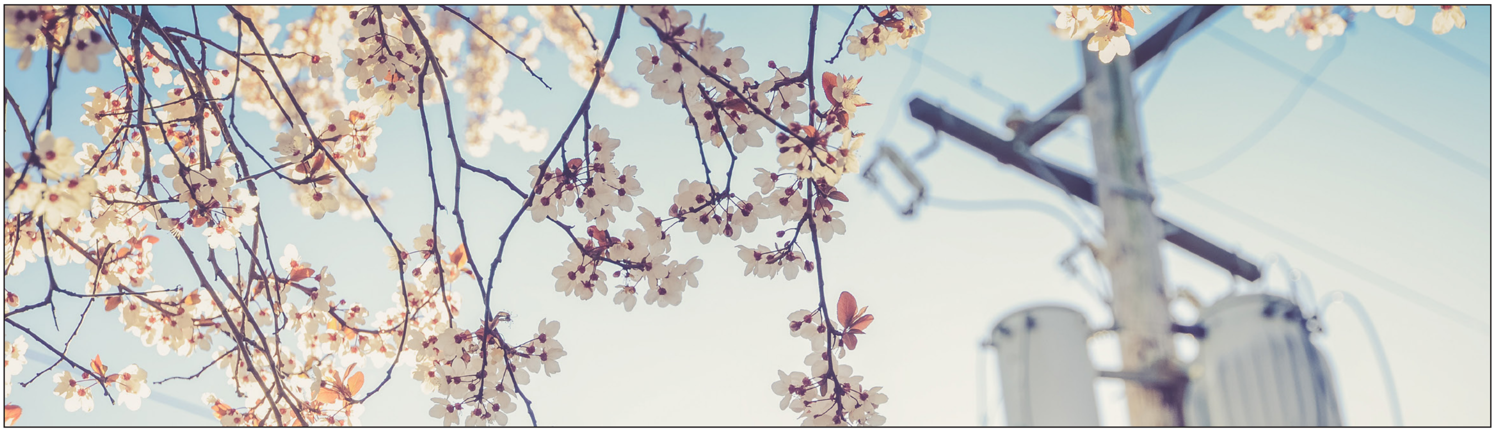
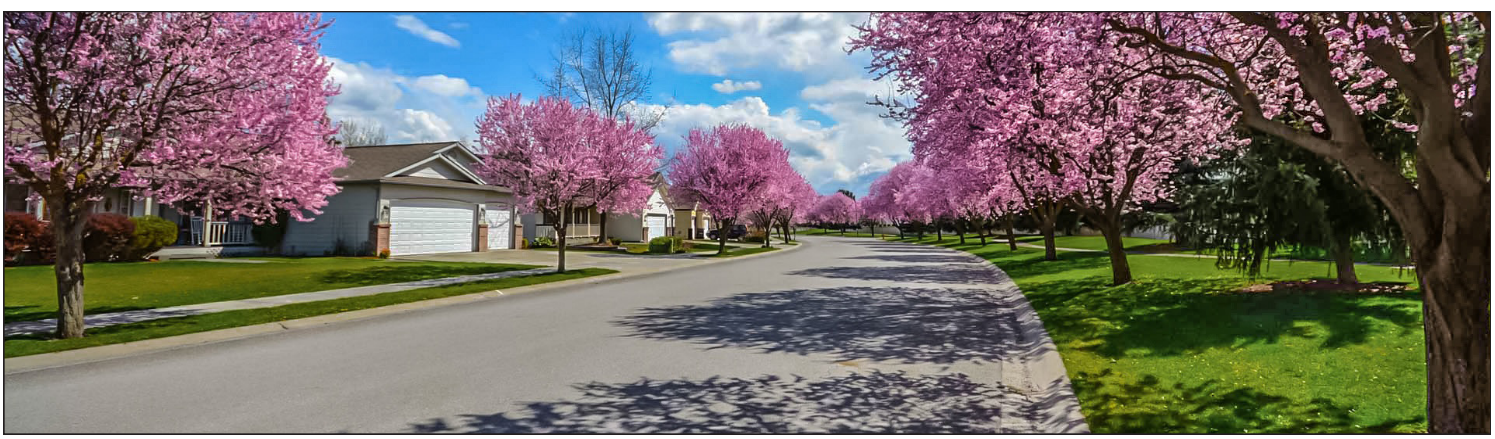
Clear Skies Ahead

The Case for Undergrounding Utility Infrastructure





Scenic America

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Executive Summary

1) Economic Benefits

Key Point: Our cost-benefit analysis shows undergrounding pays for itself.

Key Point: Power outages cost up to $110,000 per business in lost economic activity. Underground networks experience fewer outages.

Key Point: Burying overhead wires increases nearby property values by 5-20%.

Key Point: Average maintenance costs are 75-80% lower for underground wires.

Key Point: Undergrounding saves $7,000 per mile per year on average in avoided vegetation management expenses.

Although some reports cite the potentially high *upfront* costs of undergrounding wires[1], many studies have demonstrated that underground systems immediately begin to pay for themselves through long-term economic benefits. In this way, it is crucial to think of undergrounding as an investment rather than a purchase. The main economic advantages of underground lines compared to overhead wires include:

1) Less interruptions to business activity due to fewer power outages;
2) Increases in the value of nearby properties;
3) Lower maintenance costs, especially following storm events;
4) Reduced tree-trimming costs;
5) Fewer accidents, bringing smaller litigation and healthcare costs.

These are briefly expanded on below. The benefits are then aggregated to calculate the *societal* bottom-line cost of undergrounding the nation's overhead wires.

Fewer Interruptions to Business Activity

Almost every retail, industrial, service-based and online business in the country requires a supply of electricity to operate. For this reason, power outages disrupt businesses and stall economic activity. As will be discussed in the reliability section later, underground wires fail less often than overhead wires and hence result in less 'business downtime'. This is a significant economic benefit of underground wires, because power outages bring enormous costs in the form of this lost economic activity[2]:

Table 1 - The cost of lost economic activity during power outages.

	Cost per 30-minute power outage	Cost per 1-hour power outage	Cost per 8-hour power outage
Small* commercial business	$717 per business	$961 per business	$5,601 per business
Medium-large commercial business	$18,455 per business	$23,919 per business	$110,302 per business

[1]Cost estimates from studies by five US states and the District of Columbia are available in Appendix 1.

[2] Figures from a 2009 study, converted to 2018 prices by adjusting for CPI inflation rates.

*Small businesses are defined as those that use up to 50,000 kWh of electricity per year.

The President's Council of Economic Advisers and the U.S. Department of Energy collaborated on a report in 2013 that estimated the total annual cost of weather-related power outages was $18 - $33 billion. Based on the median reliability improvements we calculate in the next section, nationwide undergrounding could save $17.1 billion per year in lost economic activity.

Increased Property Values

Aesthetics are an important consideration for aspiring homeowners. A 2010 study in Australia found that the average value of properties near recently undergrounded utility lines grew by $11,700. A similar study in 2016, based in Texas (USA), found that nearby house prices were 5-20% higher. These represent growth in the value of individuals' existing assets that far exceed any gains from market price inflation, which averaged under 3.1% annually from 1996-2016.

Reduced Operational and Maintenance Costs

As underground wires are protected from external environmental factors, they encounter fewer faults and have lower maintenance costs as a result. Studies in the US and Iceland in 2013 found that maintenance costs were between 75% and 80% lower for underground lines compared to overhead wires. In Florida (USA), the reduced post-hurricane restoration costs alone were found to directly recoup 30% of the initial cost of undergrounding. Of the eight studies that analyzed operational costs in this report's compendium, all cited lower ongoing expenses for underground networks.

Reduced Tree-trimming Requirements

In overhead power systems, primary distribution lines need to be kept clear of obstructions like overgrown trees. This is especially true in storm-prone regions, where falling trees are often the leading cause of downed utility lines. Our research found that three state reports concluded undergrounding would reduce annual tree-trimming expenses. The only study to attempt to quantify these costs was in Florida (2007), which concluded that underground systems would save around $7,000 (and in some cases up to $70,000) per mile per year in tree-trimming requirements.

The Bottomline: Can Undergrounding Pay for Itself?

The array of economic benefits listed above are realized gradually over the lifetime of underground wires. As a result, the initial cost of undergrounding needs to be weighed against the lifecycle savings across all these areas in order to determine whether it is a worthwhile investment. The table below provides the estimated cost of undergrounding the entire American power grid, alongside the total estimated savings from each of the economic benefits listed above. These are the combined benefits to all major actors involved: utility companies, individual and business customers, and government. The figures are approximations based on median figures produced by state reports since the year 2000. They are the product of lengthy calculations, which are outlined and justified in Appendix 2. Appendix 2 also states the key assumptions underpinning the calculations, such as the assumed lifespan of underground wires. Note that the nature of these estimates means that they are national averages, but actual figures may vary substantially on a per-state basis or between urban versus rural areas.

Table 2 - The bottom-line cost-benefits to society of nationwide undergrounding.

Cost/Savings	Item	Amount (USD)[3]
Cost	Undergrounding the entire US power grid	+ $5.14 trillion
Savings	Business interruption costs[4]	- $0.60 trillion
Savings	Increased property values	- $1.13 trillion
Savings	General maintenance and post-hurricane restoration costs	- $1.75 trillion
Savings	Vegetation management costs	- $1.38 trillion
Savings	Health, accident and litigation costs	- $0.54 trillion
Bottomline	**% of lifetime cost directly recouped by the benefits of undergrounding**	**103.67%**

Our calculation found that the lifetime savings to society from underground wires cover their entire initial cost and generate a 3.67% profit. These calculations accounted for all economically quantifiable benefits; they do not even reflect the additional *non*-quantifiable benefits. The 3.67% return can hence be seen as just one of the benefits of undergrounding, in addition to these non-quantifiable benefits:

- Saving lives through reduced fatal power-related accidents
- Greater resiliency in the power supply during storm disasters, which could save further lives
- Visual improvements to the nation's scenic landscapes and urban communities
- Environmental benefits like reducing the number of trees being cut down and the number of birds killed by collisions with overhead structures
- Fewer disruptions to traffic, which often becomes delayed when overhead infrastructure collapses and obstructs roads

These already powerful results do not account for global climate change, which is expected to increase the frequency and severity of hurricane events moving forward. This will result in greater maintenance savings than those stated in the table, which are based on past (not future) figures. Furthermore, when combined with Policy Recommendations #1, #2 and/or #3 (outlined later), the initial costs of undergrounding could be reduced by 43% on average. Should this be achieved, it would actually result in a *net profit* for underground versus overhead networks, *in addition* to all the other social, reliability and environmental benefits discussed in this report.

[3] Cost/savings figures in the table are rounded to two decimal places.
[4] Includes missed electricity rates payable to utility companies during downtime.

2) Reliability Improvements

Key Point: Underground wires result in 69% less downtime.

Key Point: Underground wires are 97% less likely to fail during hurricanes.

Key Point: Median figures suggest that overhead power systems fail 78% more often than their underground equivalents.

Burying wires beneath the ground protects them from external disruptions that could otherwise cause power failures. Indeed, the leading causes of power outages in overhead systems are environmental factors, including the following[5]:

1) Falling trees and overgrown vegetation: 24 - 30% of outages nationwide;
2) Inclement weather (including hurricanes, ice storms, rain): 22 - 31% of outages nationwide;
3) Lightning strikes: 6 - 8% of outages nationwide.

Crucially, underground wires perform better against each of these environmental factors. This allows them to provide a more reliable supply of electricity regardless of the weather conditions or proximity to vegetation.

Overall Service Reliability

Given that underground networks are more resilient against external conditions, it is unsurprising that they increase the reliability of power. While some studies find that outages take marginally longer to fix in underground systems, almost every state report found that undergrounding reduces both the number of outages that occur and the overall downtime per year.

The table that follows lists the seven studies included in our compendium that calculated the frequency, duration and overall downtime or 'net reliability' of underground wires versus their overhead equivalents. We display the average result across the studies in the top line of the table. This provides a comprehensive set of averages that demonstrate the reliability improvements of undergrounding based on a large dataset. The main takeaways from this table are that, under normal conditions, underground wires result in:

- 78% fewer power outages than overhead wires
- A net reliability benefit of 69% less downtime in the supply of power

[5] According to two studies by Edison Electric Institute (EEI) published in 2006 and 2012.

Table 3 - Comparison of underground and overhead power outage frequency and duration data from seven state-commissioned studies. See bibliography for reports cited.

Year	Author(s) of Study	Frequency of Storm-related Power Outages	Overall Frequency of Power Outages	Median Duration per Outage	Net Reliability Benefit
AVERAGE RESULT	**twentytwenty**	**Underground wires are 94.3% less likely to fail during storm events**	**Underground wires result in 73.9% fewer power outages overall**	**Underground wires take 51.5% longer to repair**	**Underground wires provide a net benefit of 60.5% less downtime**
2013	Metsco Energy Solutions	Fewer for UG (unspecified %)	92.5% fewer for UG	95.8% longer for UG	44.0% more downtime for UG
2012	Edison Electric Institute	N/A	88.0% fewer for UG	40.5% shorter for UG	92.9% less downtime for UG
2010	Shaw Consultants International	86.5% fewer for UG	72.8% fewer for UG	12.5% longer for UG	69.4% less downtime for UG
2008	Pepco	97.3% fewer for UG	23.7% fewer for UG	N/A	23.7% less downtime for UG**
2008	Pepco (CAIDI)	99.0% fewer for UG	76.5% fewer for UG	57.1% longer for UG	63.1% less downtime for UG
2008	Oklahoma Corporation Commission	N/A	77.5% fewer for UG	N/A	77.5% less downtime for UG**
2006	PowerServices, Inc.	N/A	86.1% fewer for UG	N/A	86.1% less downtime for UG**

*Underground wires is abbreviated to UG.

**Where outage duration data was not provided, only frequency was used to calculate the net reliability benefit.

Storm Resilience

The above figures become even more significant when we isolate service reliability specifically during major storm events - which is oftentimes when a consistent supply of energy is most important to public safety. During hurricanes and ice storms, the average data across the seven state reports listed above shows that underground wires are 97% less likely to fail than overhead networks.

3) Social and Environmental Enhancements

Key Point: Fallen overhead wires are an electrocution hazard, a traffic hazard, and a leading cause of wildfires.

Key Point: Undergrounding reduces visual pollution and improves scenic values.

Key Point: Overhead power infrastructure kills up to 175 million birds per year.

Undergrounding utility lines is widely recognized for its positive social and environmental outcomes in addition to its technical and economic ones. The three main socio-environmental benefits are outlined below.

Aesthetic Improvements

Overhead wires and utility poles are not just prone to damage but constitute visual pollution in scenic landscapes across the United States. Moving this infrastructure underground would reduce these unsightly visual intrusions. Scenic beauty is not just intrinsically valuable; countless studies in the fields of psychology and sociology show that it is an essential ingredient for mental and emotional health.

Figure 1 - Overhead wires as visual pollution in our nation's treasured scenic landscapes.

