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Quantifying Siting Difficulty

A Case Study of U.S. Transmission Line Siting

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Quantifying Siting Difficulty: A Case Study of U.S. Transmission Line Siting

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Abstract

The worldwide demand for new energy infrastructures has been paralleled in recent years by the increasing difficulty of siting major facilities. Siting difficulty is the subject of widespread discussion, but because of the complexity of the problem, potential solutions are not obvious or well understood. This paper presents a two-step policy-level framework that first develops an empirical measure of siting difficulty and then quantitatively assesses its major causes. The approach is based on the creation and aggregation of four siting indicators that are independent of the common causes and localized effects of siting problems. The proposed framework is demonstrated for the case of U.S. transmission line siting. Results of the analyses reveal significant variations in state siting difficulty and industry experts' perceptions of its dominant causes, with implications for the long-term success of Regional Transmission Organizations (RTOs) and knowledge transfer among siting professionals in the deregulated industry.

Key Words: electric transmission lines, facilities siting, public opposition, Regional Transmission Organizations (RTOs), siting difficulty

JEL Classification Numbers: L94, L98

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1. Introduction

Recent decades have seen a growing worldwide demand for new energy infrastructures, including power plants, wind farms, electric transmission lines, liquefied natural gas terminals, and petroleum refineries, among other major projects. Siting such energy facilities, however, has become increasingly difficult (Casper and Wellstone, 1981; Halvorsen, 1999; Inhaber, 1998). Because of their large scale and technical complexity, many projects involve disparate risks, costs, and benefits for stakeholders, affected populations, and surrounding environments (Keeney, 1980). This asymmetric distribution of project impacts has often fueled intense local opposition and compounded already complex engineering and economic considerations and project constraints.

Siting difficulty is now frequently associated with the familiar acronym NIMBY (not in my backyard) and even more extreme acronyms like BANANA (build absolutely nothing anywhere near anything) (Fialka, 2001; Halvorsen, 1999; Maize and McCaughey, 1992); however, the problem as a whole is more complex than these expressions suggest. The term siting difficulty, as used here, is defined as any combination of obstacles in facilities planning and siting processes, including public opposition; environmental, topographic, and geographic constraints; interagency coordination problems; and local, state, and federal regulatory barriers to permitting, investment, and/or construction. Siting difficulty is thus a broad and complex problem, affecting a variety of industries, for which solutions are not obvious or well understood.

The lack of substantial data is another major obstacle to understanding the problem. Most academic research and industry trade publications focus on either individual *causes* of siting difficulty, such as public opposition, or localized *effects*, such as transmission grid congestion. These analyses are advanced in the absence of any clear empirical reference level for difficulty

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as a whole, and as a result, many of these studies have limited practical application and policy relevance.

To bridge that gap, this paper develops a policy-level framework for assessing siting difficulty, based on several datasets and statistical analyses. The next section outlines our approach and methods and organizes the sections to follow.

2. Framing the Problem

The analytical approach developed in this paper is based on a two-step structure. The first step focuses on answering the question “How difficult is siting?” using a collection of siting indicators. The second step then builds on the resulting measure of siting difficulty to address the question “What makes siting difficult?”

Our formulation is similar to that of current climate change research, where some researchers are looking for “indicators” to determine whether climate change is happening, where it is taking place, and to what extent; and others are examining possible contributing causes and mitigation strategies. Until the significance of the change has been robustly characterized, evaluations of contributing causes (and their interactions) remain out of context. Similarly, for facilities siting, a quantitative measure of difficulty must first be created and verified, and only then can the causes of siting difficulty be analyzed in context.

Figure 1 diagrams our framework and highlights the general relationships among our selected siting indicators and the typical causes and effects of siting problems for the case of electric transmission line siting. This diagram illustrates how multiple causes of siting difficulty, such as public opposition, environmental barriers, and regulatory roadblocks, could collectively lead to an underinvestment in infrastructure. The resulting lack of capacity then triggers industry-level economic, physical, and perceptual impacts, such as variations in the cost of electricity generation and changes in capacity additions. These types of large-scale impacts form the basis for the siting indicators in the analyses to follow.

The four indicators in Figure 1 are neither direct causes nor effects. Because of the numerous feedback loops and interactions among the causes and effects of siting difficulty, no single cause or effect adequately represents the overall problem. For example, one possible measure of transmission line siting difficulty is the difference between generation and transmission capacity additions; however, this metric could conceivably mask underinvestment in both generation and transmission caused by shared siting constraints. As a result, siting difficulty needs to be quantified based on a careful evaluation and aggregation of multiple impacts.

Section 3 characterizes the transmission problem, with a brief literature review. In Section 4 we develop a single quantitative measure of siting difficulty by combing four indicators—economic, geographic, construction, and perception; in Section 5 we test and validate this measure using real-world electricity market data. We then use the measure to analyze the causes of siting problems in Section 6, and in Section 7 we place these results in the context of prevailing industry perceptions, obtained from a survey of siting professionals. Finally, Section 8 concludes with a brief discussion of the policy implications of our analyses and results for other industries facing siting problems.

3. Characterizing the Grid

Transmission line siting is one of the most extreme examples of siting difficulty today (Casper and Wellstone, 1981; Henshaw, 2001; Pierobon, 1995). Although the United States has one of the most reliable electricity systems in the world, electricity transmission expansion has not matched growing demand (CECA/RF, 1990; DOE, 2002; EEI, 2002; Hirst and Kirby, 2001). In August 2001, Spencer Abraham, U.S. Secretary of Energy, noted, “The shortage of transmission lines is nationwide and will worsen as the demand for electricity grows if corrective steps are not quickly taken” (EEI, 2001b).

Siting problems are not unique to the electricity industry; however, siting difficulties associated with transmission lines are especially complex. Transmission projects can span states and regions and usually involve highly visible overhead lines regulated by multiple agencies (Smead, 2002; Smith Jr., 2002). Moreover, deregulation of the electricity industry and the transition to competitive markets have further complicated transmission ownership, financing, and management (Krapels, 2002; Joskow and Tirole, 2004; Krellenstein, 2004).

To place our empirical analyses of siting difficulty in context, we next review two specific challenges facing the electricity industry—changes in the siting process, and the complexities of the regulatory environment—and discuss the industry’s response to mitigating siting difficulty.

3.1. The Siting Process

Building major infrastructures like transmission lines involves a dynamic series of technical, economic, regulatory, and social decisions. Until the 1990s, this decision making process was largely internal to vertically integrated utilities. Siting divisions assessed the need for new lines, possible alternatives, cost-benefit considerations, technical design options, and permitting requirements in an established sequence, typically unimpeded by external influences (Houston, 1995). Traditionally, practitioners relied on a "decide-announce-defend" approach (Beierle and Cayford, 2002). With electricity deregulation and mounting opposition, this traditional approach has often failed, to the extent that it has been called the "decide-announce-defend-abandon" strategy. Transmission planning now includes public meetings and even court hearings that make the decision making process more iterative than linear (Houston, 2003).

Despite the growing awareness among siting professionals of the potential for different stakeholders to indefinitely delay or even terminate critical projects, policymakers have been slow to respond. In the case of the electricity industry, as the need for new infrastructure becomes increasingly critical, this widening disconnect between practice and policy has the potential to significantly affect the development of the grid.

