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A method to estimate the costs and benefits of undergrounding electricity transmission and distribution lines

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ABSTRACT

There has been a general shortfall of peer-reviewed literature identifying methods to estimate the costs and benefits of strategies employed by electric utilities to improve grid resilience. This paper introduces—for the first time—a comprehensive analysis framework to estimate the societal costs and benefits of implementing one strategy to improve power system reliability: undergrounding power transmission and distribution lines. It is shown that undergrounding transmission and distribution lines can be a cost-effective strategy to improve reliability, but only if certain criteria are met before the decision to underground is made.

1. Introduction

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 transmission and distribution (T&D) lines (e.g., EEI, 2013; Nooij, 2011; Brown, 2009; Navrud et al., 2008). One study found that the costs—in general—of undergrounding Texas electric utility T&D infrastructure were "far in excess of the quantifiable storm benefits" (Brown, 2009). However, this same study also noted that targeted storm-hardening activities may be cost-effective. Despite the importance of considering indirect (external) costs and benefits, policymakers have not always recognized their use within the economic evaluation of proposed policies (Arrow et al., 1996). It is possible that grid resiliency initiatives could pass a societal benefit–cost test, yet fail a private benefit–cost test and, ultimately, not be mandated by a public utility commission. Transparent assessments of the costs and benefits of undergrounding and other grid-hardening activities are useful to policymakers interested in enabling the long-term resilience of critical electricity system infrastructure (Executive Office of the President, 2013a).

Larsen et al. (2015) found that U.S. power system reliability is generally getting worse over time (i.e., average annual interruption durations are increasing), due in large part to impacts associated with increasingly severe weather. This study also found that customers of utilities with a relatively larger share of underground line miles typically experienced less frequent and total minutes of power interruptions when compared to utility customers in places that had a lower share of undergrounded line miles.

The purpose of this study is to expand on research by Larsen et al. (2015) by systematically evaluating a policy that requires investor-owned utilities (IOUs) to bury all existing and future transmission and distribution lines underground. More specifically, this analysis will attempt to address the following questions:

- What are the life cycle costs of undergrounding all existing and new transmission and distribution lines at the end of their useful life span?
- Could increasing the share of underground T&D lines lead to fewer power interruptions—and are there corresponding monetary benefits from this reduction?
- Are there aesthetic benefits from reducing the number of overhead T&D lines?
- How much might health and safety costs change if there is an extensive conversion of overhead-to-underground lines?

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- How much might undergrounding transmission and distribution lines affect ecosystem restoration costs?
- How important are assumptions, including value of lost load estimates, relative to one another within a decision to underground power lines?
- What are the minimum conditions necessary for a targeted undergrounding initiative to have net social benefits?

This article is organized as follows. Section 2 provides background on the causes of power outages, how electric system reliability is measured, and undergrounding. Section 3 contains a discussion of the over-arching analysis framework including study perspective, standing, and methods. Results and a sensitivity analysis are presented in Section 4. Section 5 concludes with a policy recommendation, discussion of the analysis shortcomings, and highlights potential areas for future research.

2. Background

The IEEE guide 1366-2012 formally defines a number of metrics to track electric utility reliability (IEEE, 2012). The System Average Interruption Frequency Index (SAIFI) is one of the most commonly used metrics to assess electric utility reliability (Eto et al., 2012).[1] Eq. (1) shows that annual SAIFI for a utility is calculated by summing all annual customer interruptions and dividing this number by the total number of customers served. In this equation, the number of customers affected by all events in year t is Affected_t and the total number of customers served by the utility in a given year is Customers_t:

$$\text{SAIFI}_t = \frac{\sum \text{Affected}_t}{\text{Customers}_t} \tag{1}$$

An IEEE survey of 106 utilities found that the median 2012 SAIFI value is 1.5 interruption events for a typical customer (IEEE, 2014).

It follows that burying power lines (i.e., "undergrounding") would mitigate some of the risk associated with weather-related events (EEI, 2013). In 2012, the Department of Energy reported that "calls for undergrounding are common from customers, elected officials, and sometimes state utility commissions. However, undergrounding is costly and the decisions are complex" (USDOE, 2012). According to a U.S. Department of Energy press release, widespread power outages, which are often caused by severe storms, "inevitably lead to discussions about burying electric utility T&D infrastructure" (USDOE, 2012). Coincidentally, just 3 months after this press release, "Superstorm Sandy"—a large hurricane affecting the U.S. Eastern Seaboard—caused power outages for tens of millions of people with damages estimated in excess of $50 billion dollars (NOAA, 2013). For nearly 60 years, researchers have acknowledged that reliable electric service (or lack thereof) has economic benefits (costs) to society (Larsen, 2016). As the electric industry evolved over this time period, so have the methods used by researchers to value lost load (VLL). For example, Sullivan et al. (2009) collected and organized information from nearly thirty value-of-service reliability studies undertaken by ten U.S. electric utilities, noting that

> "…because these studies used nearly identical interruption cost estimation or willingness-to-pay/accept methods it was possible to integrate their results into a single meta-database describing the value of electric service reliability observed in all of them. Once the datasets from the various studies were combined, a two-part regression model was used to estimate customer damage functions that can be generally applied to calculate customer interruption costs per event by season, time of day, day of week, and geographical regions within the U.S. for industrial, commercial, and residential customers."