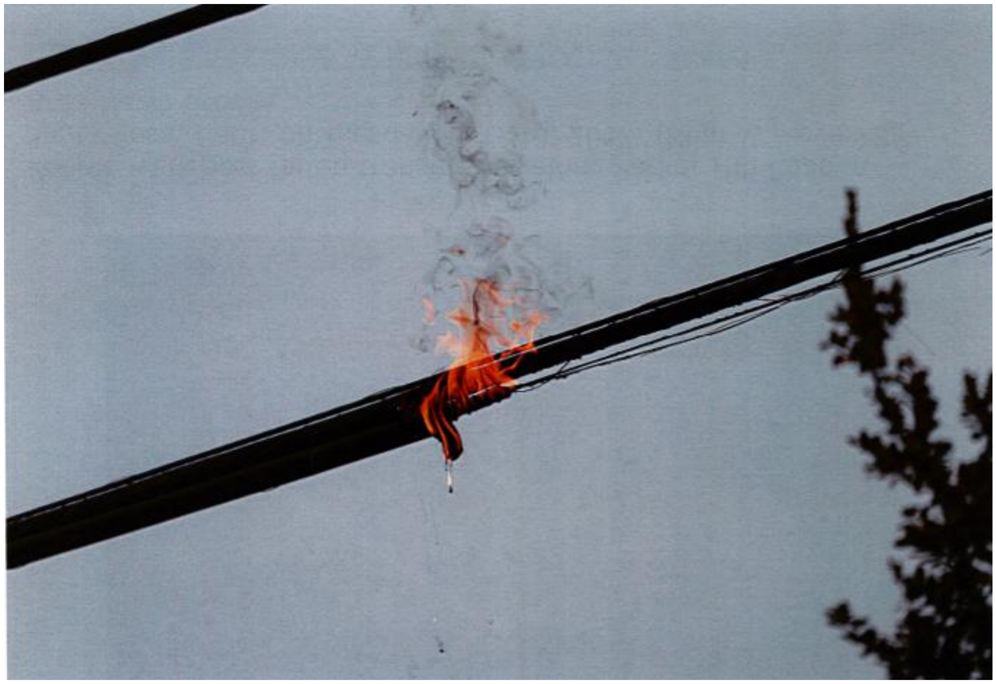
Public Safety and Health Advantages

Overhead lines pose multiple health and safety threats that can be eliminated by moving them underground. Free-hanging live-wires can be fatal on contact, and these are a frequent product of destructive storms. According to a 2006 study by the Electric Edison Institute, from 1992-2002 the number of fatal accidents caused by contact with broken overhead wires was 1,432. The equivalent figure for buried cables was substantially lower, at 35. Even after taking into account the larger number of overhead wires, this indicates that the relative rate of accidental deaths is 95% lower for underground wires. Overhead networks that run along roads and motorways also require roadside infrastructure, which can be a driving hazard. In Hawaii, 5% of all vehicular accidents are the result of collisions with utility poles and collapsed overhead wires. Moreover, breached wires or exposed distribution infrastructure can generate sparks which lead to wildfires. According to investigations by the Berkley Fire & Safety and Public Works Commissions in 2018, power infrastructure was the leading arsonist in the 2015 California wildfires - decimating over 150,000 acres of forest.

In addition to accidental injuries caused by contact, studies in Europe (2003 & 2014) and Hawaii (1999) cite a potential correlation between overhead wires and higher incidences of electromagnetic fields. Though their results were not definitive, it is widely accepted that extended exposure to this form of radiation can cause dangerous health issues for individuals, including the development of brain tumors.

Figure 2 - Downed utility poles obstruct Oakwood Road following a thunderstorm.

Figure 3 - Damaged overhead wires burn and drip in Santa Rosa, California.[6]



Ecological Benefits

Overhead wires need to be free from obstructions like greenery, to avoid them being collapsed by falling trees. The result is that they require the consistent trimming and in some cases complete removal of trees along primary utility routes. This not only destroys biodiversity but lessens the natural scenic qualities of America's landscapes and removes an important carbon sink in the fight against global climate change. Furthermore, a Stanford University study found that between hundreds of thousands and 175 million birds die every single year due to collisions with unnecessary overhead utility equipment. These represent two massive environmental costs that could be mitigated through undergrounding policies.

[6] Source: 2018 study by Berkley Public Works, referenced within this report's compendium.

Policy Recommendations

Based on the suggestions most frequently made by the studies reviewed in this report, we have compiled a list of recommendations for consideration during the development of any undergrounding policy or program. Not all the recommendations will be appropriate for every context, and some may extend the timeframe involved with the undergrounding process. However, they each represent different options for reducing costs, improving public/political support or increasing the technical feasibility of large-scale undergrounding.

1) Bury overhead power lines at the same time as other utility, water, sewage or communications lines (such as fiber optic cables) are being buried, so that the costs of undergrounding are shared across different industries and the benefits are felt across multiple services. According to Virginia's (2005) state-wide study, this could reduce undergrounding costs by 43% on average.
2) Transfer wires underground when existing overhead lines reach the end of their lifespan and need to be replaced anyway – reducing concerns about spending money to remove recently purchased overhead infrastructure.
3) Require that wires be placed underground in new developments. The construction of buildings and roads typically already involves digging up the ground to build foundations – at which point wires can simply be placed in the ground at minimal expense.
4) Public consultation is vital considering both overhead and underground wires affect everyone. The use of public consultation for all undergrounding projects would allow for the opinion of those affected to be taken into account, bringing greater public participation and support.
5) Funding for technology and R&D to encourage the investigation of technological advancements in undergrounding could reduce installation time and costs – such as the development of micro tunnels which helped avoid substantial excavations.
6) Use a Pareto analysis to take a targeted approach to undergrounding, identifying the lines that would benefit the most from putting wires underground (and would therefore bring the best return on investment) and starting with these. Typically, the best lines to target first are the ones that supply the highest population density (benefiting the most people) and the ones that are most vulnerable to storm failures (and hence incur the largest maintenance expenses).

Strategic Considerations

Which states make the best candidates for trialing undergrounding programs?

Applying the Pareto analysis (policy recommendation #6) at the national level could help determine which states are best to tackle initially. Our assessment concludes that the states likely to benefit the most from undergrounding programs are:

- Florida
- California
- North Carolina
- Texas
- Maine
- Michigan
- New York
- Georgia

These selections are based on the number of people per state affected by power outages (Appendix 3), the number of significant weather-related power outages per state per year (Appendix 4), and the number of named storms and hurricanes that made landfall in each state between 1995 - 2017 (Appendix 5). If this kind of data is available to state and local authorities at smaller scales, similar Pareto analyses can be conducted at the state or sub-state levels to determine which districts or communities would benefit most from undergrounding.

Tracking Public Support for Undergrounding

Policies that enjoy strong public support tend to gain political backing more easily. As a result, we've compiled survey and polling data from various studies that give an indication of the public appetite for undergrounding. There is limited survey data for customers in the US, so results from similarly developed countries in Europe have also been included.

Table 4 - Poll data showing public support for undergrounding.

Poll Year	Author/Pollster	Location	Result
2014	Menges & Beyer	Germany	70% 'fully agree' overhead wires impair the visual character of landscapes
2014	Tempesta et al.	Italy	55% say overhead wires have at some point reduced their enjoyment of an area
2012	EEI	United States	60% of Americans would be willing to pay higher utility rates to increase reliability through undergrounding
2012	TNS-Infratest	Germany	77% of respondents would vote in favor of undergrounding works

Lights Out: Anecdotes from an Unreliable Energy Grid

It is easy in the talk of nationwide undergrounding, billion dollar utility companies and Congressional policies to forget that energy is fundamentally intertwined with almost every aspect of our daily lives. For many individual families and businesses, a consistent power supply can be the difference between life and death or profit and loss. This section highlights the experiences of a handful of American citizens who faced power outages as a result of the nation's unreliable and predominantly overhead electricity grid. It details the tough consequences they faced, and illustrates the kind of incidents that could be minimized through a more dependable underground energy grid.

Power and Emergency Services

Montana, December 30th 2018.

The holiday period oftentimes sees a spike in emergency callouts. But what happens when the emergency phone line is down? Residents of Thompson Falls, Montana, faced an emergency they could not report: 911 call centers were unavailable after a power outage shut down all call and text services. The Sanders County Sheriff's Office reported that all contact with emergency services was temporarily entirely unavailable to those who most needed it. Calls were then redirected to a neighboring county, which delayed response times.

Power and Medicine

New York, July 29th 2018.

Over 2 million Americans use medical machinery at home to help them live more comfortable lives, and in some cases help them survive. Tens of thousands nationwide rely on ventilation and oxygen equipment to help them breathe. Power outages are nothing short of life-threatening for these individuals. Tragically, a power outage in Brooklyn made this risk a reality for a 57-year-old woman. The New Yorker suffered from obstructive pulmonary disease and was not able to survive long enough for the ambulance to arrive without her breathing aid's assistance. The victim's family maintains that this lack of electricity lead to the death of their relative.

Power and Traffic Safety

Florida, December 20th 2018.

In Southside, Florida, a 74-year-old pedestrian was killed by an oncoming vehicle during a power failure. While crossing the road at an intersection, the traffic lights and light poles were down which meant that both the pedestrian and driver were unaware of each other. Florida Highway Patrol reported that the lack of functioning traffic signals was the cause of death.

Power and Social Unrest

New Jersey, March 2018.

Energy is a fundamental part of our daily lives - and because of that, an interruption to our electricity access can lead to social dissatisfaction and even aggression. After being left without power for days following a “Nor’easter” storm, a New Jersey resident threatened Jersey Central Power & Light. He called the company and claimed he would kidnap one of their employees or blow up one of their generating stations if his home was not immediately provided with power. Police were forced to arrest the 63-year-old on terroristic charges.

Power and Water Quality

Washington, December 14th 2018.

A weather-related power failure shut down the King County’s Richmond Beach Pump Station in Shoreline, Washington. As a result, 130,000 gallons of sewage overflowed into freshwater stores in the region. It took over 2 hours before authorities were able to identify the contamination and warn residents of the health risks of drinking their water supply.

Power and Culture

Hawaii (July) and New York (November), 2018.

Helium balloons coated in foil frequently cause blackouts when they come into contact with overhead power lines. This is exactly what happened to residents of Kailua, Hawaii when a balloon-induced outage halted Fourth of July celebrations. It also turned the lights off for almost 2,000 customers and small businesses. A similar incident during Thanksgiving in Queens, New York left hundreds without power during their family holiday meals.

Power and Education

West Virginia (September) and California (January), 2018.

Educational institutions rely on electricity: well-lit classrooms and libraries to read and write in, projector screens to give lecturers and presentations, and electrical equipment to run computer rooms and science labs. On January 3rd, a squirrel chewed through some overhead wires at San Jose State University leading to cancelled classes and closed libraries for a whole day. Students in science labs were evacuated due to health risks after the lights went out and equipment powered down in the middle of chemical experiments. Similarly, in West Virginia, dozens of K-12 schools were closed in the Greenbrier, Kanawha, Wayne and Lincoln counties after storms downed utility poles across the state on September 28th.

Power and Sports

California and Arizona, July 30th 2018.

The Los Angeles Dodgers and the Arizona Diamondbacks both experienced power outages in their stadiums on the same day. They were not the only major league baseball teams to face such events during the season. At the Dodger Stadium, the match against the Milwaukee Brewers was delayed by half an hour following contact between a Mylar-balloon and overhead power lines which lead to the blackout. It necessitated the resetting of all stadium and filming equipment. The incident also had negative implications for the TV and commercial aspects of the game.

Power and Entertainment

Ohio, May 28th 2018.

After a car crashed into a utility pole in Sandusky, Ohio, the power went out at Cedar Point amusement park on Memorial Day. Many families and adrenaline-seekers at the event were trapped in rides. In particular, dozens were stranded on a 300ft rollercoaster for over 2 hours. Had this rollercoaster been halted in an upside-down position it could have caused considerable health problems for many.

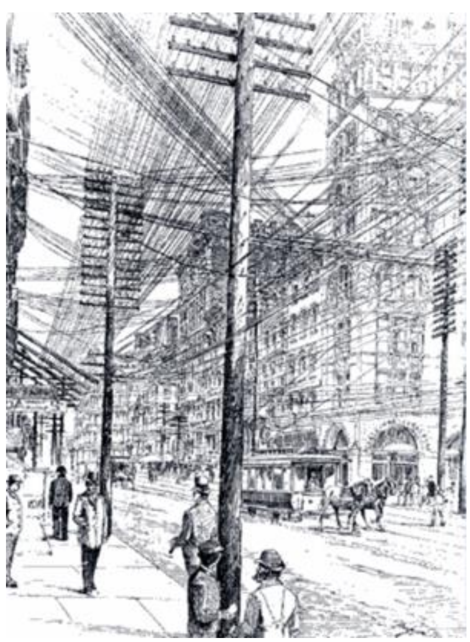
The History of Undergrounding

Between 1870 and 1880 the first underground electric distribution systems were laid in sewers and pipes in Paris and London. US Patent No.251/552, dated 1881, described the underground 'Street Pipes' invented by Thomas A. Edison - one of the earliest signs of undergrounding wires. However, these 'Street Pipes' were actually born out of a need to connect two of his previous inventions - the generator and the incandescent lamp. They operated at 110 volts and were made up of jute-wrapped copper bars that were inserted into an iron tube and the interstices filled with a bituminous or wax compound.

Since the 19th century researchers have been carrying out studies investigating undergrounding as an alternative to the "cobweb of wires" that as Jacques, W. W. said in 1885, resulted from the rapid development of communications and the sprawl of electricity across the globe. Such was the public desire to eliminate this visual blight that even artists began depicting the problem (Figure 4). Praise for underground power cables dates back decades with M. Gorman saying in 1901 that they are "*waterproof for 100 years, flexible and extensible, so volt resisting that the thinnest film suffices, sufficiently firm not to decentralise*". During the following 100 years, a number of significant products were developed for underground power cables including fluid-impregnated-paper-insulated cables which were perfected by the Pirelli Company in 1917 and cross-linked polyethylene (XLPE) insulation developed by General Electric Company in 1963. These began making the technology more viable.

A milestone in the history of undergrounding occurred in Hawaii in 1976. It was codified for the first time in law that before any approval of a high voltage transmission line (of 46 kV or greater) was going to be constructed overhead in a residential district, public consultation had to occur. This was the first appearance in the statutes of law that impacted the process in which electric wires were erected. Since then, a 2012 study has found that eleven US states now require that new developments bury wires in some or all of their districts.

Figure 4 - 19th Century art depicting the visual pollution of overhead wires in New York, New York.[7]



[7] Source: https://ethw.org/Early_Electrification_of_Buffalo

Compendium of Undergrounding Studies By Year

Year Published: 2019

Title: 'Blackout Tracker: United States Annual Report 2018'

Author(s): EATON

Location: United States

Source Type: Data Report

Funding Source: Self-funded (public multinational energy company)

Description of Study: This study does not investigate underground technology specifically. Rather, it collects and presents data about the impacts of power outages. However, given that differences in service reliability are a major point of comparison between underground and overhead systems this is a highly relevant report to review. It offers anecdotal small-scale examples of the impact of power outages on individuals, and also presents broader statistics about the damages caused by downtime at a statewide and industry-wide basis. It also considers the link between power and national security.

Key Findings:

- The country's ability to respond to a major grid collapse is poor, with large sections of the US at risk of being left without power for months according to a report by the President's National Infrastructure Advisory Council. This is a potential national security threat.
- Claims the US grid is in "desperate need" of modernization and improved reliability; cites smart grids as a potential way to do this. Smart grid technology is compatible with underground networks, and could help identify faults in underground wires more easily (without the need to dig up the entire stretch of wire). Some even boast 'self-healing' circuits that can isolate and repair some kinds of problems automatically.
    - Georgia Power estimates that this technology helped customers avoid 280,000 hours of power outages in a single year. This was achieved through the US Department of Energy's Smart Grid Investment Grant program.
- The annual nationwide economic cost of power outages is $150 billion per year
    - $8,851/minute of outage of a data center, $690,000/outage for healthcare institutions
    - 18% of companies experienced a loss of $100,000+ due to their worst outage (2018)
    - 25% of businesses surveyed experienced at least 1 outage per month
- The report notes that the FBI and Homeland Security have assessed the US grid and found it to be at risk of cyber attacks like the ones that brought down part of the Ukraine grid in 2015-16.