3.2. The Policy Problem

Although many practitioners believe that significant variations among transmission projects even within the same local area make any aggregate analysis of siting practices and problems impractical,[1] recent regulations and siting policies focus on regional or national grid approaches to managing reliability, congestion, and competition (Barton, 2005; FERC, 2000). The push toward voluntary and Regional Transmission Organizations (RTOs) by the Federal Energy Regulatory Commission (FERC) exemplifies this trend toward larger units of transmission planning and management and demonstrates the need for understanding the variability of siting difficulty across states and regions.

The Energy Policy Act of 2005 establishes a basis for "national interest electric transmission corridors" to alleviate regional congestion, but transmission line siting remains regulated primarily at the state level (EEI, 2001c). Although siting oversight is typically in the hands of the state public utilities commission (PUC), siting board, or department of natural resources, in some states it is divided among several agencies. Moreover, there is no federal standardization in siting permit applications, schedules, and review process requirements (EEI, 2001a; EEI, 2001c).

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[1] Based on personal conversations with siting officials at Allegheny Power (Greensburg, PA), GAI Consultants (Monroeville, PA), and the Tennessee Valley Authority Siting Division.

3.3. The Industry Response

The process and policy problems facing siting efforts have been compounded in recent decades by intense, organized local opposition and environmental justice activism (Halvorsen, 1999; Inhaber, 1998; Randell and McDermott, 2003, 2004). These trends have sparked conflict within many utilities between established practices and new project demands.

In response, proposed strategies for mitigating siting problems have proliferated. Researchers, planners, regulators, and utility professionals have developed guides and handbooks for overcoming siting difficulty, particularly public opposition, by facilitating public participation (Keeney, 1980; Ducsik, 1986; Hester et al. 1990; Kunreuther et al. 1993; Kunreuther and Easterling 1996; Inhaber 1998). However, as discussed above, these programs have been advanced in the absence of a clear characterization of siting difficulty. As a result, these strategies for mitigating siting problems form a collection of disaggregated solutions designed to alleviate specific constraints, instead of a coherent, replicable plan for understanding and managing difficulty as a whole. The next section takes the first step toward bridging this gap by developing an empirical measure of state-level siting difficulty.

4. Quantifying Siting Difficulty

Data and analyses on transmission line siting are limited. Recent industry research has focused instead on characterizing the decline in transmission construction and on developing investment and policy strategies needed to avert a transmission crisis (Hirst and Kirby, 2002); Most existing quantitative information is related to specific power technologies, market conditions, system reliability issues, or grid congestion, such as the Transmission Loading Relief Logs from the North American Electric Reliability Council (NERC).

We bring together several datasets representing multiple metrics. These metrics are combined using principal component analysis to construct four individual siting indicators. The four indicators are then aggregated using factor analyses.

4.1. Developing Indicators

To build a series of complementary metrics of siting issues in each state and their implications for national grid planning and policy making, this section presents four state-level quantitative indicators of siting difficulty and the need for additional transmission capacity:

an *economic indicator* based on measures of the variability of the marginal cost of electricity production;

a *geographic indicator* based on the distances separating generation capacity from demand load centers;

a *construction indicator* based on differences in transmission additions relative to generation capacity construction, net generation, and sales; and

a *perception indicator* based on a survey of industry experts.

Each of these indicators is 1) separate from the local causes and effects of siting problems, 2) large-scale to avoid results that are driven by individual case studies, and 3) focused on a different aspect of the siting problem. Together, they summarize available data to provide a "first-pass" analysis of siting issues. Other metrics could be devised to describe the problem; however, we believe that the selected indicators provide a justifiable, quantitative framework that should serve as a starting point. Transmission line siting is a complex problem, and no single metric is perfect. Because each has its limitations, we focus on combining the selected metrics using statistical techniques to form four coherent indicators. Similarly, none of the selected indicators are stand-alone, representative measures of siting difficulty. Numerous factors influence each indicator, and the value of these indicators is collective.

All four indicators are used to evaluate and compare demand and difficulty for each state in the continental United States. We treat transmission demand (the need for additional capacity or lines) and siting difficulty as related problems; states with high need and the economic incentive to build additional transmission capacity are understood to face a variety of constraints (of which siting difficulty is one) that have prevented them from adding lines. Each indicator and the reasons for its selection are discussed individually below.

4.1.1. Economic Indicator

With the recent focus on competition and deregulation, the transmission grid is being reevaluated for its ability to support competitive markets and transactions. Many high-level industry executives and government officials have raised serious concerns that the existing transmission infrastructure is inadequate for a deregulated market. In September 2001, Pat Wood, then chairman of FERC, observed, "The [transmission] grid increasingly is pushed to its operational limit, and transmission constraints frequently prevent the most efficient use of generation facilities" (EEI, 2001b). Similarly David Cook, general counsel of NERC, notes, "The lack of additional transmission capacity means that we will increasingly experience limits on our ability to move power, and that commercial transactions that could displace higher-priced generation with lower-priced generation will not occur" (EEI, 2001b). Both observations indirectly address the issues of transmission demand and siting difficulty: states that are currently unable to use their existing generation capacity efficiently have greater economic incentive to build new transmission capacity.

The economic indicator proposed here is based on the hypothesis that high variation in generation costs in one state relative to other states indicates suboptimal dispatch of generation capacity, caused in part by transmission congestion. To examine this hypothesis, cost of production data for 1,500 generating plants across the United States were evaluated at the state level (Platts/UDI, 2001a, 2001b; RDI, 1999).

In Table 1, the data are divided by size of plant into baseload and peaker categories.[2] The average, interquartile range (IQR), and standard deviation of the cost of production were calculated for each state for both categories. A final metric within this indicator is the potential savings that could be realized from reallocating the distribution of generator load hours to an optimal dispatch schedule that minimized cost of production as a percentage of total expenditures. This metric is calculated by reordering the dispatch of generators and running the cheapest generators for the most hours until all a state’s existing demand is met using online generation capacity.[3]

Actual load factors in an integrated power system are dynamically dependent on many assumptions about unit dispatch, plant operating constraints, fuel costs and availability, and shape of the load duration curve, among other variables. Although many factors affect the decision to use different generators, this measure of efficiency is also a basic indicator of the need for transmission. The potential for savings provides a “bound” for efficient dispatch with perfect transmission among all generators and consumers in a state.

Interestingly, a comparison of California and Texas provides support for the anecdotal judgment that siting in California is “notoriously difficult,” while siting in Texas is “comparatively easy” (McNamara, 2004). The mean baseload cost of production is similar in both states ($23 $/MWhr), but California has a higher standard deviation and a lower interquartile range than Texas. Because the interquartile range is more robust to outliers, the lower interquartile range and higher standard deviation indicate a larger number of expensive baseload plants in California. Although the dispatch of different plants is in part dictated by

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[2] The baseload category includes all hydro plants, all nuclear plants, and all other plants that operated for greater than 7,445 hours load in the year 2000, or 85% of the total possible hours in a year. The peaker category includes all plants that ran fewer than 1,315 hours in the year 2000, or 15% of the total possible hours.

[3] All hydro plants have been removed from the optimal dispatch calculations in the baseload category because it is assumed that these plants are already run at their maximum capacity.

regional fuel availability and environmental regulations, these outliers could reinforce the widely held perceptions of high transmission demand and extreme siting difficulty in California. In fact, the differences captured by even these two seemingly similar economic metrics support the need for additional metrics, since any single one could miss key underlying factors. As expected, states that export a large percentage of their electricity, such as Wyoming, have low costs of production and low potential for savings.