Earlier studies can provide a basis for estimating the avoided damages from strategies to improve grid resilience (e.g., Sullivan et al., 2009, 2010; Leahy and Tol, 2011). Brown (2009) conducted a narrow cost–benefit analysis of storm-hardening strategies on behalf of the Public Utility Commission of Texas. This study indicated that undergrounding T&D lines is significantly more expensive when compared to traditional overhead installations. Brown (2009) assumed that converting existing overhead transmission lines to underground lines would cost approximately $5 million per mile.[2] For comparison, Brown (2009) indicates that it costs ~$180,000/mile to replace single wood pole transmission lines and ~$459,000/mile to replace state-of-the-art overhead transmission lines that meet current National Electric Safety Code (NESC) standards.[3] Brown (2009) estimated that undergrounding local overhead distribution lines would cost ~$1 million per mile. For comparison, the minimum replacement costs for existing overhead distribution lines ranged from $86,700 to $126,900/mile with maximum replacement costs ranging from $903,000 to $1,000,000 (EEI, 2013).

It is unfortunate, but likely, that replacing a large amount of overhead infrastructure with underground infrastructure will lead to relative increases in risk to utility operational staff working in the field. EEI (2013) indicates that undergrounding infrastructure has "created a significant safety hazard for crews attempting to locate and repair failed equipment." For this reason, it was assumed that worker health and safety costs will increase—above levels observed with the status quo—as the share of underground lines increases.

Reducing risk of power outages from severe storms is not the only reason given by stakeholders during discussions about burying T&D lines. Aesthetic improvements are a commonly listed benefit of undergrounding electric utility infrastructure (Brown, 2009; EEI, 2013; Navrud et al., 2008; Headwaters Economics, 2012). EEI (2013) notes that utility customers "prefer underground construction" with "customer satisfaction" and "community relations" being the primary benefit of undergrounding. For example, the community of Easthampton, New York issued a stop-work order and threatened to sue the local utility, PSEG Long Island, over their plan to build new high-voltage transmission lines (Gralla, 2014). This community and others are advocating for the undergrounding of future high-voltage transmission lines.

Des Rosiers (2002) found that a direct view of a transmission system pylon or conductors had a significantly negative impact on property prices with lost values ranging from −5% to −20% depending on the distance from the overhead infrastructure to the residence. Sims and Dent (2005) also evaluated how property prices changed based on proximity to high-voltage overhead transmission lines. Sims and Dent studied four different types of property and found that the relationship is not linear, but that there was a ~10%–18% reduction in value for semi-detached properties and a ~6%–13% reduction for detached properties. Furthermore, properties having a rear view of a pylon were found to have their value reduced by ~7%. By comparison, the negative impact on value for property having a frontal view was found to be greater (14.4% loss).

[1] Although not the focus of this analysis, other popular reliability metrics include the System Average Interruption Duration Index (SAIDI) and Customer Average Interruption Duration Index.

[2] EEI (2013) reported a minimum overhead-to-underground transmission line conversion cost of $536,760–$1,100,000/mile and a maximum conversion cost of $6,000,000–$12,000,000. EEI (2013) reported a minimum overhead-to-underground distribution line conversion cost range of $158,100–$1,000,000/mile and a maximum conversion cost range of $1,960,000–$5,000,000. The Edison Electric Institute (EEI) estimates that the minimum replacement costs for overhead transmission lines range from $174,000 per mile (rural) to $377,000 (urban). The maximum replacement costs for existing overhead transmission lines ranges from $4.5 million/mile (suburban) to $11 million/mile for urban customers (EEI, 2013). EEI (2013) also reported that installing new underground distribution lines costs from $297,200–$1,141,300/mile (minimum) to $1,840,000–$4,500,000/mile (maximum). EEI noted that installing new underground transmission lines costs from $1,400,000–$3,500,000/mile (minimum) to $27,000,000–$30,000,000/mile (maximum).

[3] Brown (2009) assumes that future costs and benefits are discounted 10% annually. In addition, underground and overhead T&D infrastructure have forty- and sixty-year life spans, respectively.