Strengths and Limitations of Study: This study is extremely beneficial in its statistics about the impacts of power outages. It offers anecdotal stories about the tragedies that can occur during downtime, which more clearly illustrates the real-world impact power outages can have. Lastly, the report's discussion of national security issues relating to grid reliability provides a different perspective not considered in most other reports in this field. Its downside in terms of utility for this undergrounding study is that it does not specifically address the benefits/costs of undergrounding as a solution to those outages.

Availability
Accessible online at: http://electricalsector.eaton.com/forms/BlackoutTrackerAnnualReport

Year Published: 2018

Title: 'Public acceptance of high-voltage power lines: The influence of information provision on undergrounding'

Author(s): Pascal Lienert, Bernadette Sütterlin, Michael Siegrist

Location: Switzerland

Source Type: Academic Journal Article

Funding Source: N/A (likely a university research grant)

Description of Study: This paper highlights the balance between Switzerland's expansion of its energy system and the social acceptance of overhead wires. In the face of the perceived benefits of undergrounding overhead wires, the study aims to identify the public's attitudes towards overhead power lines after being told about the impacts of burying wires underground.

Key Findings:

- The changes in Switzerland's energy system, such as increased renewable generation, has led to the need for more storage sites which in turn increased the need for high-voltage power line expansion. This expansion has inevitably been met with social acceptance issues.
- Negative views towards certain technologies can lead to lower perceived benefits of those technologies. The paper cites a study that concludes that overhead wires negatively influence the judgment of landscapes. Therefore, thinking of overhead wires invokes negative emotions which is related to the decreasing acceptance among the public.
- Despite disputed evidence as to whether electromagnetic fields related to overhead wires can cause an adverse effect on human health, 70% of European citizens believe their health was affected to some extent due to overhead electric wires. Electromagnetic fields are commonly at the top of the list when it comes to public concerns about overhead systems.
- This paper highlights another reason attributed to low public acceptance of overhead wires: the negative visual impacts on landscapes. Many see overhead wires as lacking the contextual fit with the surrounding environments, and view them as an intrusion.
- The authors mention a study carried out in England and Wales where 87% of respondents preferred undergrounding wires in comparison to overhead high voltage power lines.
- The study explains that underground lines still create electromagnetic fields on the surface despite the cable's insulation, but this is often lower in level.
- The study's survey showed that general public acceptance was higher for underground wires.

Strengths and Limitations of Study: Arguably the biggest advantage of this study is the investigation of public perceptions after being told the negative impacts that still remain with underground systems, something that has not been looked at in detail before. A disadvantage of this study is that the questions in its questionnaire were in some cases oversimplified which meant that the benefits/disadvantages of underground versus overhead systems was lost.

Availability

Accessible online at:
https://www.sciencedirect.com/science/article/pii/S0301421517306845?via%3Dihub

Year Published: 2018

Title of Study: 'Undergrounding Utility Wires in Berkeley'

Author(s): Berkeley Public Works, Disaster and Fire Safety, and Transportation Commissions

Location: Berkeley, California, United States

Source Type: Presentation (with local studies cited)

Funding Source: Self-funded by authoring organizations (government entities)

Description of Study: This presentation document provides an update of the status of undergrounding efforts in the city of Berkeley by citing relevant reports. These efforts were originally started in an attempt to make the city more resilient against disasters, but their progress is still being measured. The presentation also highlights some of the public safety and health issues related to undergrounding overhead wires. In particular, it explores how power lines can cause wildfires.

Key Findings:

- Power infrastructure was the main cause of California wildfires in 2015, destroying 150,000 acres of forest that year alone. Underground wires would have been far less likely to cause these fires, because many of them originated from sparks caused by free-hanging live-wires.
- Various cities in California have already began implementing undergrounding programs, including: San Diego, Santa Barbara, Los Angeles, Palo Alto, Anaheim, Laguna Beach and Santa Rosa.
- Characterizes overhead wires as a small but real public safety hazard.
- It is possible to gain a public mandate to implement an undergrounding program, as was achieved in San Diego and Palo Alto.

Strengths and Limitations of Study: The main limitation of this source is that it takes the form of brief presentation slides, which do not contain information as extensive as reports or articles. This is especially true because the original audio that accompanies the lecture is unavailable. However, the presentation provides many visuals to help illustrate some of the social and environmental issues related to undergrounding, which few other studies do. It also concisely covers multiple topics and provides some good broad points about the overall benefits of undergrounding.

Availability:
Accessible online at:
https://www.cityofberkeley.info/Clerk/City_Council/2018/02_Feb/Documents/2018-02-20_WS_Item_03_Conceptual_Study_for_Undergrounding_-_Pres.aspx

Year Published: 2017

Title of Study: 'Projecting future costs to U.S. electric utility customers from power interruptions'

Author(s): Larsen, Boehlert, Eto et al.

Location: United States

Source Type: Academic Journal Article

Funding Source: University research grant

Description of Study: This study used regional models of power reliability to estimate future interruption costs to the US economy. It details what these costs would be in a 'business as usual scenario' as well as an 'aggressive undergrounding' scenario.

Key Findings:

- By 2050, the study finds that the total cumulative cost of outages to US energy customers would be the following:
    - $1.5 – 3.4 trillion without aggressive undergrounding
    - $1.5 – 2.5 trillion with aggressive undergrounding
- By 2100, the study finds that the total cumulative cost of outages to US energy customers would be the following:
    - $1.9 – 5.6 trillion without aggressive undergrounding
    - $2.0 – 3.6 trillion with aggressive undergrounding
- Indicative conclusion: aggressive undergrounding policies could save customers up to $900 billion by 2050, and up to $2 trillion by 2100

Strengths and Limitations of Study: The study's main shortfall is that it does not specify the costs incurred by the economy at large – only those incurred by customers. It also does not state the costs to the utility company itself. However, its strength is in modelling future expected costs and returns, as most other studies focus exclusively on past costs/savings.

Availability:
Partially accessible online (behind pay wall) at:
https://www.sciencedirect.com/science/article/abs/pii/S0360544217321242

Year Published: 2016

Title of Study: 'A Method to Estimate the Costs and Benefits of Undergrounding Electricity Transmission and Distribution Lines'

Author(s): Peter H. Larsen (Stanford University)

Location: Texas, United States

Source Type: Research Report

Funding Source: U.S. Government research grant

Description of Study: This study develops an analytical framework to estimate the societal benefits and costs of undergrounding power distribution and transmission infrastructure. It uses this framework to try and determine whether the societal benefits of underground wires can be quantified and whether they are large enough to justify the upfront costs of undergrounding. The indirect benefits measured include the effect on nearby property values, health, ecology and aesthetics. Forecasts and calculations are offered for 2013-2050 for undergrounding versus the status quo.

Key Findings:

- Targeted undergrounding of transmission and distribution lines can be cost-effective, especially in storm-prone regions and densely populated areas.
- Even in contexts where undergrounding may not appear cost-effective, it can be made so by minimizing the costs. In particular, the report suggests undergrounding overhead wires when they reach the end of their lifetime and need to be replaced anyway. This would increase the time it takes to underground the entire system, but improves the cost-benefit ratio.
- Power disruptions from Hurricane Sandy affected tens of millions of people. Underground systems would have provided far greater resistance against the hurricane.
- The quantified societal and environmental benefits were as follows:
    - Property prices where wires are moved underground improve by 5-20% on average, according to 2002-2005 data.
    - Up to 175 million birds are killed every year due to collisions with overhead transmission infrastructure.
    - Texas would save $5.8 billion in reduced power interruption costs if it implemented an undergrounding policy, and it would see a $2 billion increase in property values.
- As storm reliability is a big part of what makes undergrounding financially attractive, climate change (which is increasing the frequency of extreme weather events) is likely to make undergrounding more economically worthwhile moving forward.

Strengths and Limitations of Study: This study claims to be the first to attempt to quantify the indirect benefits of undergrounding. Some of these, such as the impact on property values, can be significant in value. This is hugely important because it may be the case that these indirect long-term benefits more than outweigh the upfront costs of undergrounding, which could determine whether or not it is viable.

Availability:
Accessible online at: https://emp.lbl.gov/sites/all/files/lbnl-1006394_pre-publication.pdf

Year Published: 2015

Title of Study: 'Consulting with Public About Undergrounding Power Lines for Downtown Revitalization: The Case of Hockanum Road and Manhan Rail Trail at Pleasant Street in Northampton, MA '

Author(s): Noam Goldstein (University of Massachusetts)

Location: Amherst, Massachusetts, United States

Source Type: Research Report

Funding Source: Center for Public Policy and Administration (university research grant)

Description of Study: The State of Massachusetts made available a grant program called 'MassWorks', which was to enable local communities and cities to apply for infrastructural funding. The City of Northampton chose to apply for funding to achieve 'Pleasant Street Futures'. The initiative envisioned public streets that people would find aesthetically pleasing and livable. This research helped measure the public appetite for such a program, including their willingness to allocate money to undergrounding wires as a means to achieve the more pleasant street conditions.

Key Findings:

- Urban beautification grants can be used as a method to help fund undergrounding, because undergrounding is not just about reliability and economic but also visual pollution.
- The City of Concord (Massachusetts) demonstrates that undergrounding electric lines can be extremely affordable when combined with the undergrounding process for other utility infrastructure.
- Grants are also an effective way of supporting an undergrounding policy because they tend to be voted for by the public, who are often receptive to the benefits of such a policy.
- Streets become safer post-storms if the infrastructure has been buried, because there is a reduced risk of free-hanging live-wires which can cause fatal harm or spark fires.

Strengths and Limitations of Study: The study takes a unique angle by stressing the potential for alternative funding routes to pay for undergrounding programs. In particular it considers co-undergrounding initiatives and community grant initiatives. While undergrounding is cost-effective in many areas, this paper demonstrates that it can even be realistic in areas that may not initially appear to be prime candidates for underground systems - because there is a wide array of options to raise money with.

The only clear weakness of this study was a methodological one: it did not disclose details of the demographics of the members of the public that provided feedback about the undergrounding grant proposal. This means there is always a possibility that an over-represented demographic may have skewed the results.

Availability:
Accessible online at:
https://scholarworks.umass.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=1037&context=cppa_capstones

Year Published: 2014

Title of Study: 'Feasibility study for undergrounding electric distribution lines in Massachusetts'

Author(s): Massachusetts Department of Energy Resources

Location: Massachusetts, Untied States

Source Type: Research Study

Funding Source: Massachusetts Department of Energy Resources

Description of Study: The 2011 Halloween Nor'easter storm proved to be the basis of this study given the electric outages that were caused. Undergrounding was to be looked at as a viable option. The study reviews the feasibility of undergrounding the Massachusetts electrical distribution system with consultation from the Department of Public Utilities by summarizing national, state and municipal studies.

Key Findings:

- A $3bn statewide investment in targeted undergrounding would reduce outages by 97%
- Because electrical lines are often buried along existing public streets and right-of-ways, undergrounding projects are best incorporated into plans for street improvement to reduce costs and community disturbance. This will also reduce the project construction time.
- 43% of all the outages were caused by weather, with the number one cause being tree contact, often associated with high winds. An underground line is protected from these conditions.
- Electrical utilities recover their debt by increasing the rates of customers who benefited from the project. Which customers are required to pay the increased rate is determined by which customers are affected. For example, with the current DC undergrounding project discussed below, low income customers are exempt from increased rates and commercial and residential customers have separate rate increases.
- Governor Deval Patrick recognized the high cost of utility restoration following major storms.
- Massachusetts General Law (MGL) Chapter 166 § 22D allows municipalities to pass an ordinance or bylaw requiring their utility to bury existing overhead electric utility lines and the utility to recover costs by increasing rates.
- Following the Mayor's Power Line Undergrounding Task Force report recommendations in 2013, the Council of the District of Columbia passed the Electric Company Infrastructure Improvement Financing Act of 2014.

Strengths and Limitations of Study: This study is based specifically in Massachusetts which makes it fantastic for those looking at the suitability of undergrounding in the state. The plethora of figures and images in the study makes it extremely easy to visualize the information it discusses. The study at times discusses information such as the 'basics of the grid' in too much detail which would not necessarily assist in determining policy for undergrounding or certain issues that arise with the question of undergrounding. It does, however, provide some useful quantitative insights.

Availability:
Accessible online at: https://www.mass.gov/files/documents/2016/08/od/undergrounding-distribution-lines.pdf

Year Published: 2014

Title of Study: 'The landscape benefits of the burial of high voltage power lines: A study in rural areas of Italy'

Author(s): T. Tempesta, D. Vecchiato and P. Girardi

Location: Italy

Source Type: Academic Journal Article

Funding Source: N/A (most likely a university research grant)

Description of Study: The knowledge that overhead transmission wires cause major blight and damage to the landscape quality have provided the basis for this article. The decline in the aesthetic quality forms the foundation for an article which looks that the willingness of the Italian population to pay to eliminate this negative impact produced by high voltage overhead power lines using three different landscape contexts.

Key Findings:

- A positive 77% of respondents are willing to pay to reduce the impacts on the landscape produced by high voltage overhead power lines.
- The endless negative externalities produced by overhead wires such as visual damage, damage to wildlife and health risks has contributed to the negative attitude felt by citizens for overhead wires leading to delays in new power lines. The disregard for these negative externalities have been cause of opposition by the citizens of Italy and it should be noted that negative externalities often lead to market failure and should be investigated diligently.
- The article also reports several studies which have shown that the quality of the landscape can affect people's wellbeing by interacting with several physiological parameters, even leading to a restorative effect on individuals.
- A common counter-argument to undergrounding wires is to perhaps change the tower design, however this is only solving one issue. A study showed that although certain people have a preference to one tower design compared to other designs that the best method for reducing impacts on the landscape is to simply bury them.
- The importance of landscape preservation is highlighted in a study conducted by the authors which shows 55% considered that cables and pylons markedly spoilt the landscape and enjoyment of the places they visited.

Strengths and Limitations of Study: This article is great at pointing out a number of significant studies which paint a positive picture to undergrounding wires, including studies on the best way to deal with visual blight and the projects which the public are willing to pay. The article also clearly highlights a large amount of support for undergrounding public utility wires across a whole country - which bodes well for the US. Although the article is attempting to add to the literature on the social benefits of undergrounding it fails to tackle any other important benefits which are highly relevant.

Availability:
Accessible online at: https://ac.els-cdn.com/S0169204614000693/1-s2.0-S0169204614000693-main.pdf?

Year Published: 2014

Title of Study: 'Underground cables versus overhead lines: Do cables increase social acceptance of grid development? Results of a contingent valuation survey in Germany.'

Author(s): Roland Menges and Gregor Beyer

Location: Germany

Source Type: Academic Journal Article

Funding Source: International Journal of Sustainable Energy Planning and Management

Description of Study: Transmission development plans across Germany have sparked a large amount of debate and subsequently led to protests. The article investigates this issue in Germany and discuses the use of undergrounding cables as a means to increase the public agreement of the plans. The article also attempts to draw conclusions on households' views to underground utility wires and their willingness to pay for the undergrounding process.