4.1.2. Geographic Indicator

A second indicator of siting difficulty and the demand for transmission capacity is the geographic relationship between the locations of existing generation capacity and demand load centers in a state. We hypothesize that 1) states with populations served by proximate generating plants need less transmission than states with dispersed populations and/or generation, and conversely, 2) high population densities concentrated around plants are associated with greater siting difficulty. As Figure 1 illustrates, many dynamics contribute to the need for additional capacity. Consequently, our two hypotheses are complementary (not contradictory), and together they focus on capturing those states with high transmission demand and low siting difficulty and vice versa.

Using a Geographic Information Systems (GIS) model for all generating plants in the United States, footprints of 5-mile incremental radii were plotted around each plant (Figure 2). . These plant data from the Environmental Protection Agency e-Grid database (2002) and their circular footprints were overlaid on census zip-code population data, and then the total population within each footprint was calculated (U.S. Bureau of Census, 2000). Based on the annual power demand for each state (EIA, 2001a), a consumption per capita estimate was used to approximate the power consumed by the population in each concentric 5-mile-radius circle around each plant. The population sufficient to consume a plant’s yearly output was then calculated for each footprint.[4] Finally, the population actually served within a given radius of all plants was calculated as a percentage of the state’s total population (Table 2).

Although this indicator focuses specifically on population-based estimates of demand, a comparison of U.S. Bureau of Census economic data (1997) with population data (2000) reveals that county populations are highly correlated with measures of local industry, specifically

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[4] If the population within a given footprint was greater than the total population potentially served by the plant’s net generation, then only the population able to be served based on state average consumption in MWhrs per capita was counted as served.

manufacturing—the most electricity-intensive sector.[5] Furthermore, all analyses in this paper focus on total transmission capacity in circuit-miles, not MW-miles, since industries make up a large percentage of total consumption but are often represented by highly concentrated point loads that require fewer total miles of transmission lines at higher effective capacities. We believe that the higher number of dispersed lines required to serve residential and commercial loads is a better indicator of siting difficulty (because of the number of people affected) and also the overall need for additional miles of line. As a result, this analysis uses population density and distribution data as a surrogate for all demand.

As Table 2 shows, a high population (as a percentage of the state's total) served within a small radius indicates close proximity to generation plants and population loads and suggests a low demand for transmission, and vice versa. For example, North Dakota, where less than 40% of the potential population is served within a 25-mile radius of its power plants, is hypothesized to have a high demand for transmission lines; whereas New Hampshire, where 100% of the potential population is served within a 25-mile radius, indicates a low need for lines. For this model, we assume that states that export electricity will first use in-state generation capacity to serve in-state demand, and that states that import electricity can never reach 100% demand served. Since this analysis focuses on the relative need for additional capacity and not the specific amounts of additional capacity, any lack of in-state generation capacity satisfied by imports is also an indicator of a need for transmission capacity.

4.1.3. Construction Indicator

An intuitive indicator of siting difficulty is the difference in miles between proposed and constructed transmission. Although this indicator is perhaps the most direct measure of siting difficulty, state-level data on transmission construction are extremely limited and of poor quality because of frequent changes in data collection and reporting protocols. Additionally, such a measure could both overestimate siting difficulty, assuming that some projects are canceled for other reasons (such as internal economic considerations), and underestimate siting difficulty, assuming that some projects and lines are never proposed because of anticipated problems.

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[5] County population estimates for the continental United States are correlated with the number of in-county manufacturing establishments, the number of employees, the annual payroll, the average number of production workers, the number of production worker hours, production worker wages, economic value added, and total capital expenditures at an average correlation of 0.9. This relationship supports the assumption that this indicator properly captures not only the geographic distribution of residential and commercial demand, but also industrial consumption.

Given those limitations, this indicator is based on changes in total transmission capacity (circuit miles) relative to the changes in generation capacity (MW), net annual generation (Mwhrs), and electricity sales (Mwhrs). Generation and transmission data for these metrics were compiled for a ten-year period from 1988 to 1998 (EEI, 2001d; EIA, 1999, 2001a) and normalized to 1 for the first year. The slope of a regression line, or the rate of increase from the baseline, was then calculated for transmission, generation capacity, net generation, and sales in each state. For the entire United States, the transmission capacity increased by 1.7% per year from 1988 to 1998, compared with 0.7%, 2.0%, and 2.5% average increases for generation capacity, net annual generation, and sales, respectively. Similar data for slopes (rates of change) and the differences between slopes for transmission capacity and generation capacity, net generation, and sales in each state are presented in Table 3. For example, the large positive difference of 9.4% per year of net generation relative to transmission capacity in Mississippi indicates a lag in construction associated with the need for additional transmission capacity, whereas the –16.2% in Delaware indicates greater growth in transmission construction than net generation.

For this indicator, the selection of 1988 as a baseline year is based solely on data availability. The indicator does not take into account any overbuilding or under building of capacity prior to the baseline year, nor does it capture important differences in line voltages or effective transmission capacity. However, we still believe that it provides a relevant dimension not captured by the other indicators.

4.1.4. Perception Indicator

The final indicator of siting difficulty is based on a survey of siting experts. Transmission planning and site selection are influenced not only by objective factors, such as economics and geography, but also by perceptions of siting difficulty. A region known for its siting difficulty is likely to be avoided during the process of site selection (Houston, 2003); therefore, it is important in any quantitative analysis to consider indicators that capture both perceived and actual siting difficulty.

To create a perception indicator of state siting issues, an online survey was administered to siting experts and professionals across the United States to elicit their opinions about and experience with siting. A total of 56 respondents from 31 states participated in the survey and completed approximately 1,100 state evaluations consisting of ratings for familiarity, siting difficulty, and siting constraints for a given state.

Survey respondents completed evaluations for an average of 20 states, ranging from as few as 1 state to as many as 49. Familiarity with siting was rated on a 5-point scale, where 1 represented "No familiarity with siting difficulty" and 5 represented "Worked on more than 3 siting projects." Siting difficulty was rated on a 10-point scale, where 1 was easiest and 10 was hardest. Respondents' ratings of siting difficulty in a state were weighted based on their familiarity with siting in that state; that is, responses from those with greater siting experience in a state received more weight.

In Table 4, higher numbers indicate greater siting difficulty in a state. As expected, California is ranked 4th overall for weighted average difficulty by all respondents, and Texas is ranked 44th. Survey results on the causes of siting difficulty are discussed in Section 7.

4.2. Aggregating the Indicators

Each of the indicators described above provides a different view of transmission demand and siting difficulty, but transmission line siting is simultaneously affected by all of the metrics associated with each indicator. As a result, a comprehensive picture of the siting problem requires an aggregation first of each set of metrics and then of the four resulting indicators.

To summarize the economic, geographic, and construction data for input into a common factor analysis, a single principal component was first calculated for each of these three indicators.[6] All data were standardized, and selected metrics from each indicator were input into individual principal component analysis, as shown in Table 5.[7] The resulting loadings on the three components are also included in parentheses next to each associated variable.

