safety (cost)**	**Ecosystem restoration (benefit)**
1	1978 replacement cost of undergrounding dist. lines ($2015 per mile)	$60,814	$304,070	$547,326	*				
2	Alternative values of lost load for each customer class ($ per event)	-80% below base case values	See Figures 40–42	+80% above base case values		*			
3	Alternative aesthetic-related property loss factors (% of property value)	2.5%	12.5%	22.5%			*		
4	Alternative conservation easement prices ($/acre)	$1,091.2	$5,456	$9,820.8					*
5	Alternative lifespan assumptions for overhead dist. infrastructure (years)	20	40	60	*	*	*	*	*
6	Outage duration and frequency change due to undergrounding activities	25 outages/240 minutes (1978); 22.8 outages/224.3 minutes (2015)	25 outages/240 minutes (1978); 14 outages/161.5 minutes (2015)	25 outages/240 minutes (1978); 5.2 outages/98.7 minutes (2015)		*			
7	Workers compensation direct and indirect cost ($/accident)	$32,143.4	$160,717	$289,290.6				*	