Key Findings:

- There has been an overwhelming rejection of overhead utility wires across the population with fears for the natural landscape being destroyed and potential radiation being emitted.
- A study by Deutsche Umwelthilfe in 2010 asked participants: "do overhead lines impair a landscape's character?" - an overwhelming 70% 'agree fully' to the statement.
- Given public disputes, another study in October 2012 by TNS-Infratest asked almost 4,000 households under which conditions they would agree undergrounding construction work to be carried out. More than three quarters (77%) stated they would support the works.
- Part of the evidence presented in this article determined that underground cables were a means to increase the social acceptance of the Energy Transition and the development of its transmission network which it requires.
- The article also concludes that positive public opinion was not the sole argument to support undergrounding cables and includes the low social costs that are produced, the high environmental benefits, less visual blight and the improved health outcomes that would be encountered due to the absence of overhead wires' electromagnetic radiation fields.
- Results show that a majority of around 60% favour underground wires compared to overhead wires with regards to both regional and supra-regional work. A sample of 4 areas in Germany were asked about their willingness-to-pay. Given the costs associated with undergrounding wires a positive 40% of respondents were willing to make extra payments for a conversion.

Strengths and Limitations of Study: Although this article yields fantastic results which make a strong case for undergrounding, through its diligent use of surveys to illicit positive conclusions, it is extremely specific in its scope. The methods used in this article could be reproduced in other areas to increase reliability of the results. When calculating the WTP, the article could have included a choice of different methods to illicit which payment type the respondents are more willing to agree to.

Availability:
Accessible online at: https://journals.aau.dk/index.php/sepm/article/view/539

Year Published: 2013

Title of Study: 'An Updated Study on the Undergrounding of Overhead Power Lines'

Author(s): Kenneth L. Hall (Hall Energy Consulting, Inc.)

Location: District of Columbia, United States

Source Type: Research Report

Funding Source: Edison Electric Institute (EEI)

Description of Study: The study provides a data analysis of customer feedback, costs, reliability (using three industry-standard indices: CAIDI, SAIDI, and SAIFI), cost (using varying forms of undergrounding utility wires, namely transmission or distribution) and of conversion efficiency.

Key Findings:

- 34% of customers polled said they would be happy to be slightly more to have their utilities put underground, and 26% would be willing to face moderate to large price increases.
- Underground reliability may be even higher than studies suggest, because many underground systems are still fed by overhead infrastructure - which means they are still susceptible to the easier disruptions faced by overhead systems.
- Underground systems contribute to fewer power outages on both a per-mile and a per-customer basis.

Strengths and Limitations of Study: The study does not specify whether the 1003 survey-takers were representative of the nation, or representative of a region, or randomly selected. It does, however, deploy various industry-leading calculation methods ensuring that its findings are in-keeping with best practices. Additionally, it has the advantage of being balanced in nature; giving due attention to both the challenges and the benefits of burying overhead wires.

Availability:

Accessible online at:
http://www.eei.org/issuesandpolicy/electricreliability/undergrounding/Documents/UndergroundReport.pdf

Year Published: 2013

Title of Study: 'Comparison of Underground and Overhead Transmission Options in Iceland'

Author(s): Metsco Energy Solutions

Location: Iceland

Source Type: Research Report

Funding Source: Landvernd (NGO)

Description of Study: Provides an analytical comparison of the overhead and underground power options being considered as part of a program to strengthen transmission infrastructure in Iceland. The study was commissioned because underground wires have replaced overhead wires at increasing rates in the country - but the effects of this had not yet been properly monitored. The report focuses on a comparison of both construction costs and operating costs, using data from Iceland as a case study. Owing to limited long-term data on the topic, it operates on the assumption that overhead wires and underground wires have similar lifetime lengths in terms of technical (non-environmental) faults.

Key Findings:

- Upfront construction costs were 2.5 times higher for underground wires than overhead wires, but operating/maintenance costs were 4-5 times lower.
- The lifetime costs of underground wires were 4-20% higher, but this moderate premium brought indirect economic benefits, notable improvements to reliability, enhanced the aesthetics and tourist perception of areas, and aided public safety.
- Underground wires were up to 93% less likely to fail than overhead wires.
- Undergrounding wires could lead to deep-rooted plants being harmed during excavation, but overhead wires were deemed more environmentally damaging when it came to soil erosion and pest infestation.
- The public safety concerns of overhead free-hanging wires can almost entirely be eliminated by undergrounding.

Strengths and Limitations of Study: This report's main shortfall is that the data is exclusively drawn from Iceland, which has different infrastructural systems and climate conditions than much of the USA. The result is that its conclusions may not translate accurately to the USA.

It's strengths, however, include the fact that it is the only study of its type that analyses this new Icelandic data - whereas many other studies simply review old data from existing reports. Although its focus is on costs, the report also benefits from commenting on the broader benefits and challenges of undergrounding on society and the environment.

Availability:
Accessible online at: http://landvernd.is/portals/0/_FrettaSkjol/1_Iceland%20UG-OH%20Report_FINAL.pdf

Year Published: 2013

Title of Study: 'Feasibility Report: Underground Electric Utilities'

Author(s): CHA Consulting, Inc.

Location: Rye, New York, United States

Source Type: Research Report

Funding Source: Con Edison (private energy company)

Description of Study: Clough Harbour & Associates (CHA) LLP was instructed to complete an extensive field investigation of feeders in Staten Island and Westchester to determine the optimal method for converting to underground systems. It reviews the different categories of storms, and analyses the extent to which each type of storm can have an impact on energy infrastructure.

Key Findings:

- New York City has relatively low outage rates yet features one of the highest rates of undergrounded systems nationally, with 82% of customers being served by underground networks.
- All eleven state reports commissioned as of the published date of this report recognized the greater capacity of underground networks to combat weather-related outages.
- The number of severe weather disasters seems to be increasing (perhaps due to global climate change), with threats to overhead supplies growing as a consequence.
- Thermal loading was the only tested factor that underground wires scored worse for. They proved to be more reliable against atmospheric threats, vehicular accidents, falling trees, and ice loading.

Strengths and Limitations of Study: The study considers very specific areas within New York City, which is far more urban and densely populated than most of the United States. As a result its findings are not necessarily representative of nationwide trends.

Availability:
Accessible online at:
http://www.nyc.gov/html/planyc2030/downloads/pdf/power_lines_study_2013.pdf

Year Published: 2013

Title of Study: 'Utilization of Underground and Overhead Power Lines in the City of New York'

Author(s): Office of Long-Term Planning and Sustainability

Location: New York, New York, United States

Source Type: Research Report

Funding Source: Office of the Mayor

Description of Study: This study shows how plans by Edison Electrical Institute (EEI) would perform in New York. It attempts to address the New York City Council's questions about the vulnerabilities of their overhead systems, resulting from adverse weather conditions. The report conducted assessments such as the System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Duration Index (CAIDI) and System Average Interruption Duration Index (SAIDI). In doing so, the study provides a cost-analysis of undergrounding utilities in the New York City boroughs.[8]

Key Findings:

- The calculations suggest a feasible route to undergrounding New York City's electric infrastructure. The high population density of this urban area means that any upfront costs can be shared across more customers and more utilities companies, making it cost-effective.
- Based on public and industry feedback, the report suggests that advocacy efforts should focus on the optimal degree of undergrounding. This may include a complete undergrounding program in some boroughs.

Strengths and Limitations of Study: Whereas other studies rely on reviews of older reports using old data, this study develops its own calculations that suggest undergrounding can be inexpensive in densely populated areas. However, much of the focus of this research is on overhead resiliency policies rather than undergrounding.

Availability:
Accessible online at:
http://www.nyc.gov/html/planyc2030/downloads/pdf/power_lines_study_2013.pdf

[8] Includes: Manhattan, Queens, Brooklyn, Bronx and Staten Island.

Year Published: 2012

Title of Study: 'Cost and Reliability Comparisons of Underground and Overhead Power Lines'

Author(s): Steve Fenrick & Lullit Getachew

Location: United States

Source Type: Academic Journal Article

Funding Source: N/A (most likely an academic research grant)

Description of Study: This article outlines the benefits of placing overhead lines underground. It focuses on operational costs and reliability. The research uses a large dataset from 163 electric utilities companies and associations in the USA to compare the frequency of power outages and technical failures in different underground and overhead systems throughout the country.

Key Findings:

- Undergrounding reduces not only the frequency of power outages but also their duration, resulting in all-around greater reliability. This was true using both the SAIDI and the CAIDI calculations, two industry-standard methods.
- Underground wires reduce the operational and maintenance costs associated with power distribution.
- The assessment shows that these benefits can and should be balanced against the construction costs of underground distribution infrastructure.

Strengths and Limitations of Study: This article's main strength is the large size of the dataset it analyses, which makes its conclusions more reliable and well-evidenced. However, it mains drawbacks are its limited accessibility (it sits behind a pay-wall) and its lack of statistical statements; oftentimes asserting conclusions but not going into detail about the figures behind those conclusions.

Availability:
Limited* online access at: https://www.sciencedirect.com/science/article/pii/S0957178711000622#!
*Access to the summary and abstract is freely available, but the full article requires a paid membership.

Year Published: 2012

Title of Study: 'Out of Sight, Out of Mind'

Author(s): Kenneth L. Hall (Hall Energy Consulting, Inc.)

Location: United States

Source Type: Research Report

Funding Source: Edison Electric Institute (EEI)

Description of Study: This research report for EEI reviews decade's worth of state reports on undergrounding America's electric infrastructure. The document aims to provide a comprehensive analysis of all the major implications of this process: reliability, cost, safety, and storm resilience. It synthesizes data from every major state investigation into undergrounding published prior to 2012.

Key Findings:

- 60% of Americans polled said they would be willing to pay higher electricity bills for the sake of having the overhead wires in their homes and communities placed underground.
- From 2004-2011, the total amount of annual downtime experienced by customers was a minimum of 10 times lower for underground systems.
- From 2009-2011, the duration of outages in underground systems was lower than that of overhead systems.
- Overhead wire failures result in three times as many power outages as underground wire failures.
- Environmental factors caused 54% of power outages in the USA between 2000-2011. Listed below are the most common causes, all of which would have better resisted by underground systems:
    - Falling or overgrown vegetation - 24% of outages nationwide
    - Weather (wind, rain and ice) - 22% of outages nationwide
    - Lightning strikes - 8% of outages nationwide
- Undergrounding is at its most attractive to customers and utilities companies during new developments, when the ground is often dug-up for other reasons anyway - saving massively on costs.
- When utility companies have worked democratically with local communities, public demand tends to result in a commitment to ensure that at least 20% of future power lines are placed underground.

Strengths and Limitations of Study: This research is strong in breadth and depth; providing a useful and complete overview of the topic. However, its thorough analysis only includes studies from previous decades, and does not reflect the latest data that has emerged in the field since 2012.

Availability:
Accessible online at:
http://www.eei.org/issuesandpolicy/electricreliability/undergrounding/Documents/UndergroundReport.pdf

Year Published: 2011

Title: 'Delivering London 2012: power lines undergrounding'

Author(s): David Twine, Howard Shiplee and Mark Thurston

Location: London, United Kingdom

Source Type: Project Report

Funding Source: Institution of Civil Engineers

Description of Study: This study outlines the foundations of a large interdisciplinary project in London, the biggest in Europe at the time, to underground two sets of power lines ahead of the London 2012 Olympic and Paralympic Games. The paper discusses the extensive planning, collaboration and innovative methods that went into to building tunnels to underground a set of electricity lines that were previously hampering the 2012 Olympic Park site.

Key Findings:

- Outlines the benefits of negotiation in undergrounding projects. The project had the potential to displease a number of landowners, over fifteen railways and multiple rivers. Many citizens were concerned about the impact of the works, but continuous negotiations kept the project going.
- With over 200km of cable needing to be laid and tested with just 13 months remaining, this paper highlights the need for intelligent and innovative planning. The use of off-site mock tunnel environments helped trial and develop different techniques until the most safe and efficient was found. These mock environments allowed for testing without interrupting the main site.
- The use of bespoke tunnel vehicles was used in order to be able to pull extraordinary amounts of cable through the tunnels in record time. This technology may benefit other projects.
- The paper provides a number of suggestions for those carrying out similar projects, some of which are detailed below:
    - Co-location of the key clients and parties to allow for strong personal relationships, which ultimately aid with a faster rate of decision making - particularly important with projects that have limited deadlines or significantly impact local communities.
    - A compelling overarching common goal that all parties can work with in order for the standard of work to be coherent; underground systems come in many varieties.

Strengths and Limitations of Study: The biggest strength of this study is that it can aid those project managers wishing to carry out an undergrounding project, the paper details ways in which to avert obstacles that may appear. However, some of the suggestions such as the use of tunnel vehicles or off-site testing may not be available for other smaller scale projects, to which no other solution was presented for the reader.

Availability

Accessible online at: https://www.icevirtuallibrary.com/doi/10.1680/cien.2011.164.6.11

Year Published: 2011

Title of Study: 'Households' willingness to pay for overhead-to-underground conversion of electricity distribution networks'

Author(s): McNair et al.

Location: Australia

Source Type: Academic Journal Article

Funding Source: N/A – likely a university research grant

Description of Study: This study gathers survey data about willingness to pay for undergrounding by Australian energy customers. It breaks down their reasons for wanting, or not wanting, to underground their neighborhood's power lines. It compares the amount people claim to be willing to pay to the additional house price value for homes that already have underground systems, to see whether they are consistent and reliable indications of the value people attach to undergrounding.

Key Findings:

- The study's polling found that the benefits of undergrounding that Australian customers most care about were the following:
  - 50%+ say better safety, especially in terms of storm reliability and wildfires
  - 50%+ say improved appearance of their home and neighborhood
  - 40%+ say reduced tree-trimming needs
  - ~15% say fewer restrictions on yard space
  - ~10% say fewer power cuts
- The study 'conservatively estimates' that the average willingness to pay is between A$5,500 and A$8,500, but one third of all respondents would be willing to pay over A$11,700.
- They note that there is no complete study of all the benefits of undergrounding to a household; only studies about the benefits specifically on house prices or power reliability.
- The per-property cost of undergrounding in Australia was estimated to be A$10,000 – A$20,000.

Strengths and Limitations of Study: This study does a great job of finding out not just the level of public support for undergrounding, but also which reasons for undergrounding they actually care about – mainly safety and visual improvements.

Availability:
Accessible online (partially, behind pay wall) at:
https://www.sciencedirect.com/science/article/pii/S0301421511001030

Year Published: 2011

Title of Study: 'Undergrounding Electric Lines'

Author(s): Kevin McCarthy

Location: Connecticut, United States

Source Type: Research Report

Funding Source: Connecticut General Assembly

Description of Study: This study was carried out to ascertain the benefits and economic dynamics of undergrounding distribution lines, with a particular focus on urban areas. The study also served to identify any barriers to the undergrounding process. The report analyses a number of studies including state reports from Florida and North Carolina to reach its conclusions.

Key Findings:

- Undergrounding substantially reduces the costs of tree trimming and other vegetation management, as well as damages to electric facilities caused by vehicle crashes.
- Undergrounding reduces the costs of post-storm restoration of the electric system and reduces revenue losses for electric utilities resulting from storm-induced outages.
- In addition, undergrounding provides aesthetic benefits by reducing visual clutter. This may increase the value of nearby properties.
- Maryland requires that all distribution lines for new subdivisions be placed underground. Since 1967, the California Public Utilities Commission has required that all new service connections be placed underground. It has also established a ratepayer-supported fund to help pay for undergrounding existing lines.
- In December 2002, a major ice storm blanketed North Carolina with up to one inch of ice, causing power outages for approximately two million customers. In the aftermath of the storm, the public expressed considerable interest in burying all overhead power lines in the state.
- The investigation identified the major arguments for undergrounding. These include reduced maintenance, smaller rights of way, less susceptibility to weather damage, fewer traffic accidents involving poles, improved aesthetics, and increased property values. The investigation found that underground systems are more reliable than overhead.
- The department, state and local highway authorities and municipalities should identify opportunities for undergrounding in construction and repair work and work closely together.