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[6] The use of principal component analysis (PCA) and factor analysis (FA) in sequence here is intended to first capture the total variance among all metrics within an indicator (PCA), and then only the common variance across indicators (FA). Using a simple linear combination of the metrics within each indicator or across indicators does not address problems of multicollinearity or the overweighting of highly correlated metrics. Similarly, inputting all of the selected metrics directly into a factor analysis without first aggregating each indicator is likely to capture shared variance between metrics that, while important, is unrelated to our siting difficulty and transmission demand hypotheses.

[7] Because many states did not include a sufficient number of peaker plants to calculate variability based on the standard deviation and interquartile range, the principal component analysis for this metric uses only the standard deviation and interquartile range variables for the baseload level and the percentage savings from optimal dispatch at the peak. Based on the available data, neither Delaware nor Rhode Island has a sufficient number of baseload plants to calculate variability using the standard deviation and the interquartile range; therefore, these values are defined as zero and the scores for both states in the economic principal component analysis are based largely on the peak savings measure.

Overall, the results of these individual principal component analyses yielded one significant component for each metric[8]; these components were then used as input variables in a common factor analysis. The weighted average of perceived siting difficulty by survey respondents (perception) was used as the final input variable in the factor analysis, with one variable representing each original metric.

4.3. Analyzing Factors

The four chosen input variables (indicators) load on two significant factors that can be characterized as siting difficulty (Factor one) and transmission demand (Factor two).[9] All four variables load on both factors as expected, and together both factors explain approximately 70% of the total variance. Table 6 shows the detailed variable loadings on each factor and the associated variance and communality estimates. Different metrics, input variables, and analytic assumptions could produce slightly different results; however, by combining multiple indicators, we believe that our factors and resulting rankings are robust.

The perception and geographic variables load principally on the siting difficulty factor, and the construction variable loads on the demand factor. Interestingly, the economic variable loads almost equally on both factors. In other words, as the construction indicator increases, the need for transmission lines also increases. Similarly, as either the geographic or the perception indicator increases, the siting difficulty factor also increases. In the case of the geographic variable, this relationship supports the hypothesis that high population densities near generating plants indicate higher siting difficulty, more than dispersed populations indicate a greater need for total transmission capacity. Finally, the economic variable, which loads positively on both factors, also supports the idea that high variations in the cost of electricity production indicate a greater need for transmission and also higher difficulty associated with building additional capacity. Overall, the relationships between the selected input variables and the resulting factors robustly support the initial hypotheses.

To compare the situation across the United States, the factor scores for each state were calculated and plotted, with the demand factor on the x-axis and the difficulty factor on the y-axis. Scores for both factors range from –3 (very low) to +3 (very high), where 0 is the average

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[8] Significance was determined based on both a scree test and the commonly used Kaiser-Guttmann rule, where all components with eigen values greater than 1 are considered significant.

[9] Using a principal components method of extraction and a Varimax rotated factor pattern, two significant factors were extracted based on the latent root cutoff value where the eigen values of both significant factors are greater than the average of the input variable communality estimates (mineigen> 0.695).

demand and difficulty for all states. As shown in Figure 3, each point on the factor score plot is a state, and states can be grouped into four categories of transmission demand and siting difficulty based on the four quadrants of the graph. Figure 4, a map of this factor score plot, shows the geographic variations in transmission demand and siting difficulty by state. States like Connecticut and California, with above-average transmission demand and siting difficulty, appear in the darkest shade on the map; Mississippi, Nevada, and other states with below-average difficulty and demand appear in the lightest shade. Overall, these analyses characterize both transmission demand and siting difficulty across states and regions.

The next section places this analysis in the context of other transmission investment constraints and validates our siting difficulty measure using real-world market data.

5. Validation and Implications

The current attitude toward transmission construction can be summarized by a statement by William McCormick (1999), former chairman of CMS Energy Corporation, criticizing federal regulations that limit investors' stake in transmission projects: "You can't build it and even if you could, you wouldn't want to invest in it."

Like McCormick, writers for trade publications and the popular media focus on a financial constraints and siting difficulty to explain why transmission infrastructure is not being built. First, the market for power that would justify the construction of a new line does not provide adequate investment incentive even in the absence of siting difficulty (Collins, 2002; Krapels, 2002). Second, siting is simply so difficult that the additional costs imposed by uncertainty and confounding factors further reduce investment incentive (Bangor Daily News Editorial, 2001; EEI, 2001a; Gale and O'Driscoll, 2001). We now consider the economics of transmission line construction to see whether empirical evidence corroborates our quantifying measure.

5.1. Empirical Evidence

Each point in Figure 5 represents a transmission line connecting a pair of markets and illustrates the potential yearly revenues annualized over a 25-year investment period for a transmission owner of a dedicated 230 kv transmission line (EIA, 2001b). The lengths of the proposed lines connecting 55 pairs of western markets and 6 pairs of eastern markets are estimated as the straight-line distance in miles between market center points (EMR, 2002). This analysis assumes that the owner collects rents for a transmission line between any given market pair equal to the average annual price difference between those markets.[10]

To compare the potential revenues with possible engineering costs, three cost estimates for AC and DC transmission construction are overlaid on the plot. For AC lines, the estimated low cost of transmission is $650,000/circuit-mile, average cost is $800,000/circuit-mile, and high cost is $1,000,000/circuit-mile (EIA, 2001b; Hirst, 2002). These cost estimates are then multiplied by the length of each line, and an annualized cost estimate is calculated based on a payback period of 25 years at a 10% annual discount rate. For lines longer than 400 circuit-miles, DC transmission becomes cheaper than AC transmission; therefore, each of the cost estimate lines includes a break-even pivot point from AC to DC transmission costs at 400 circuit-miles on the graph (Lucas, 2001). For DC lines, the estimated low cost is $400,000/circuit-mile, average cost is $550,000/circuit-mile, and high cost is $700,000/circuit-mile (Cassaza, 1993). From Figure 5, revenues exceed average construction costs for approximately 38% of all possible lines at a minimum 10% return on investment.

Based on that simple analysis, if siting costs are not considered, then there appear to be opportunities for profitable transmission investment. Note, however, that project viability in this analysis is defined based on the collective private costs and benefits that could accrue to a group of investors. Transmission ownership is rarely consolidated in the hands of a single owner who sees all the costs and revenues of a project; however, this aggregate characterization of costs and benefits is still relevant within the current market structure, where the "unbundling" of transmission ownership has resulted in a shift from traditional methods of system-based transmission financing toward single-project or merchant financing (Krellenstein, 2004). Also note that although the benefits and costs in this analysis are discussed in aggregate, this is not a *social* benefit-cost analysis. All of the projected costs and benefits considered here are specific to a private investor or a collection of investors, not society as a whole. At a more detailed level of evaluation, these costs and benefits would be disaggregated among various investors and

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[10] The total annual price differential is calculated using absolute daily price differences averaged for the selected two-year period (January 1, 1999, through December 31, 2000) at the given prices for 16-hour blocks of on-peak trading and 8-hour blocks of off-peak trading. Transactions between market pairs are assumed to occur for 24 hours a day and 350 days per year at the effective capacity (1,060 MW) of the line. The authors acknowledge that the 1999–2000 period reflects unusually high prices because of drought conditions in the Pacific Northwest during summer 2000, examples of capacity withholding, and the impacts of deregulation in California. However, a comparison of the calculated averages with EMR data from January 1, 1997, through December 31, 1997, for the same western markets yields comparable average annual price differentials for both peak and off-peak periods. Additionally, transactions between market pairs are assumed to be small enough that they do not affect long-term market prices and price differentials.

stakeholders, and the viability of any individual project would depend on their allocation and the regulatory uncertainties and market characteristics affecting the project financing (Hogan, 2003; Joskow, 2004; Joskow and Tirole, 2004). At this level of aggregation, the analysis simply provides an important estimate or bound of the potential benefits and engineering and siting costs of a set of plausible transmission projects.

Since none of the lines in this analysis are currently under consideration for construction, additional factors, such as siting costs and uncertainty, must be increasing costs and making the lines unprofitable. Ranking these lines by the potential profits, dividing the data into five equal groups, and comparing the means of these groups with a generic concave siting-difficulty cost measure yields a set of monotonically increasing values.[11] Figure 6 shows this relationship: as the potential profits from a line increase, so do the associated siting difficulty costs. This comparative analysis not only validates the results of the siting difficulty measure, it also highlights the relative importance of siting difficulty to investment incentive.

Overall, this analysis does not attempt to suggest that any of these lines would be profitable given a detailed evaluation of land costs, rights-of-way, and market uncertainty; nevertheless, it provides an independent validation for the measure of siting difficulty developed above. The next section discusses the policy implications of the state-level variations in siting difficulty defined by our measure.

5.2. Policy Implications

Several major policy strategies to improve local, state, regional, and national grid development, management, and reliability have been developed by both Congress and FERC (Barton, 2005; FERC, 2000). Regional Transmission Organizations (RTOs) have been advanced by FERC as a policy solution to increase transmission construction and overall grid reliability (Hirst, 2002), and their designs have been studied in terms of overall market impacts, economic benefits and costs, and improvements in reliability and congestion (FERC, 2002a; FERC, 2002b), but little attention has been paid to the existing conditions in each state—both transmission demand and siting difficulty—that could determine their success or failure. The current structure of RTOs, based on voluntary participation, does not guarantee a desirable

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[11] This analysis uses the first 43 most profitable lines from the economic justification analysis based on the average engineering cost ($800,000/circuit mile). The siting difficulty factor score for each state is rescaled from 0 to 6 and multiplied by a generic concave weighting function in the form $(1-e^{[-x/\alpha]})$ where the results are robust for a range of values of $\alpha > 0$. The average distance-weighted siting difficulty scores are then calculated for each line based on the length of line in each state.

outcome. The analyses above reveal large variations in existing transmission demand and levels of siting difficulty across states and regions (Figure 4). We believe that these variations will likely affect incentives to join a specific RTO, thereby resulting in unanticipated patterns of joining behavior and creating additional interstate siting issues.

Comparing the still-evolving boundaries of current RTOs with Figure 4 indicates configurations of Southeast and Northwest RTOs that could have no states with both high demand for new transmission lines and high difficulty of siting them, while a possible Northeast RTO could have as many as six such states (FERC Staff, 2004). Depending on the siting difficulty and transmission demand of utilities and states within a given RTO, participants will likely have more or less incentive to join that RTO based on their own needs for power. For example, using the state as the level of consideration, there is little incentive for a state to enter an RTO if it is located between a high-difficulty state that needs power and another state that has excess power to export. A specific example, at the scale of a single transmission line, is the Cross-Sound Cable connecting Connecticut and New York. This line under Long Island Sound has faced years of extremely high-profile opposition on both environmental and equity grounds that Long Island communities will benefit at the expense of Connecticut consumers (Randell and McDermott 2003, 2004; Krellenstein, 2004).

In the same way, states with a high demand for power lines (and/or power), such as Iowa, have little incentive to join an RTO with adjacent high-demand, high-difficulty states: the lower difficulty in Iowa could likely result in transmission lines built across the state to serve states with even higher demand and difficulty. This is supported by Iowa's piecemeal participation in the surrounding MISO RTO during its earliest phases (FERC Staff, 2004). Similarly, the low-difficulty states adjacent to South Carolina have little incentive to include their high-difficulty neighbor in an RTO. On the other hand, a group of low-demand and low-difficulty states adjacent to a high-demand, high-difficulty state have a greater incentive to join an RTO that allows them to profit from exporting power to their high-demand neighbor. This would be the case with California and RTO West. Finally, two adjacent high-difficulty states have little incentive to join the same RTO; they would instead benefit from joining bordering low-difficulty states.

Overall, high-difficulty areas have the potential to act as barriers both within and between RTOs, and RTOs are likely to form easily only when states with excess power and low siting difficulty are co-located with states with high need. These potential interactions are even more important at smaller scales of evaluation. Depending on a utility's individual incentives to join a specific RTO, the “seams” of new RTOs may fall along already-defined areas of intrastate and interstate transmission congestion.

Additionally, the consolidation of transmission and siting management into RTOs has the potential to create umbrella organizations that collect and compound existing siting difficulties. For example, even in states such as California, where siting authority is consolidated under a single agency, siting difficulties persist (California State Auditor, 2001). If RTOs are unable to resolve the problems of states within their region and coordinate siting solutions, the binding siting constraint of one state has the potential to become that of the region.

These findings have far-reaching implications outside the United States as well. The repercussions of high siting variability are relevant for a variety of infrastructures worldwide, where local incentives to site new infrastructure could conflict with the best interests of a larger region, and a clear framework for justifying regional decision making and developing targeted mitigation strategies is necessary for effective project implementation. The next section builds on these policy-level findings to evaluate in detail the relative contributions of different siting constraints to the problem as a whole.

6. Assessing Primary Causes

In the Introduction, we defined siting difficulty broadly. Houston (2003) defines siting constraints equally broadly as “locations where a transmission line might have a potentially adverse impact on sensitive resources, or locations where conditions might affect reliable and safe operation or economical construction of the line.” Based on these definitions and industry literature, the main causes of siting problems can be grouped into three categories: environmental barriers, regulatory roadblocks, and public opposition. Although these constraints are frequently interconnected, each presents its own problems in the process of route selection and transmission construction. Attributes of the natural environment, the characteristics of the local public, and the regulatory standards along prospective routes all have the potential to significantly increase the cost of a project, lengthen the timeline of implementation, and perhaps most importantly, undermine the certainty of project completion.

With deregulation and other changes to the industry, the traditional “decide-announce-defend” siting system (Section 2, above) has been shifting to a more flexible approach: “avoid-anticipate-communicate.” Planners and stakeholders first seek to avoid problematic areas. After eliminating unviable alternatives, they then focus on anticipating obstacles that could affect the remaining sites. Inevitably, this involves making trade-offs. In some cases, constraints are both familiar and static, such as unusual stream crossings or soil conditions that alter construction plans, and the trade-offs are easily quantified and certain; however, this phase is also associated with unfamiliar and dynamic constraints, such as public opposition. As a result, the final step has been to work with stakeholders to identify the unacceptable alternatives.

For this more flexible approach to succeed, planners and siting professionals need a systematic method for characterizing the relative importance of different constraints. Based on the measure of siting difficulty (Section 4), we next focus on predicting regional variations in the magnitude of specific constraints and their interactions, using another exploratory factor analysis and regression model. This goal of this model is not only to develop a method for assessing "trouble spots" that can be targeted for early management and mitigation, but also to establish a framework for evaluating potential impacts of changes to siting policy or regulation for affected industries.