Strengths and Limitations of Study: This study excels in its discussion of legislative work, particularly the Maryland Legislative Task Force (2003), which makes it highly relevant for policy makers. This report also concisely summarizes a number of studies, inter alia, in North Carolina and Oklahoma. Despite pointing out the positives of undergrounding electrical wires, the study fails to fully delve into these positive factors in detail. The issue of property devaluation due to overhead wires, which makes a strong case for undergrounding is not extensively discussed in this report.

Availability:
Accessible online at: https://www.cga.ct.gov/2011/rpt/2011-R-0338.htm

Year Published: 2010

Title of Study: 'Estimating the Value of Undergrounding Electricity and Telecommunications Networks '

Author(s): Ben McNair and Peter Abelson

Location: Australia

Source Type: Research Report

Funding Source: Melbourne Institute of Applied Economic and Social Research

Description of Study: This article investigates the benefits that are afforded to households by exploring relationships between house prices and the type of power network in the area. The article provides information to policymakers that are making the argument to begin undergrounding. This study also estimates the implicit price for underground low-voltage electricity distribution and telecommunications wires.

Key Findings:

- The study on house prices in Australia has concluded that undergrounding wires will lead to increase of 2.9% in housing prices. This equates to roughly $11,700 per property.
- Underground wires lead to more aesthetically pleasing residential areas and savings from lower network energy losses, avoided pole maintenance costs and avoided costs of trimming trees around power lines.
- The expense of undergrounding must be justified primarily by the benefits to households. The estimated value of benefits to households is therefore a key component in the economic evaluation of undergrounding programs.
- Turning to households 'willingness to pay' for underground wires, it is observed that 31 per cent of households in the sample chose to pay the price premium for a house serviced by underground wires. This figure is constant with a previous study by McNair, Bennett and Hensher (2010) that found that 32 per cent of Canberra home-owners currently serviced by overhead wires are willing to pay $11,700 or more for undergrounding in their suburb.

Strengths and Limitations of Study: The results of this study on the increase on housing prices provides great concrete foundations for policy makers that intend to introduce programs or policy to underground electrical wires, this is an area that was previously completely un-investigated. Having said that, this study only focused on Australia and a small sample, so its study would need to be carried out across other countries to make its results fully reliable. Nonetheless, it is a great starting point and addition to the literature.

Availability:
Accessible online at: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1467-8462.2010.00608.x

Year Published: 2010

Title of Study: 'Study of the Feasibility and Reliability of Undergrounding Electric Distribution Lines in the District of Columbia'

Author(s): Shaw Consultants International

Location: District of Columbia, United States

Source Type: State Report

Funding Source: Public Service Commission of the District of Columbia (government entity)

Description of Study: This research was commissioned in order to determine the technical reliability and economic feasibility of undergrounding overhead wires in Washington, DC. Its primary methodology involved a literature review of existing undergrounding studies, with an emphasis on the studies conducted by Pepco. It also provides a comparison to alternative proposals for distribution systems, such as storm-hardening for existing overhead wires.

Key Findings:

- Underground wires suffer 1.4 - 1.5 outages per mile per year in DC, compared to 1.9 - 4.8 incidents for overhead wires. As a result, despite longer average repair times, undergrounding boasts a reliability improvement of up to 70%.
- Storm-related power outages are estimated to be 7 times lower for underground wires compared to overhead wires.
- Undergrounding should not be judged solely by its high upfront costs because its indirect benefits (which are harder to quantify) can reduce this cost by approximately 50%.
- Targeted undergrounding can be extremely cost-effective. Strategically spending less than one-fifth of the amount it would take to underground DC's whole power system could reap 65% of the benefits of a complete undergrounding program.
- Five American states (not specified) already require undergrounding for new developments, with a further six states requiring undergrounding within specific municipalities. Additionally, most major cities in America require this.
- Converting DC's power grid to an underground system would reduce the number of annual power outages in the area by 1030.

Strengths and Limitations of Study: This study concisely summarizes multiple undergrounding studies, a good resource for quickly learning about the topic. Its strength stems from the fact that it offers new data based on a real-world case study, Washington DC. This data is used to compare underground wires and overhead wires across different criteria, focusing on reliability as well as costs - offering more insights than other, more narrowly-focused reports.

Availability:
Accessible online at:
https://oca.dc.gov/sites/default/files/dc/sites/oca/page_content/attachments/Study%20of%20the%20Feasibility%20&%20Reliability%20of%20Undergrounding%20Electric%20Distribution%20Lines%20in%20DC%20(July%201,%202010)%20-%20ShawConsultantsforPSC.pdf

Year Published: 2009

Title of Study: 'Estimated Value of Service Reliability for Electric Utility Customers in the United States'

Author(s): Ernest Orlando Lawrence Berkeley National Laboratory

Location: United States

Source Type: Research Report

Funding Source: U.S. Department of Energy (government entity)

Description of Study: This report is not specifically targeted at undergrounding electricity lines. It measures the indirect economic benefits of a reliable power supply more generally. It does this by attempting to estimate the cost of lost economic activity during power outages. However, as reliability forms a significant part of the underground versus overhead wires debate, this paper helps provide clues as to whether the increased reliability of one option over the other is a worthwhile investment. The emphasis is on the economic benefits for individual energy customers, but it also provides estimates for lost industrial/commercial economic activity for businesses.

Key Findings:

- The economic costs of shorter but more frequent power outages is generally greater than that of fewer longer outages. This bodes well for underground wires, which sometimes take longer to repair when they fail but generally fail much less frequently.
- The cost of lost economic activity during outages was determined to be substantial, as follows:

	Cost of 30 minute power outage	Cost of 1-hour power outage	Cost of 8-hour power outage
Residential customer	$3.30 per customer	$3.90 per customer	$10.70 per customer
Small* commercial business	$610 per business	$818 per business	$4,768 per business
Medium-large* commercial business	$15,709 per business	$20,360 per business	$93,890 per business

*Small businesses were taken to be those that use up to 50,000 kWh of energy per year, medium-large businesses were ones that used more energy than that.

Strengths and Limitations of Study: This report's strength lies in the fact that, unlike most other papers in this field, it does not focus on the physical direct costs of undergrounding wires. Instead, it attempts to calculate the indirect benefits of uninterrupted economic activity that result from a more reliable energy supply. Given that most studies show underground wires are more reliable than overhead ones, this allows us to estimate the long-term return on investment that underground wires could bring by reducing the number of power outages in the economy. It also benefits from using a large data set (which improves the accuracy of the calculations), using figures from 28 studies spread across a 16-year period (1989 - 2005). The only minor limitation is that the calculated figures were accurate as of 2009, but owing to inflation the figures may no longer be as good a representation.

Availability:
Accessible online at: https://emp.lbl.gov/sites/default/files/lbnl-2132e.pdf

Year Published: 2009

Title of Study: 'Cost-Benefit Analysis of the Deployment of Utility Infrastructure Upgrades and Strom Hardening Programs'

Author(s): Richard Brown (Quanta Technology)

Location: Texas, United States

Source Type: State Report

Funding Source: Public Utility Commission of Texas (government entity)

Description of Study: The cost-benefit analysis used in this paper assesses the benefits of storm-hardening programs for electricity infrastructure in Texas, one of the states that is most vulnerable to extreme weather events. One of the hardening programs it explores is the undergrounding of overhead power lines. The piece relied to hurricane simulations to model cost forecasts for different scenarios, adjusting the figures based on actual historic cost data from previous disasters in the region.

Key Findings:

- From 1998-2009, Texas incurred $1.8 billion in restoration costs to power infrastructure damaged during storm events. Hurricanes, gale force winds, falling trees and flying debris were found to be the most common causes of damage - all of which are less of a risk to underground wires than they are to overhead lines.
- Found that storm-hardening options of all kinds were generally not cost-effective for distribution infrastructure, but targeted undergrounding was cost-effective specifically for transmission infrastructure.
- Storm surges (the flooding of coastal areas when storm winds blow seawater inland) are the only major byproduct of storms that underground wires were found to be more susceptible to than overhead wires, but these posed a minimal threat nationwide in relative terms (with only some coastal areas facing higher risks).

Strengths and Limitations of Study: Although computer models can never perfectly predict the costs or benefits of complex economic decisions, they work far better when they are based on actual data. As a result this forecast-based paper benefits from calculations that use real-world statistics about the historic cost of storms in Texas. For this reason, it can be deemed reasonably accurate - but still must be treated as an estimate given the limited reliability of modeling more broadly.

Availability:
Accessible online at:
http://www.puc.texas.gov/industry/electric/reports/infra/utlity_infrastructure_upgrades_rpt.pdf

Year Published: 2009

Title of Study: 'Willingness to pay for improved quality of electricity supply across business type and location'

Author(s): Morrison and Nalder

Location: Australia

Source Type: Academic Journal Article

Funding Source: N/A

Description of Study: This study measures the willingness of businesses (by business type and location) to pay for improved reliability in their energy supply. Undergrounding is one method of improving this reliability, so this data acts as an indicator of potential willingness to pay for undergrounding.

Key Findings:

- 40% of all companies stated that the frequency of power outages damaged some of their equipment within the last year, which forced them to have to pay for repairs or replacements
- Their survey found that service-based companies and rural businesses rated their power reliability lowest, which indicates that they might be the most likely to support undergrounding
- Manufacturing companies rated as the least likely to pay for undergrounding, likely because
- States undergrounding is an easy way to improve reliability
- The business surveys mainly involved businesses with ~50 employees, representing medium-small businesses
- The survey found that the average business experiences 2-4 outages per year, each lasting between 1.5 hours and 3.5 hours on average

Strengths and Limitations of Study: This valuable research uniquely measures businesses' willingness to pay for undergrounding as opposed to customer willingness. The survey data is now slightly outdated, but it offers useful indications nonetheless.

Availability:
Accessible online (behind pay wall) at:
https://www.jstor.org/stable/41323236?seq=1#page_scan_tab_contents

Year Published: 2008

Title of Study: 'Inquiry into Undergrounding Electric Facilities'

Author(s): Oklahoma Corporation Commission, Public Utility Division

Location: Oklahoma, United States

Source Type: State Report

Funding Source: Governor's Office (government entity)

Description of Study: The aim of this report was to help policymakers in Oklahoma make an informed decision about whether undergrounding power lines was a good option for the state. It was commissioned in response to Oklahoma's vulnerability to ice storms, which have often caused service issues for utilities customers.

Key Findings:

- Oklahoma's susceptibility to icy conditions is one of the greatest barriers to its power reliability - one which targeted undergrounding of its most vulnerable circuits could help remedy.
- In December 2007, a single ice storm disrupted the energy supply to over 600,000 homes and businesses in the state. Thirteen of the deaths caused by this storm could be directly attributed to the loss of electricity (and subsequent loss of heating).
- Underground wires would bring 4-5 times fewer outages, especially during the colder months.
- Underground wires would demand less maintenance than the current overhead ones.
- Recommends requiring undergrounding wires when new roads and highways are being built, because these will likely involve digging up the ground anyway - which constitutes the most expensive part of the undergrounding process.
- Recommends undergrounding all overhead wires in high-density areas, and to replace those in areas that are sparsely populated when their usable life ends.

Strengths and Limitations of Study: The primary limitation of this research initiative is that it relies almost entirely on older data from only 2-3 states (mainly Florida) but does not consider data from other states. The result is that its conclusions may not be as good a representation of the overall advantages and disadvantages of undergrounding nationwide.

Availability:
Accessible online at: http://digitalprairie.ok.gov/cdm/ref/collection/stgovpub/id/5156

Year Published: 2008

Title of Study: 'Overhead to Underground Conversion'

Author(s): NEI Electric Power Engineering

Location: New Hampshire, United States

Source Type: Research Report

Funding Source: New Hampshire Public Utilities

Description of Study: This study was carried out in light of the recent statewide ice storms, wind storms and thunderstorms among other natural events that over the last decade have caused billions of dollars worth of damage to overhead electric systems.

Key Findings:

- During a 2002 ice storm, approximately two million or 24% of the 8.5 million residents in North Carolina lost power. Likewise, an estimated 63% of the 1.3 million residents in New Hampshire were without power during the December 2008 ice storm.
- With the extensive amount of damage caused by these storms, and the resulting repair and replacement costs, it is only natural to contemplate placing an overhead system underground.
- While the number of outages due to the distribution system may be far fewer with underground than with overhead lines, a common argument is that the duration of an outage will be far longer with underground systems. However, there are ways around this, such as installing an empty conduit next to the main electrical line or using a 'looped system'. These have been shown to minimize outage times for customers fed by underground systems.
- The cost of an underground distribution line may vary greatly depending on: soil conditions, urban versus rural, three phase versus single phase, cable in conduit versus direct buried, concurrent construction with other underground utilities and road work, main feeder construction versus lateral construction, type of equipment required.
- Some utilities have reported construction as low as $200,000 per mile for single-phase lines.
- Under the best conditions, such as no adverse soil or installation problems, the work can be coordinated with the work of other city departments (e.g., road construction), right-of-ways are easily obtainable, and restoration of customer's property is minimal, the average cost per customer in any of the published reports amounts to $3,000

Strengths and Limitations of Study: The strength of this study is that it impartially covers both the benefits and disadvantages of undergrounding overhead wires. It includes a number of 'mini-studies' in a number of states including Maryland and California. The study discusses in perhaps too much technical detail the different types of distribution cables and conductors that exist, which at times can be off-topic for the brief. Despite all the positive factors it discusses, policy recommendations are lacking in this study.

Availability:
Accessible online at: https://www.puc.nh.gov/2008IceStorm/Final%20Reports 2009-10-30%20Final%20NEI%20Report%20With%20Utility%20Comments/Appendix%20B%20-%20Overhead%20to%20Underground%20Conversion%20Final%2010-28-09.pdf

Published: 2007

Title of Study: 'Literature Review and Analysis of Electric Distribution Overhead to Underground Conversion'

Author(s): Quanta Technology

Location: Florida, United States

Source Type: Literature Review

Funding Source: Florida Electric Utilities

Description of Study: This report critically discusses previous undergrounding studies conducted in Florida and reviews literature on the issue both nationally and internationally.

Key Findings:

- Tree trimming is one of the most expensive activities related to overhead distribution systems. Actual tree trimming costs can range from $7,000 to $70,000 per mile depending on the size and height of trees, the climate and annual rate of growth, the number of trees per mile, necessary equipment, and whether the work is being done in rural or urban locations.
- Differences in accounting treatment can easily vary per-mile undergrounding cost estimates by 100% or more, for precisely the same construction activities. Therefore, care must be taken when comparing undergrounding cost studies.
- There are many funding options to cover undergrounding costs, and selecting the most appropriate financing approach is a critical part of the process. The list of financing options includes: higher taxes, federal funding, or higher customer electricity rates.
- This study described a wide array of benefits of undergrounding including improved aesthetics, lower tree trimming costs and fewer outages.
- An electric utility can make no sale of electricity when its electric system is out of service. Thus, if undergrounding results in fewer customer hours of interruption, utilities will lose less revenue.
- One of the most commonly cited improvements from undergrounding is the removal of unsightly poles and wires.
- A Municipal Underground Utilities Consortium (2006) acknowledges that underground systems will result in reduced utility operations and maintenance (O&M) spending.