6.1. Categories Defined

Environmental constraints are an essential consideration in the routing process. Physical conditions along a route, including variations in topography, soil, bedrock, and land and forest cover, influence the structural and mechanical limits of tower design, thereby affecting the cost and viability of a project. Because transmission lines typically have inflexible endpoints, such as generating plants or substations, avoiding difficult areas completely is rarely an option. Instead, planners are make trade-offs between line attributes and site characteristics, and rarely does one alternative dominate all others (Keeney and Raiffa, 1976; Hester et al. 1990). Many of the regulations, permits, and approvals required for transmission projects also relate to regional environmental features, such as stream crossings, parks, or protected habitats.

Consequently, a second factor affecting siting is regulation. Most transmission line siting is currently regulated at the state level; however, the agencies that govern siting processes and their respective roles vary significantly. Based on data from EEI (2001), 6 states have no state-level oversight of transmission line permitting except for specific geographic situations, such as river crossings; 39 states have a single permitting agency with the overriding authority to approve or deny construction permits; and 6 states have multiple permitting agencies that may include the public utilities commission, a siting board, or the department of natural resources. Federal agency involvement occurs only after state and local permitting has begun. Overall, the regulatory barriers to siting are compounded by fragmented permitting processes, nonstandard permitting requirements, and interagency redundancy.

Last but not least, the third major constraint is public opposition. Reasons for public opposition include the negative impacts of transmission lines on property values, the adverse aesthetic impacts of transmission towers, health and safety concerns related to electromagnetic fields, equity and fairness issues, insufficient compensation for easements and related tax implications, and inadequate justification of the need for the line (Vierima 2001).[12] Because permitting processes typically require public meetings and reviews, public opposition is heavily intertwined with both local environmental concerns and the associated regulatory standards for public safety and community consensus. Although the blame for additional siting uncertainty and complexity is almost entirely directed toward the public, citizens' opposition is not homogeneous. The umbrella characterization of all opposition as NIMBY has obscured the heterogeneity of public and stakeholder opinions (Quah and Tan 1998). We emphasize this diversity here because public concerns related to ecological or equity issues are inextricably linked to the other two categories of siting constraints described above.

Environmental and regulatory constraints are often ignored in discussions of siting difficulty, for two reasons. First, these issues are still typically addressed as part of internal project decision making. Second, siting projects rarely fail because of inadequate technical or environmental considerations (Kuhn and Ballard, 1998). Similarly, regulatory roadblocks may slow a siting process, but rarely are they unanticipated or crippling (California State Auditor 2001). Incongruently, proposed solutions to overcoming difficulty focus on individual constraints and perceived causes, often project-specific and based on industry anecdote. This attention to the symptoms of siting difficulty without an eye toward treating the underlying condition has proved to be largely ineffective. It is essential to consider the relationships and interactions among constraints to successfully mitigate any single constraint, as well as siting difficulty as a whole.

To tease out the effects of individual constraints, we next construct a regression model of the causes of siting difficulty, and then, in Section 7, present the results of a survey of transmission line siting professionals (introduced above as the basis for the perception indicator, Section 4.1.4) to provide a subjective context for the regression model.

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[12] The difference between scenic impacts and tower aesthetics is subtle. Different tower sizes or designs could reduce the unpleasant appearance of the towers themselves but still disrupt a scenic view shed. Additionally, opposition based on the justification for a line can be related to either the need for particular route or the need for a line overall, or both.

6.2. Selection of Variables

Using the three categories of constraint—environment, regulation, and public opposition—as a framework for the selection of regression predictors, we identified 12 variables that we believe are the most representative and robust indicators of the causes of siting difficulty. We hypothesize that each of these predictors is associated with a parallel increase in siting difficulty. Variables are grouped equally into each of the three categories based on our hypotheses of their primary relationships with siting difficulty as a whole. These categories are not mutually exclusive, and variables in any one category are related to the other categories to varying degrees. Each selected variable and its underlying hypotheses are described in detail below.

6.2.1. Public opposition

Population density. Public opposition is typically associated with the number of people who are affected (or who believe they are adversely affected) by a facility and as a result protest a siting process or decision. We hypothesize that the likelihood of public opposition and siting difficulty as a whole will increase as the number of people potentially affected increases. Source: U.S. Bureau of Census (2000).

League of Conservation Voters score. Environmental concerns are frequently identified as reasons for public opposition. We hypothesize that preferences of populations for environmentally sensitive policies or their support for environmental activism could indicate a greater likelihood of opposition. This predictor variable is derived from the League of Conservation Voters' State Environmental Scorecard, which assigns U.S. senators and representatives a score based on their votes for or against selected environmental legislation. Scores for each congressman range from 0 (least environmental) to 100 (most environmental). A proxy for public environmental activism and preferences, this variable is the average of scores of each state's delegation to the House of Representatives from 1998 through 2002. Source: League of Conservation Voters (1998–2002).

Median housing value. Another major reason for public opposition is the potential loss of value of property adjacent to unwanted facilities (Vierima, 2001). We hypothesize that the higher the median value of owner-occupied homes, the higher the potential loss and the more probable it is that affected residents will oppose a project. Source: U.S. Bureau of Census (2000).

Education. Public protest can focus on concerns about risks to health and safety from exposure to EMF and risks of ecological damage (Vierima, 2001). We hypothesize that the severity and complexity of protests related to these concerns are positively correlated with the education level of the affected population. Our variable is the percentage of a state's population over age 25 who hold a bachelor's degree. Source: U.S. Bureau of Census (2000).

6.2.2. Regulation

1. Permitting by kv. We hypothesize that any increase in the amount of regulation is an indicator of longer siting processes with greater uncertainty. This variable is constructed from the 2001 Edison Electric Institute state-level siting directory map of state requirements for permitting of new lines based on their voltages. Some states require no oversight, some require permits only for lines larger than 200kv, other states require permits for lines larger than 100kv, and still other states require permits for all lines, even those less than 100kv. These four levels of regulation are assigned scores of 0 to 3, respectively; that is, 0 is associated with the least regulation and lowest difficulty, and 3 is associated with the highest. Source: EEI (2001c).

2. State natural resources employment. Because many siting regulations are based on environmental protection considerations, we hypothesize that the greater the percentage of state officials working on natural resources issues, the more likely it is that environmental issues are a priority, relative to other sectors. As a result, siting regulations could be more stringent and lead to increased siting difficulty. This input variable is full-time equivalent employment as a percentage of total state full-time equivalent employment. Source: U.S. Bureau of Census (2004).

3. Siting authority. Regulatory difficulties are associated not only with the types of required permits, but also with the numbers and types of agencies involved in granting approvals. This variable is also based on the EEI state-level siting directory. A state with no primary siting authority is assigned a 0 (easiest), a state regulated by a PUC is 1, a state with a consolidated siting board is 2, and a state with a nonsiting agency as the primary authority is 3. Our rationale is that PUCs are the most experienced in reviewing siting permits (low level of difficulty); siting boards have fewer established standards and procedures (moderate difficulty); and a non-dedicated siting authority, such as a state department of natural resources, has other priorities and responsibilities (high level of difficulty). Source: EEI (2001c).

4. Number of siting agencies. The total number of state agencies involved in siting and permitting processes may also affect the process. Using the 2001 EEI state-level siting directory, we assign scores to states as follows: no state siting authority (0, easiest), a single siting agency (1), or multiple agencies (2). Source: EEI (2001c).