Strengths and Limitations of Study: This study is great at providing alternative ways of undergrounding in the face of an exacerbated cost, suggesting a targeted method of undergrounding - this is a great starting point for policy writing. The study is based solely on Florida making it very specific and well informed including a large number of financing options. This is useful considering the large cost of undergrounding.

Availability:
Accessible online at: https://quanta-technology.com/sites/default/files/doc-files/QuantaPhase1FinalReport.pdf

Year Published: 2006

Title of Study: 'Out of Sight, Out of Mind'

Author(s): Kenneth L. Hall (Hall Energy Consulting, Inc.)

Location: United States

Source Type: Research Report

Funding Source: Edison Electric Institute (private entity)

Description of Study: This report, requested by the biggest association of private energy companies in the US (EEI), summarizes an array US-based studies about the costs and benefits of undergrounding power systems. It examines data about the historical performance of existing underground wires, as compared to the overhead lines they replaced.

Key Findings:

- While underground wires typically suffer from longer power outages, these outages occur far less frequently.
- Approximately two-thirds of all power outages are weather-related. Underground wires fare better than their overhead counterparts during periods of bad weather. The most common causes of power failures were as follows:
  - General inclement weather: 31%
  - Falling trees and flying debris (due to wind): 30%
  - Lightning strikes on utility poles: 6%
- From 1992-2002, the number of fatal accidents caused by contact with overhead wires was 1,432. The equivalent figure for buried cables was substantially lower, at 35.
- Eleven states have already commissioned reports to investigate the ways in which power systems can be more resilient against extreme weather events. Six states have already published the results of these investigations[9].
- Documents the positive impacts that the aesthetic improvements of removing overhead utility infrastructure can have on customer satisfaction and community-building.
- Between 2000-2006, all major utilities companies were committed to at least 25% of new distribution lines being constructed underground.

Strengths and Limitations of Study: This research does not present much new data - it primarily compiles and analyses existing information. However, its strength comes from its comprehensiveness. The study reviews a significant portion of all published literature on the topic of undergrounding. In doing so, it features relatively in-depth discussions of most major factors involved in decisions about undergrounding: economics, health and safety, aesthetics, storm resilience and general reliability.

Availability:
Accessible online at: https://woodpoles.org/portals/2/documents/OutofSightOutofMindRevisited.pdf

[9] Maryland (1999), North Carolina (2002), Virginia (2003), Florida (2005), Oklahoma (2007) and Texas (2008).

Year Published: 2006

Title of Study: 'Cost Effectiveness of Undergrounding Electric Distribution Facilities'

Author(s): PowerServices, Inc.

Location: Florida, United States

Source Type: Research Report

Funding Source: Municipal Underground Utilities Consortium (utilities association)

Description of Study: This report was commissioned in response to the unusually destructive storm seasons of 2004-2005. This period saw ten major named hurricanes and tropical storms hit Florida, resulting in power failures that lasted weeks. The document discusses potential storm-hardening options for power infrastructure in the state - focusing heavily on the possibility of undergrounding wires. Its main data collection method was site visits and information requests to Florida Power & Light, who submitted a slew of statistics ready for analysis. These were used in an attempt to quantify the qualitative benefits of undergrounding, such as: improved health and safety, aesthetics, reliability, economic development, and community identity.

Key Findings:

- The defining conclusion was that the upfront cost of underground wires is mitigated by 50% in the long-term because of their economic benefits: namely reduced maintenance and post-hurricane restoration costs, which cut overall expenses by 30% alone.
- The Brunswick Electric Membership Corporation, through a FEMA-funded initiative, has been undergrounding wires since the 1990s. The project has seen a near-100% success rate in terms of storm reliability improvements since then.
- From 2001-2005 there were 87 power interruptions per mile for overhead wires compared to just 12 for underground ones.
- Underground wires have also brought fewer litigation costs owing to the reduced number of accidents they foster. This was projected to reduce overall expenses by 10% compared to overhead wires.
- Underground wires in Florida have reduced the incidence of damage due to lightning strikes and sea spray.
- At the time of publishing, this report's analysis found that 70% of all new distribution lines in Florida were being placed underground.
- 10.43% of the initial cost of undergrounding would be recouped via reduced litigation costs.

Strengths and Limitations of Study: The key differentiator of this study is its attempt to calculate both the quantitative and the qualitative costs and benefits of underground wires. This all-inclusive type of analysis has to this day only been conducted by one other study. This may make the report vulnerable to criticism, however, because quantifying qualitative factors is not typically seen as objective.

Availability:
Accessible online at:
http://www.psc.state.fl.us/Files/PDF/Utilities/Electricgas/EnergyInfrastructure/UtilityFilings/docs/CostEffectiveUnderground_Nov2006.pdf

Year Published: 2005

Title of Study: 'A review of Electric Utility Undergrounding Policies and Practices'

Author(s): Navigant Consulting, Inc.

Location: Long Island, New York, United States

Source Type: Research Report

Funding Source: Long Island Power Authority (LIPA)

Description of Study: This study was carried out by on behalf of the Long Island Power Authority (LIPA) due to requests by customers to underground new and current wires. This study is one of many by LIPA to recognize the preference within communities to have utility lines be put underground. The study evaluates potential undergrounding policies and practices, including their probable reliability and cost impacts. This study updates an earlier report produced for LIPA and carries out a survey of the current state of the industry on the subject of undergrounding electric distribution systems.

Key Findings:

- 68% of LIPA wires are overhead - over 90% of the annual number of customer interruptions on the LIPA distribution system occur on overhead constructions.
- Undergrounding systems are more reliable than overhead systems under normal conditions suffering around half the number of outages.
- Colorado Springs City Council's policy establishes a system improvement fund to provide for burying overhead distribution lines.
- Even in areas where undergrounding is least cost-effective, recommends adopting a "targeted" approach to undergrounding projects which focuses on undergrounding portions of the overhead distribution system.
    - Edmond Electric in Oklahoma is taking a one-section-at-a-time approach.
    - Dominion Virginia Power annually identifies the "worst 10 circuits" and "worst 10 devices" in each of its three Virginia regions.
- The primary driver for undergrounding existing overhead power lines continues to be aesthetic considerations, not reliability or economic benefits.
- KeySpan estimates that undergrounding the LIPA distribution system will result in a SAIFI improvement rate of approximately 4% to 5% per year in the early years of the program.
- An Australian undergrounding study identified four items as significant in the benefit/cost calculus: Motor-vehicle accidents, Maintenance costs, Tree-trimming costs, and Line Losses.

Strengths and Limitations of Study: The strengths of this study is that impartially covers both the benefits and disadvantages of under grounding overhead wires equally. It pointed out the seemingly main reason for the need to underground wires. The main strength of this study is that it includes a number of 'mini-studies' in a number of states including Maryland and California. The study could have included more practical policy recommendations that could be applied when producing legislation.

Availability:

Accessible online at: http://grouper.ieee.org/groups/td/dist/sd/doc/2005-03-Review-of-Undergrounding.pdf

Year Published: 2005

Title of Study: 'A statewide feasibility study of undergrounding all existing overhead electric utility distribution facilities'

Author(s): Virginia Corporation Commission

Location: Virginia, United States

Source Type: State Report

Funding Source: Virginia Governor's Office (government entity)

Description of Study: This was a statewide cost-benefit analysis of undergrounding energy infrastructure in Virginia. It aimed to calculate, in particular, the portion of the cost of putting wires underground that would be recouped as a result of the long-term economic benefits of undergrounding. The investigation involved a review of previous reports, the collection of cost data from utilities companies, and a survey of customers' willingness to pay for conversion.

Key Findings:

- The bottom-line figure asserts that at least 38% of the additional set-up costs involved with undergrounding would be recovered in the form of restoration savings.
- Undergrounding power lines while simultaneously undergrounding communications lines could reduce the costs of undergrounding by approximately 43%, in the sense that the excavation costs would be shared across multiple industries and serve multiple purposes.

Strengths and Limitations of Study: The survey conducted by this study asked customers whether they would be willing to pay for undergrounding based on its upfront cost. However, it did not re-attempt the survey once the long-term savings were calculated - which may mask the true public appetite for a more reliable power supply. The report's strength, however, is in its strategic advice; offering the first estimate of how much money could be saved by sharing underground facilities with other services such as communications lines.

Availability:
No longer accessible in full online, but a summary can be found on page 23 at:
https://oca.dc.gov/sites/default/files/dc/sites/oca/page_content/attachments/Study%20of%20the%20Feasibility%20&%20Reliability%20of%20Undergrounding%20Electric%20Distribution%20Lines%20in%20DC%20(July%201,%202010)%20-%20ShawConsultantsforPSC.pdf

Year Published: 2005

Title of Study: 'Preliminary Analysis of Placing Investor-Owned Electric Utility Transmission and Distribution Facilities underground in Florida'

Author(s): Florida Public Service Commission

Location: Florida, United States

Source Type: Research Report

Funding Source: Florida Public Service Commission

Description of Study: Given the large amount of storm damage during the hurricane season of 2004, the staff of the Committee on Utilities and Telecommunications requested for the Florida Public Services Commission (FPSC) to produce a report on the costs of undergrounding electrical wires in Florida. The FPSC ended up providing study based on a ten year conversion period. The main purpose as mentioned was to develop a ballpark estimate.

Key Findings:

- The hurricane season of 2004 left the electric service in almost every county in Florida affected due to the particularly hard hit to the overhead electric service facilities.
- Some hurricane-induced outages in Florida lasted up to 2 weeks. Businesses lost a large amount of income due to these outages.
- A joint report by the Davis Islands Civic Association, the University of South Florida and the Florida Department of Community Affairs concluded that conversion to underground networks would be cost-effective due to lower external, operational and maintenance costs, and because increased real estate values were expected to offset the higher construction costs.
- The cost due to the hurricane season of 2004 to five investor-owned electric utility companies totaled over $1.4bn across the four major hurricanes.
- Most storm damage to power facilities is caused by high winds or flooding, insulating and undergrounding wires completely protects the electric wires from these devastating impacts.
- There are a number of financing options available when looking at the cost of undergrounding, including: electric utility company funded, private sector funded, taxpayer funded and customer funded.

Strengths and Limitations of Study: The graphics in the study proved to be very useful to visualize the undergrounding procedure - this is something that could be used on one-pagers, for example. Although this study looks at cost in detail it is based on a ten year period which given the large scale and cost of the operation seems a very small amount of time to truly calculate the costs. The study also fails to consider all the costs, omitting the costs to remove service masts and any modifications.

Availability:
Accessible online at:
http://www.psc.state.fl.us/Files/PDF/Publications/Reports/Electricgas/Underground_Wiring.pdf

Year Published: 2003

Title of Study: 'Cost Benefits for Overhead/Underground Utilities'

Author(s): Edward and Kelcey, Inc & Exeter Associates, Inc

Location: Maryland, United States

Source Type: Research Report

Funding Source: State Highway Administration

Description of Study: This research report was produced to aid the Maryland State Highway Administration on making a cost-effective decision for utility relocation projects in the future. It discusses a number of vital topics including the reliability information for undergrounding wires compared to overhead wires and the number of benefits that this conversion brings through a literature search.

Key Findings:

- There is increased public safety: a study from the State of Maryland from 1994-2002 concluded that in an average year there will be over 2,000 vehicular accidents with utility poles.
- Properties in areas with underground utilities are more desirable and the report estimates an increase of 2.5% in housing values.
- The report concludes that under grounding wires can reduce the exposure to electromagnetism fields which in turn reduces health hazards.
- Underground utilities can utilize a joint-use trench by using a single trench which is shared between a number of utilities, resulting in lower costs of construction.
- The conversion of lines from overhead to underground will also mean an update in cables. This will result in old copper lines being replaced by new high-capacity fiber-optic lines resulting in an investment in better infrastructure.
- A 1999 survey conducted by Maryland Utilities found that out of six pairs of circuits that were reported on, five stated that undergrounding wires would be more reliable with only one determining that overhead wires were more beneficial.

Strengths and Limitations of Study: This research report has done well to point out the large number of positive benefits for undergrounding wires, however due to the large amount of information it attempts to cover it can sometimes be rather limited. The report style of this document has done well to breakdown and identify the different issues and topics that need to be covered in the literature. Although this report attempts to distinguish the reliability between overhead and underground wires, it does so with little confidence. The research report recommended that this 'reliability factor' be measured on a case by case basis for higher accuracy of results.

Availability:
Accessible online at: https://www.roads.maryland.gov/opr_research/md-03-sp208b4c-cost-benefits-for-overhead-vs-underground-utility-study_report.pdf

Year Published: 2003

Title of Study: 'Overview of the Potential for Undergrounding the Electricity Networks in Europe'

Author(s): ICF Consulting Ltd

Location: Europe

Source Type: Research Report

Funding Source: European Commission (intergovernmental agency)

Description of Study: This report was prepared on behalf of DG TREN to assist the European Commission to assess the potential for undergrounding the electricity networks in the Member States of the Europe Union, plus Norway and Switzerland. The report assesses the technical, economic, environmental and regulatory issues of undergrounding in addition to looking at recent developments in the techniques and benefits of such a policy.

Key Findings:

- 95% of lines across Europe are overhead wires.
- One of the principal advantages of underground cables is that they cannot be seen.
- Among most member states the construction of new aerial lines has met with strong opposition by local communities and authorities as well as by environmental organizations.
- Over the years there has been a lot of research worldwide to determine a link between the presence of electromagnetic fields (EMFs) and an adverse effect on human health. In 1999 the EU issued a recommendation concerning restriction to the exposure of EMF's.
- Although there is no policy relating specifically to the construction of aerial lines or underground cables, Belgium has a voluntary region-specific ban on the construction of new overhead lines and in France there is an agreement between the government and the industry with respect to targets for undergrounding.
- There has been an increase in technology aimed at making a case for undergrounding easier including the use of micro tunnels to lay longer cable lengths made to save on joints, installation time and costs and mechanized laying methods that avoid extensive excavations.
- Two other major benefits of underground cables are that they are not susceptible to storm and icing damage and are far less likely to cause death or injury due to accidental contact with the lines/cables.

Strengths and Limitations of Study: The strengths of this study are that it considers a large number of factors, such as regulatory, economic and political dynamics. In addition, this article is also particularly good at investigation new technologies in the field which can subsequently be used for policy. On the other hand, this can also be a negative as it attempts to also cover a lot of different case studies in the way of country studies, this means it cannot go into too much depth but also gives the reader too much information to process.

Availability:
Accessible online at:
https://ec.europa.eu/energy/sites/ener/files/documents/2003_02_underground_cables_icf.pdf

Year Published: 1999

Title of Study: 'Undergrounding Public Utility Lines'

Author(s): Pamela Martin

Location: Hawaii, United States

Source Type: Research Report

Funding Source: Hawaii Legislative Reference Bureau (government entity)

Description of Study: This report was written by the request of the Senate Concurrent Resolution No.30 in 1999 regarding a Legislative Reference Bureau to Conduct a Policy and Issue Study for undergrounding overhead wires. The report attempts to provide a resource for policymakers to make informed decisions on undergrounding wires and subsequently makes the appropriate recommendations.