6.2.3. Environment

1. Land cover. The type of land along a route significantly influences siting decisions. This variable is developed based on data from the global climate models that characterize surface roughness as a measure of wind turbulence. We hypothesize that the higher the roughness length, the more difficult the physical environment for construction. Water bodies have the lowest roughness length, followed by pastures, and fields; dense scrub, hills, urban construction, and unevenly forested regions make up the roughest land covers. Source: Collins et al. (2003).

2. State forest acres. We hypothesize that the amount of state forest land limits the total available area for siting and also affects the ease of access to potential sites, the cost of construction, and overall physical difficulty. Our measure is state forest area as a percentage of total land area. Source: National Association of State Foresters (2003).

3. Standard deviation of elevation. Site selection and project construction can be constrained by very steep, rocky, or mountainous areas. Given the limited infrastructure in regions such as the Rockies and Appalachians, we hypothesize that extreme changes in terrain are associated with higher environmental siting difficulty. This variable was calculated based on the standard deviation of the average elevations of all zip codes in each state. Source: Zip-codes (2005).

4. Farmland (inverse). As a counterpart to the "bumpiness" variable defined by variations in the elevation, we hypothesize that flatter, more easily accessed farmland (as a percentage of total land area) is associated with lower physical and environmental siting difficulty. This variable is multiplied by −1 to maintain a positive relationship with increasing siting difficulty. Source: USDA State Fact Sheets (2002), adapted.

All 12 variables above were normalized and input into a factor analysis. The resulting significant three-factor solution explains approximately 65% of the total variance. Table 7 shows the Varimax rotated factor loadings for all three factors, which are defined as public, environment, and regulation, respectively. As hypothesized, the selected variables load primarily on the three categories of constraints as grouped above.[13] The next section builds on this analysis, using the state factor scores as input variables in a regression model.

6.3. Regression Analysis

To understand the relative contributions of individual siting constraints to overall siting difficulty, the three factor scores were regressed on the quantitative measure of siting difficulty (Section 4). The regression equation below shows that the coefficients of all three factors are significant at $p<0.05$, and together they account for approximately 64.4% of the total variance in the dependent measure, state siting difficulty. Taken as a whole, the results of this analysis strongly support current qualitative judgments about the relative importance of different constraints to siting difficulty, where the coefficient for the public factor is significantly higher than for either the environment or the regulation factors.

At the state level, this model is a valuable tool for understanding the relative importance of different siting constraints.

Siting Difficulty Factor =
0.62 Public Opposition + 0.47 Environment + 0.18 Regulation

Predictor	Coefficient	SE Coef.	T	P
Constant	0.00000	0.08899	0.00	1.000
Public	0.62255	0.08994	6.92	0.000
Environment	0.47264	0.08994	5.26	0.000
Regulation	0.18211	0.08994	2.02	0.049

N= 48 S= 0.617 R^2 = 64.4% R^2 (adj)= 62.0%

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[13] Although the Natural Resources Employment variable loads positively on the regulation factor, as hypothesized, it also loads negatively on both the public and the environment factors. These negative relationships could be caused in part by interactions among public and regulatory concerns surrounding the environment. As the number of state officials working on natural resources increases, it is possible that public confidence in state environmental priorities could limit public opposition to major facilities on environmental grounds, under the assumption that strict regulation reduces the need for parallel public oversight. A second slightly unusual loading is the negative loading of the Elevation variable on the environment factor. This relationship can be explained by the connections among variables loading on the factor, where land cover, state forest acreage, and farmlands all have slightly negative correlations with variability in elevation.

7. Evaluating Industry Perceptions

We now return to our survey of siting professionals, introduced above in Section 4.1.4. Of the 56 total survey participants, approximately 45% came from public electric utilities, 24% from government regulatory agencies, 16% from consulting firms, 7% from investor-owned utilities, and 7% from equipment manufacturing and other siting-related companies. Respondents described their field as permitting and regulation (31%); civil, mechanical, or electrical engineering (29%); line routing (22%); management (11%); or research (7%).

Different respondent groups correspond with significant differences in perceptions of siting difficulty and its dominant causes. For example, the average ratings of siting difficulty from Section 4 support the prevailing perception that California is the most difficult state; it was ranked first by all respondents, and Texas was ranked 46th. However, as the ratings are weighted by familiarity, California drops to fourth and Texas rises to 44th, indicating that more familiar professionals do not share the extreme perceptions of siting difficulty in either state to the same degree as less familiar respondents. Below, we compare major findings by respondents' employer, work experience, and home state.

Because participants rated multiple states, state evaluations by the same respondent are not independent from one another. However, since respondents were not required to respond for all states, the data structure does not allow for a full repeated measures analysis. Instead, most of the following analyses are based on between-subject comparisons of within-subject values that account for variations in their perceptions of siting difficulty and its causes across all states.

7.1. Variations by Employer

Public opposition is widely perceived to be the dominant cause of siting difficulty across all states; however, different types of professionals have significantly different perceptions. In informal conversations with approximately a dozen siting professionals at utilities, consulting firms, and regulatory agencies, individuals articulated their specific concerns. Several regulators felt that environmental issues were of major importance and said that many project proposals did not give these issues sufficient attention. Other regulators expressed concerns about the uncertainty surrounding changes to federal energy policy that could complicate current regulatory requirements. Similarly, several utility engineers and routing specialists said that even existing state regulation was already frustratingly complex without federal oversight. The analyses in this section test selected hypotheses from these early conversations.

Figure 7 illustrates the variations in perception for respondents from investor-owned utilities, consulting companies, state government regulatory agencies, equipment and manufacturing firms, and public electric utilities. Each bar on the graph represents the average percentage that respondents from a given agency selected public opposition, topography/environment, state regulation, federal regulation, or interagency coordination as the most important constraint on siting difficulty across all states.

As the graph shows, on average, respondents from public electric utilities consider topography/environment the primary siting constraint only 5% of the time relative to all other constraints, compared with 14% for government regulators (t(36)= 1.28, p=0.104) and 20% for consultants (t(32)= 2.01, p=0.026). Regulators identify state regulation as the dominant siting constraint far less (10%) than utility respondents (29%) (t(36)= -1.92, p=0.031);[14] this result corroborates anecdotal evidence of public utility professionals' frustrations about state regulations. Finally, although state regulators selected federal regulation more often as the dominant cause (10%) than consultants (3%) and utility employees (3%), these results are not significantly different.

We hypothesize that the variations in the perception of siting constraints among professionals can be associated with their control over or involvement with a given constraint. For example, utility siting officials begin by eliminating economically or physically infeasible locations, whereas government regulators working with topographical or environmental issues are involved in the siting process only after utilities have already selected potential routes and narrowed the choices.

As Figure 8 illustrates, although there is some overlap, a siting project generally begins with preliminary economic feasibility, necessity, and routing analyses internal to the company considering the project, then continues with the submittal of applications for construction permits and approvals to the required state, local, and federal regulatory agencies, and concludes with public hearings and participation efforts prior to the issuance of final permits and construction (Houston, 2003; California State Auditor, 2001). In all states, regulations governing transmission line siting require filing a Certificate of Public Convenience and Necessity (CPCN),

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[14] Because of missing values, these data does not allow for a full ANOVA or Chi-square analysis. As a result, this section includes only results for selected pair-wise comparisons of agencies based on two-sample t-tests assuming equal variances.