Key Findings:

- 5% of all traffic accidents in the last 3 years in Hawaii involved a utility pole. Traffic accidents involving utility poles also increase the damage and repair costs of poles for the utilities.
- The safety benefits of underground utility lines include the reduced risk of accidents caused by lines downed by weather or by vehicle accidents.
- Civil defense planners and utilities alike have acknowledged that underground wires are less susceptible to damage from hurricanes and high winds.
- Improved public health has been identified as a benefit of undergrounding because of reduced risk to known and unknown environmental hazards. The public health arena encompasses the issues related to the electric and magnetic field (EMF) issues and pesticides. EMF emissions have a direct relationship to the installation of utility wires while pesticide issues are raised indirectly regarding the maintenance of the aboveground utilities.
- Preserving the natural beauty of the land is a basic concern to the State as expressed in the Constitution of the State of Hawaii.
- A good example of a clearly stated policy on the conversion of aboveground lines to underground lines can be found in the Revised Code of Washington (Section 36.88.410, Revised Code of Washington).

Strengths and Limitations of Study: This report has investigated the different benefits of undergrounding in great detail building a strong case to bury overhead wires. Given the high level of useful information in the report, it has had to limit its scope considerably to do this considering the breadth of literature on undergrounding wires.

Availability:
Accessible online at: http://lrbhawaii.info/lrbrpts/99/undrgr.pdf

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Appendices

Appendix 1 – Table of undergrounding cost estimates

Table 5 - Estimated cost of building new underground lines from seven state-commissioned reports.

Year	State	Title of Study / Case Study	Cost Per Mile
MEDIAN	**N/A**	**This study**	**$0.4 - $2.5m**
2016	Texas	A Method to Estimate the Costs and Benefits of Undergrounding Electricity Transmission and Distribution	$1.0 - $5.0m
2010	DC	Study of the Feasibility and Reliability of Undergrounding Electric Distribution Lines in the District of Columbia	$0.4 - $1.6m
2010	California (Anaheim)	Study of the Feasibility and Reliability of Undergrounding Electric Distribution Lines in the District of Columbia	$3.0 - $3.5m
2008	Oklahoma	Inquiry into Undergrounding Electric Facilities	$0.4 - $2.5m
2007	Florida	Infrasource Study Phase 2: Case Studies	$0.4 - $1.6m
2006	Florida	Cost-Effectiveness of Undergrounding Electric Distribution Facilities in Florida	$1.1m
2006	Various	Out of Sight, Out of Mind	$1.0m
2000	Maryland	Maryland PSC	$1.0m

Table 6 - Estimated cost of converting existing overhead lines to underground lines.

State Report	Year of Study	Estimated or Actual Cost	Minimum, Maximum or Average Cost	Conversion Cost Per Mile	Cost Per Mile Inflation-Adjusted
North Carolina	2003	Estimated	Minimum	$151,000	$206,568
Maryland	1999	Estimated	Minimum	$350,000	$528,807
Florida (Allison Island)	2007	Actual	Actual	$414,802	$503,567
Florida (County Road)	2007	Actual	Actual	$883,470	$1,072,527
Florida (Sand Key)	2007	Actual	Actual	$917,532	$1,113,879
Virginia	2005	Estimated	Average	$1,195,000	$1,540,173
Oklahoma	2008	Estimated	Average	$1,540,000	$1,800,423
Florida (Pensacola Beach)	2007	Actual	Actual	$1,686,275	$2,047,128
Maryland	1999	Estimated	Maximum	$2,000,000	$3,021,753
North Carolina	2003	Estimated	Maximum	$3,000,000	$4,104,000

Appendix 2 – Bottom-line cost calculation methodology and assumptions

Assumptions

The calculations for the all-inclusive lifetime cost/benefits of undergrounding, presented in the Executive Summary, are based on several important assumptions:

- Assumption #1: The average lifespan of an underground wire is 40 years. This is based on the median lifespan figures used by most of the seven state reports reviewed in this compendium.
- Assumption #2: There are approximately 5.7 million miles of power lines in the United States. Data on the total length of the grid is limited; this figure was taken from Scientific American.[10]
- Assumption #3: Approximately 32% of the US power grid is already buried. Data on the percentage of the grid that is underground is rare at both the national and state levels. This figure was adopted by taking the average of the EEI's (2012) two estimates, which found that between 25% (based on an analysis of urban developments) and 39% (based on self-reported customer feedback) of utility lines were supplied underground.

All calculations were made without adjusting for predicted future price inflation or discounting. This reduces a layer of uncertainty and improves the transparency of the data. Implicit in this decision is an assumption that future price inflation will not significantly change the cost-benefit ratio of undergrounding. Key results are underlined and rounded; but the bottom-line figure used exact figures.

Methodology

First, the total US power grid mileage was taken to be 5.7 million. Next, the number of grid miles yet to be placed underground was calculated using the assumption that 32% are already buried. As a result:

5.7 million * 68% = <u>3,876,000 miles</u> of wires that still need to be moved underground

The number of miles was then multiplied by the average conversion cost per mile in order to determine the total cost of undergrounding the remainder of the US grid. The average conversion cost was taken to be $1,327,026 per mile – the median of the actual and average inflation-adjusted costs listed in Appendix 1, Table 6. Hence:

Total grid conversion cost = $1,327,026 per mile * 3,876,000 miles = <u>$5.14 trillion</u>

From here, the savings from each major economic benefit of undergrounding were deducted from the total cost. First, combined savings from general operational/maintenance costs and post-storm restoration costs were estimated using two established calculations. State-commissioned studies by Florida (2006) and Virginia (2005) found these savings to be the equivalent of 30% and 38% of the initial cost of undergrounding, respectively. Taking 34% as the average saving, the total cost of undergrounding was multiplied by this figure to compute a <u>$1.75 trillion</u> saving from this category.

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[10] Source (accessed 02/12/2019): https://www.scientificamerican.com/article/what-is-the-smart-grid/

The savings from vegetation management were then accounted for. Only one study has quantified savings from this source on a per-mile basis: Florida (2007). It found that tree-trimming expenses were between $7,000 and $70,000 per year per mile of overhead wires. However, it also acknowledges that some urban areas may have lower costs than this if they have few or no trees. For fairness, the lower figure of $7,000 was taken as a consequence. At 2019 prices, this translates to $8,498 per mile.

$8,498 per mile per year * 40 years * 3,876,000 miles = $1.32 trillion in vegetation management savings

Next, the savings from lost economic activity (and lost consumer rates payable) due to outages were calculated by adopting the findings of two major studies: the President's Council of Economic Advisers (2013) and the 2009 energy reliability report prepared for the US Department of Energy. The 2013 report concluded that the annual losses from missed economic opportunities during outages in the USA is between $18 billion and $33 billion per year. The average of these was taken to be $25.5 billion. This figure was then adjusted for inflation, resulting in a figure of $27.49 billion per year.

Extracting the equivalent data from the 2009 study was more involved. This study's lost economic costs were expressed on a per-business and per-home basis rather than a nationwide basis. The per-entity costs also varied depending on the length of the outage. First, the cost per half hour outage, per 1 hour outage and per 8 hour outage was plotted on a graph in Excel to extract a line of best fit equation that would allow us to calculate the approximate cost of an outage of any length of time. We then researched the average length of per-person power outages nationwide, which was found to be 1.867 hours (112 minutes).[11] Inserting this time value into the equations computed the following results:

- Annual cost per small business: $1,573.46
- Annual cost per large business: $34,923.83
- Annual cost per residential home: $5.49

The next step was hence to find the number of small and large businesses and the number of residential homes in the USA. The results are cited below:

- Number of small businesses: 28 million[12]
- Number of large businesses (500+ people): 18,500
- Number of occupied residential homes: 127.59 million[13]

Multiplying the above cost per entity by the number of each entity computed the following annual economic costs:

- Small businesses: $44 billion

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[11] Source: EIA (2018), accessible at: https://www.eia.gov/todayinenergy/detail.php?id=35652

[12] Source for the large business count as well. Accessed from the Small Business Administration at: https://www.sba.gov/sites/default/files/FAQ_Sept_2012.pdf

[13] Source: Census Bureau (2018), accessed at: https://www.statista.com/statistics/183635/number-of-households-in-the-us/

- Large businesses: $0.64 billion
- Residential: $0.70 billion
- Total lost economic opportunities during annual outages: $45.4 billion

The average of the figures from both the 2013 study ($27.49bn) the 2009 study ($45.4bn) was then worked out: $36.45 billion.

Undergrounding reduces downtime by 60.5% (Table 3, Executive Summary). However, some of those costs cannot be reduced by undergrounding because parts of the grid are already underground (32%). Therefore:
$36.45 billion * 60.5% (proportion of outages avoided by undergrounding) * 68% (portion of wires yet to be placed underground) = $15.00 billion per year in avoided economic losses

$15.00 billion per year * 40 years (wire lifetime) = $0.60 trillion saved through avoided power outages

The increases in property values (which benefit from improved power reliability and aesthetics) were treated as a 'cost saving'. The total value of US properties was taken to be $33.23 trillion[14] and it was assumed that the proportion of homes connected to the grid via underground systems is approximately equal to the overall proportion of the grid that is underground (taken earlier to be 32%). The average increase in value for a property in an undergrounded region was taken to be 5% - the middle of the 3%, 5% and 20% figures found by studies in the compendium. Thus:

5% price increase * 68% of homes currently using overhead systems * $33.23 trillion = $1.13 trillion in increased property values

Lastly: accident, health & litigation costs were taken to be 10.43% of the initial cost of undergrounding, based on the only study to quantify these (Florida 2006). $5.14 trillion * 10.43% = $0.54 trillion saved

So, profit = $5.14 trillion (cost) - $1.75 trillion - $1.3 trillion - $0.60 trillion - $1.13 trillion - $0.54 trillion = $188.84 billion, an annualized profit of $4.72 billion.

Put differently, the initial cost of undergrounding is entirely recovered and a small profit is generated by recurring savings.

[14] Property inflation-adjusted value from the $31.8 trillion figure indicated in the following source (accessed 02/12/2019): https://www.prnewswire.com/news-releases/all-us-homes-worth-cumulative-318-trillion-300575669.html

Appendix 3 – Number of people affected by power outages per state (2017)

Source: https://switchon.eaton.com/blackout-tracker

Rank	State	People Affected
1.	Florida	4,242,964
2.	California	767,188
3.	Maine	765,164
4.	Michigan	730,016
5.	Georgia	692,360
6.	Texas	378,820
7.	New York	342,592
8.	New Hampshire	283,309
9.	North Carolina	276,850
10.	Tennessee	248,832
11.	Massachusetts	214,358
12.	Wisconsin	182,193
13.	Ohio	176,316
14.	Oregon	162,734
15.	Washington	155,150
16.	South Carolina	142,301
17.	Missouri	130,788
18.	Oklahoma	122,202
19.	Pennsylvania	117,594
20.	Hawaii	104,783
21.	Louisiana	103,836
22.	Virginia	85,280
23.	Mississippi	79,543
24.	New Jersey	75,312
25.	Illinois	73,584

Rank	State	People Affected
26.	Nebraska	72,067
27.	Indiana	69,228
28.	Montana	58,188
29.	Arkansas	51,532
30.	Alabama	49,620
31.	West Virginia	47,290
32.	Arizona	42,174
33.	Kansas	41,024
34.	Idaho	38,880
35.	Maryland	36,690
36.	Colorado	36,640
37.	Nevada	35,640
38.	Iowa	33,852
39.	Kentucky	30,019
40.	Utah	29,350
41.	Minnesota	20,670
42.	Connecticut	19,465
43.	New Mexico	19,326
44.	Vermont	18,640
45.	Rhode Island	13,136
46.	Delaware	8,510
47.	Wyoming	6,244
48.	Alaska	5,240
49.	South Dakota	3,000
50.	North Dakota	2,413

Appendix 4 – Number of weather-related blackouts per state (2017)

Source: https://switchon.eaton.com/blackout-tracker

Rank	State	Outages
1.	California	124
2.	Texas	65
3.	New York	64
4.	Michigan	56
5.	Pennsylvania	47
6.	Ohio	42
7.	Massachusetts	38
8.	North Carolina	35
9.	Wisconsin	33
10.	Tennessee	32
11.	Virginia	32
12.	Colorado	32
13.	Washington	29
14.	Illinois	28
15.	Oklahoma	27
16.	Indiana	27
17.	Oregon	26
18.	Maine	23
19.	South Carolina	23
20.	Florida	22
21.	Georgia	19
22.	Nebraska	19
23.	Missouri	18
24.	New Jersey	18
25.	Arizona	18

Rank	State	Outages
26.	Louisiana	17
27.	Mississippi	17
28.	Connecticut	17
29.	Kansas	16
30.	Alabama	15
31.	Idaho	15
32.	Maryland	15
33.	Minnesota	15
34.	New Hampshire	13
35.	Montana	13
36.	Arkansas	13
37.	Iowa	12
38.	Kentucky	11
39.	West Virginia	10
40.	Nevada	10
41.	Utah	10
42.	Rhode Island	8
43.	Hawaii	7
44.	Wyoming	7
45.	New Mexico	6
46.	Vermont	5
47.	Alaska	5
48.	South Dakota	3
49.	Delaware	1
50.	North Dakota	1

Appendix 5 – Number of named storms/hurricanes per state 1995-2017

State	Storms
Florida	42
North Carolina	27
Texas	22
Georgia	19
Alabama	18
Louisiana	17
South Carolina	16
Virginia	13
Mississippi	13
Tennessee	11
Arkansas	7
Kentucky	7
Maryland	6
New York	6
Massachusetts	6
New Jersey	4
West Virginia	4
Connecticut	4
Indiana	4
Pennsylvania	3
Delaware	3
Missouri	3
New Hampshire	2
Maine	2
Oklahoma	2
Illinois	2
Rhode Island	1
Michigan	1
All other States	0

Source: https://www.accuweather.com/en/weather-news/in-depth-analysis-of-us-hurricanes-which-states-are-hit-most-frequently-by-devastating-storms/70005326

Appendix 6 – Largest US utility companies by number of customers (2014)

Rank	Entity	State	Undergrounding Information
1	Pacific Gas & Electric	CA	Pacific Gas & Electric converts numerous miles of overhead electric facilities to underground per year. This is completed by following the California Public Utilities Commission (CPUC) Rule 20 guideline that is an electric distribution tariff. There are 3 sections - Rule 20A, 20B and 20C and the use of a particular Rule 20 section is determined by the type of area to be undergrounded and who pays for the work.
2	Southern California Edison	CA	Southern California Edison undergrounds a large number of overhead structures every year. This is completed by following the California Public Utilities Commission (CPUC) Rule 20 guideline that is an electric distribution tariff. There are 3 sections - Rule 20A, 20B and 20C and the use of a particular Rule 20 section is determined by the type of area to be undergrounded and who pays for the work.
3	Florida Power & Light	FL	Florida Power & Light has been undergrounding facilities for over 40 years with a strong commitment to continuing to underground overhead facilities. More than 37% of their current system has been underground compared to the national average of 20%. Florida Power & Light have received a number of requests to underground for various reasons, however, have made it clear to inform their clients via their website to the positives and negatives of converting overhead wires into underground facilities.
4	Consolidated Edison	NY	Consolidated Edison has almost three times more underground cable than overhead wires - with 93,000 miles underground compared to 36,000 miles above ground. In 2016, Consolidated Edison made a commitment to its underground facilities by installing vented manhole covers and new cabling to protect the public and prevent outages.
5	Georgia Power	GA	According to Georgia Power, in 2017 Hurricane Irma damaged almost 1,500 utility powers and knocked over in excess of 2,000 trees, leading to calls to underground more. Georgia Power have said that the common line of

			thought is that if they underground more than when there are natural disasters there will not be as much damage - however, they have said that floods can still affect wires and it can take even longer to fix due to having to dig up the affected area first. Having said this, in metro Atlanta, Georgia Power have more underground wires than overhead facilities - with 13,000 miles currently buried compared to 11,000 miles still overhead.
6	Dominion Energy	VA	Dominion Energy have adopted a strategic system-wide initiative to shorten restoration times after weather events by undergrounding certain vulnerable overhead wires underground estimated to cost $2 billion. Dominion Energy adopted the strategy by proactively speaking to its clients about the project rather than awaiting them to contact the utility company. This won the company the Chartwell's 2018 Bronze Award in Communications for its effort.
7	DTE Energy	MI	DTE Energy currently has no undergrounding projects.
8	Public Service Electric & Gas	NJ	Public Service Electric and Gas in 2015 continued its investment in infrastructure by choosing to upgrade several underground circuits in its territory, this includes replacing existing conduits with new conductors and general reinforcements. Across five years they have invested more than $290 million to upgrade over 80 miles of existing underground facilities, with a further $150 million estimated to be invested.
9	Duke Energy Carolinas	NC	Duke Energy has taken a targeted approached to its undergrounding projects by improving storm responses and subsequent reliability by choosing outage-prone lines to move underground. By doing so they are successfully reducing the length of outages and reducing costs. They believe target undergrounding is more than providing electricity but to ensure that all customers receive a high level and quality of service.
10	Consumers Energy	MI	Consumers Energy currently has no undergrounding projects.

Source (accessed March 2019):
https://www.eia.gov/energyexplained/index.php?page=electricity_home#tab2

Appendix 7 – Survey of undergrounding legislation by state (March 2019)

State	Undergrounding Information[15]
Alabama - AL	**Ordinance No: 2009-32** of the State of Alabama sets out regulations for Underground Utilities for the City Council of the City of Phoenix City. This ordinance outlines the unlawfulness for any person or utility to erect or construct, poles, overhead wires and associated overhead structures to supply electric, communication or other similar or associated service to any subdivision development within the corporate limits of the City of Phoenix City.
Alaska - AK	**Ordinance No. 21.07.050** of the Municipality of Anchorage outlines the rules and regulations for new and relocated lines.
Arizona - AZ	Arizona Public Services Company **Schedule 3** - *"Conditions Governing Extensions of Electric Distribution Lines and Services"* **section 7.9** authorises APS to upgrade, relocate and/or convert its facilities for a requestor's convenience or aesthetics if the requestor pays the cost thereof. Usually, the requestor provides the trench and conduit and pays APS for removing overhead facilities and installing underground facilities. For more information on the rules and regulations of undergrounding under APS visit https://www.glendaleaz.com/clerk/Contracts/8498.pdf
Arkansas - AR	The Arkansas First Electric Cooperative (FEC) produced a guide which is intended for use by property owners, developers, and their engineers who request the installation of an underground electric distribution system to serve a residential subdivision. The Member Installation Standards Manual by the FEC was produced for use in planning and constructing electrical wiring and equipment installations. These guides can be viewed at https://www.firstelectric.coop/standards-and-requirements
California - CA	The California Public Service Commission annually allocate funds under **Rule 20** to communities, either cities or unincorporated areas of counties, to convert overhead electric and telecommunication facilities to underground electric facilities. Rule 20 also includes tariffs for diminishing ratepayer funding for the projects. More information on Rule 20 can be found at http://www.cpuc.ca.gov/General.aspx?id=4403
Colorado - CO	Municipal Code (The City of Brush, Colorado) **Sec. 5-5-450 -** The Public Utility Commission (PUC) shall allocate an annual amount, equivalent to one percent (1%) of the preceding year's electric revenues derived by the Company from the distribution of electricity to residents within the City, for the purpose of undergrounding its overhead electric distribution facilities in the City. **Sec. 5-5-460 -** If PUC requires a system-wide program or programs of undergrounding electric distribution facilities at the Company's expense, the City shall not be responsible for paying the costs of any undergrounding pursuant to such program. **Sec. 5-5-465 -** The City and the Company shall mutually plan in advance the scheduling of approved undergrounding projects to be undertaken (Ord. 762-04 §9)
Connecticut - CT	No undergrounding provisions currently in place.
Delaware - DE	No undergrounding provisions currently in place.
Florida - FL	"The Florida Public Service Commission is not aware of any legislation related to undergrounding of wires. Relevant mentions of 'undergrounding' in the Florida Statute (Florida Senate): **Chapter 190** *(Community Development District)* **Section 12** *(Special powers; public improvements and community facilities)* **1(d)** District roads equal to or exceeding the applicable specifications of the county in which such district roads are located; roads and

[15] Note the information presented in this table includes statewide legislation only. Local municipalities, districts and many large cities have their own undergrounding policies.

	improvements to existing public roads that are owned by or conveyed to the local general-purpose government, the state, or the Federal Government; street lights; alleys; landscaping; hardscaping; and the undergrounding of electric utility lines. Districts may request the underground placement of utility lines by the local retail electric utility provider in accordance with the utility's tariff on file with the Public Service Commission and may finance the required contribution. **Chapter 337** *(Contracting; Acquisition, disposal, and use of property)* **Section 401** *(Use of right-of-way for utilities subject to regulation; permit; fees)* **5 (d)(i)** A wireless provider shall, in relation to a small wireless facility, utility pole, or wireless support structure in the public rights-of-way, comply with non-discriminatory undergrounding requirements of an authority that prohibit above-ground structures in public rights-of-way. Any such requirements may be waived by the authority."
Georgia - GA	No undergrounding provisions currently in place.
Hawaii - HI	The Hawaii Public Utility Commission is not aware of any additional pending legislation regarding this topic besides the below. **Hawaii Revised Statute** **HRS269 27.5** - Construction of high-voltage electric transmission lines; hearing. Whenever a public utility plans to place, construct, erect, or otherwise build a new 46 kilovolt or greater high-voltage electric transmission system above the surface of the ground through any residential area, the public utilities commission shall conduct a public hearing prior to its issuance of approval thereof. **HRS 269 27.6** - Construction of high-voltage electric transmission lines; overhead or underground construction. (a) Notwithstanding any law to the contrary, whenever a public utility applies to the public utilities commission for approval to place, construct, erect, or otherwise build a new 46 kilovolt or greater high-voltage electric transmission system, either above or below the surface of the ground, the public utilities commission shall determine whether the electric transmission system shall be placed, constructed, erected, or built above or below the surface of the ground; provided that in its determination, the public utilities commission shall consider a number of factors inter alia; whether a benefit exists that outweighs the costs of placing the electric transmission system underground or whether there is a governmental public policy requiring the electric transmission system to be placed, constructed, erected, or built underground, and the governmental agency establishing the policy commits funds for the additional costs of undergrounding. For full factors considered please see HRS 269 27.6.
Idaho - ID	No undergrounding provisions currently in place.
Illinois - IL	Bill HB1563 introduced into the Illinois General Assembly outlines that public utilities are to underground specified electric transmission lines under certain conditions. Sec. 11-15.5-5 outlines these conditions - the bill can be viewed at http://www.ilga.gov/legislation/101/HB/PDF/10100HB1563lv.pdf
Indiana - IN	No undergrounding provisions currently in place.
Iowa - IA	According to the Iowa Environmental Council there is currently no legislation pending re: undergrounding power lines in Iowa. There are utilities going this direction for reliability purposes such as Farmer's Coop in Kalona. There is also a developer planning a major merchant transmission line that, if approved, would run entirely underground. That project is called the SOO Green Line.
Kansas - KS	No undergrounding provisions currently in place.
Kentucky - KY	The Kentucky Public Service Commission is not aware of any proposed or pending legislation on undergrounding besides the below. The only statute or regulation regarding undergrounding of electric lines in Kentucky is **807 KAR 5:041 section 21**, which deals with the cost allocation for underground distribution lines

	to new residential customers. Undergrounding to existing customers is generally done at customer expense unless the utility is doing so because of a reliability or safety issue.
Louisiana - LA	No undergrounding provisions currently in place.
Maine - ME	No undergrounding provisions currently in place.
Maryland - MD	The Maryland Energy Administration is tracking several energy-related bills this legislative session, and are still in the process of evaluating that proposed legislation.
Massachusetts - MA	There is currently no open legislation on undergrounding utility wires in Massachusetts. Generally, distribution planning, including undergrounding projects, is completed by the local distribution companies under the authority of the Department of Public Utilities (DPU) or municipal light plants. In terms of local control, **Massachusetts General Law (MGL) Chapter 166 § 22D** allows municipalities to pass an ordinance or bylaw requiring their utility to bury existing overhead electric utility lines and the utility to recover costs by increasing rates but rate recovery is limited to 7% which may not cover the costs of a large project. Additionally, town may impact underground decisions through local zoning by-laws.
Michigan - MI	No undergrounding provisions currently in place.
Minnesota - MN	No undergrounding provisions currently in place.
Mississippi - MS	**Bill No. 2003** (Senator Blackwell) - **Section 11** outlines requirements for wireless providers to underground facilities.
Missouri - MO	The Missouri Public Service Commission are not aware of any Missouri Statutes that address the undergrounding of wires. The Missouri Public Service Commission does have the authority to adopt rules. One of the rules does address the topic of undergrounding of lines: **4 CSR 240-23.010 (10) Residential Subdivision Undergrounding.** Where reasonable and consistent with utility easements and applicable law, electrical corporations are to locate all newly installed electrical corporation-owned residential subdivision distribution facilities underground. This provision applies to residential subdivisions with average lots no larger than 0.5 acres. As used in this provision, subdivision distribution facilities refer to terminal poles, manholes, feeder lines, service lines, switchgear, pad-mounted, pole-mounted, or submersible transformers, and pedestals utilized to provide electric service to subdivisions but does not include sub-transmission lines and three (3)-phase distribution feeders/backbone circuits (portion of distribution system directly interconnected with distribution substation and prior to the first protective device). If an electric corporation determines that it is not reasonable to place a residential subdivision's distribution facilities underground and the subdivision has average lots no larger than 0.5 acres, the electrical corporation shall maintain records available or Public Service Commission (PSC) inspection to demonstrate why undergrounding was unreasonable.
Montana - MT	No undergrounding provisions currently in place.
Nebraska - NE	No undergrounding provisions currently in place.
Nevada - NV	No undergrounding provisions currently in place.
New Hampshire - NH	No undergrounding provisions currently in place.
New Jersey - NJ	Introduced to the 218th Legislature - State of New Jersey **A-621/S-298:** Requires electric distribution lines be located underground in areas affected by severe weather or natural disasters. **A-2131/S-2458:** Directs BPU to prohibit Internet service providers from installing broadband

	telecommunications infrastructure on certain poles or underground facilities unless Internet service providers adhere to principle of "net neutrality." **S-2291:** Expands One-Call Damage Prevention System to include underground contamination with engineering or institutional controls. *The following was passed into law in 2004:* **A-1771:** Concerns procedures with respect to placement, replacement or removal of public utility poles and underground facilities under certain circumstances.
New Mexico - NM	No undergrounding provisions currently in place.
New York - NY	As of this date, it appears that the Legislature has yet to introduce bills on this subject in the 2019 Legislative Session. While slightly off topic, in 2016 and 2017, several laws were enacted authorizing the creation of underground utility districts in the Towns of Southampton **(Chap 399 of 2017)** and East Hampton **(Chap 389 of 2016).** As a point of information, for Commission regulations regarding the undergrounding of electric transmission facilities, see **16 NYCRR parts 101 and 102**, available on this Department of Public Service web page: http://www3.dps.ny.gov/W/PSCWeb.nsf/All/49775FD17CDEE7F285257C910059DEED?OpenDocument . Also note that **Parts 607 and 608** relate to underground telephone construction, while **Part 753** relates to the protection of underground facilities.
North Carolina - NC	No undergrounding provisions currently in place. However, Duke has put forth a grid mod agenda (Power/Forward) with the hopes to modernize the electric system by, inter alia, moving targeted power lines underground.
North Dakota - ND	No undergrounding provisions currently in place.
Ohio - OH	No undergrounding provisions currently in place.
Oklahoma - OK	No undergrounding provisions currently in place.
Oregon - OR	No undergrounding provisions currently in place.
Pennsylvania - PA	**The Pennsylvania Code** - *Subchapter H - Underground Electrical Service In New Residential Developments* - **under *§ 57.82. Installation of distribution and service lines*** outlines requirements for distributions and service lines to be placed underground as well as lines for street lighting in new developments. This section also details the specifications for undergrounding beyond the boundary of new developments.
Rhode Island - RI	The Rhode Island Division of Public Utilities and Carriers is not aware of any plans for new undergrounding legislation in the current session. No new bills have yet to be introduced. One was heard and not voted out of committee in 2018: **7774 Solomon -** Requires power company to bury power lines to home if service is lost for 96 hours Possibly the single most notable legislation related to underground relocation of utility lines was related to a transmission relocation between Providence and East Providence. The law supporting the project was approved in 2003 *(Title 42 - State Affairs and Government - Chapter 42-98 - Energy Facility Siting Act - Section 42-98-1.1)* The Energy Facility Siting Board Docket in that proceeding is still active. This original project would have included two separate river crossings. Issues related to a bridge alignment are now in dispute. A number of local communities have, over the years, enacted requirements/directives for

	underground utilities in new subdivisions.
South Carolina - SC	No undergrounding provisions currently in place.
South Dakota - SD	The South Dakota Public Utilities Commission is not aware of any legislation or discussions relating to the undergrounding of wires in South Dakota. The South Dakota Public Utilities Commission did not introduce any legislation this year that dealt with the issue and there are not any other third party bills currently before the legislature addressing it. As to whether there are any plans or discussions to introduce any new legislation for the undergrounding of wires; the Commission has not discussed the issue, but it will be add to the list of topics to discuss for next year.
Tennessee - TN	**Title 17 of the Metropolitan Code of Laws, the Zoning Ordinance of the Metropolitan Government of Nashville and Davidson County - requires lines to be constructed underground in new residential developments.**
Texas - TX	No undergrounding provisions currently in place.
Utah - UT	The Public Service Commission of Utah is unaware of any new legislation on the undergrounding of wires. **Title 54, Chapter 8 - Utah Underground Conversion of Utilities Law** - Undergrounding of utility wires may be required by municipalities in certain circumstances. You would have to contact the individual municipalities for their requirements. **Title 54 Chapter 14 - Utility Facility Review Board Act**, this 2010 Utah Code outlines a number of findings such as: **54-14-102. Legislative findings** **(1) (a)** The Legislature finds that the construction of facilities by public utilities under this title is a matter of statewide concern. **(b)** The construction of these facilities may affect the safety, reliability, adequacy, and efficiency of service to customers in areas within the jurisdiction of more than a single local government. **(c)** Excess costs imposed by requirements of a local government for the construction of facilities may affect either the rates and charges of the public utility to customers other than customers within the jurisdiction of the local government or the financial viability of the public utility, unless the local government pays for those excess costs. **(2)** The Legislature finds that it is in the public interest to establish the Utility Facility Review Board to resolve issues regarding the construction and installation of public utility facilities.
Vermont - VT	No undergrounding provisions currently in place.
Virginia - VA	The House Joint Resolution 100 enacted by the 2006 General Assembly directed Joint Legislative Audit and Review Commission to study the criteria and policies used by the State Corporation Commission in evaluating the feasibility of undergrounding transmission lines in Virginia - submitted in 2006 for review. (House Document No.87). However, no undergrounding provisions currently in place.
Washington - WA	No undergrounding provisions currently in place.
West Virginia - WV	No undergrounding provisions currently in place.
Wisconsin - WI	No undergrounding provisions currently in place.
Wyoming - WY	No undergrounding provisions currently in place.