Environmental Impact Statement (EIS), or an equivalent letter of intent. Detailed permit applications, reviews, and public hearings specific to each state and local areas then follow (Houston, 1995). During this process, environmental issues are generally addressed first, followed by state and federal regulation, interagency coordination, and finally public opposition.

Since respondents from different employers become involved at different phases along a project timeline (top of Figure 8), their perceptions of the contributing factors of siting difficulty vary with their exposure to and control over the challenges. For example, public involvement generally occurs after many details of a proposal have already been carefully considered and decided upon. Public opposition could be the primary focus of media and research attention to siting constraints because public involvement occurs relatively late; citizens could feel as though they are being presented with an inflexible proposal against which there is no alternative but vigorous opposition. Overall, these variations in the perception of siting constraints among respondent groups reveal the importance of timing for effective siting, and the implications of delayed stakeholder involvement.

7.2. Variations by State

Additional variations in industry perceptions are evident across respondents' states of residence and employment. The survey asked respondents to identify their primary state of residence and employment. The correlation of respondent's difficulty ratings for a given state and the average difficulty of their own states was then calculated. As with the comparisons of difficulty by familiarity, all correlations were calculated and evaluated within-state. In this case, the correlations are not significant, indicating that respondents' difficulty ratings are robust to changes in where they live and work.

In contrast, respondents' perceptions of the dominant causes of difficulty are significantly associated with where they work. Based on a median split of respondents' own state difficulty values, respondents from below-average-difficulty states (n=25) selected public opposition as the dominant cause of siting difficulty 70.4% of the time on average; respondents from above-average-difficulty states (n=29) selected public opposition only 53.7% overall, relative to all other causes ($t(50)$= 1.6, p=0.116).

Furthermore, respondents from low-difficulty states felt that regulation was significantly less of a problem (n= 25, $\bar{x}$ = 18.1%) than respondents from high-difficulty states (n= 29, $\bar{x}$ =

37.7%); *t*(50)= –2.10, *p*= 0.041).[15] This result has implications for the relative magnitude of the perceived difficulty associated with different states. Overall, understanding the prevalence and distribution of different causes of siting difficulty is as relevant to the success of a project as characterizing the magnitude of siting difficulty affecting the project.

7.3. Variations by Experience

Finally, survey respondents' perceptions of siting difficulty are affected by two measures of their level of involvement in siting projects: degree of familiarity with siting, and total years of work experience with siting projects. We hypothesize that respondents' ratings of difficulty within a state could be influenced by their familiarity with siting in that state. Calculating the correlation of familiarity and difficulty ratings for each state shows that 43 of 48 states have positive correlations between familiarity and difficulty. This indicates that respondents with higher familiarity think that siting difficulty is higher than less-experienced respondents do across all states.

There are several possible reasons for this difference. The simplest explanation is that experienced siting professionals are assigned more difficult projects; more junior workers may anchor their ratings on their own experience and underestimate siting difficulty. However, it is also possible that the lack of recent construction means that only straightforward projects with high certainty of completion and high forecasted rates of return are being proposed and built. This is in contrast to previous decades, when long-term planning on a 30-year time horizon was typical, and challenging route proposals could have been pursued in an effort to build reserve capacity.

The results are particularly interesting for their implications in an industry that has undergone dramatic transformations in recent decades. In response to these changes, and with the recent lack of construction and uncertainty surrounding transmission ownership, many utilities and companies have downsized or completely eliminated their siting divisions. Although this trend has been paralleled by the creation and growth of independent transmission companies, some experienced siting professionals have retired (EEI, 2002), confronting the industry with the task of training new employees. This shift in the workforce could have potential advantages: the

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[15] Given the low percentages of respondents who identified federal regulation and interagency coordination as the dominant causes of siting difficulty across all states, the data for state regulation, federal regulation, and interagency coordination were combined into a single regulation category. The average percentage of respondents who selected environment as the dominant cause across all states was not significantly different between groups of respondents from above-average and below-average difficulty states.

rapid changes in the industry require new strategies for addressing public opposition and legal challenges, and new professionals could foster positive changes to outdated siting processes.

In fact, evidence that younger professionals may bring new approaches is apparent from the survey. Respondents rated their perceptions of the current balance between business considerations and environmental concerns on a scale of –4 (emphasis on the environment) to +4 (emphasis on business), where zero indicated a good balance between business and environment. On average, respondents felt there was a slight overemphasis on the environment ($\bar{x} = -1.31$; $t(55) = -6.75$, $p < 0.001$). However, based on a median-split of the data, respondents with less than 15 years of siting experience said that there was a better balance between business and environment ($n = 27$, $\bar{x} = -0.85$) than respondents with 15 or more years of work experience, who felt there was a significant overemphasis on the environment ($n = 28$, $\bar{x} = -1.75$; $t(52) = 2.42$, $p = 0.019$). These changing views within companies could benefit an industry being pushed to make more environmentally sensitive siting decisions. On the other hand, it is likely that new workers will face many of the same technical, engineering, and communications challenges encountered by retiring professionals. As a result, the limited venues for knowledge transfer between these two “generations” could prove to be a major stumbling block in the transition to a truly competitive grid.

7.4. Discussion

Overall, we find that the survey results detailed above validate the regression model in Section 6: both show that public opposition is the most important factor across all states. These results constitute a first step toward breaking down the siting problem and prioritizing mitigation efforts, including federal policies, state regulations, and local practices. At a more detailed level of disaggregation, the order of importance of the regression predictors (public, environment, then regulation) most closely aligns with the consultants’ perceptions of the overall causes of siting problems in Figure 7. Given that consultants have the greatest degree of familiarity and work experience in the most states compared with all other agency groups, this evaluation provides important independent support for the regression model and the major findings.[16]

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[16] Respondents’ evaluations of the dominant causes of siting difficulty within each state were never used as input variables into any of the factor or regression analyses in either paper; therefore, they provide independent points of comparison for this analysis here.

8. Conclusions

Taken as a whole, this work provides a fundamental framework for characterizing and evaluating transmission line siting difficulty and its major causes. The two-tier analytical approach presented here could be applied to siting problems facing other infrastructures and industries. The selection of industry-relevant indicators independent from the common causes and localized effects of siting problems allows for broad-based characterizations of siting difficulty. For example, possible indicators of siting difficulty and infrastructure demand for wind farms could be developed based on variations in regional renewable portfolio standards (RPS) or measures of backup power available on the grid. Overall, the emphasis here is on constructing complementary indicators that represent a diverse set of impacts across an industry.

Siting difficulty and its associated constraints are not monolithic. This paper also makes a first step toward breaking down the causes of siting problems into manageable pieces for evaluation and planning, while simultaneously maintaining a large-scale view of the problem. The results here are not intended to identify and blacklist areas of high siting difficulty or to suggest that all siting difficulty can be predicted and addressed in advance of a planning process. Nor are our analyses the only appropriate characterizations of a broad and complex problem. This work is simply intended to give structure to the ever-expanding discussion of energy facilities siting, management, and planning.

As more parties have become involved in the debate over siting, technical solutions and policy solutions to infrastructure demand and siting difficulty have increasingly diverged. Successful development of energy infrastructures requires the integration of both technological system-level innovations and large-scale policy changes. This paper serves as an initial bridge between the quantitative and qualitative issues affecting siting, where a sound strategy for managing siting problems is critical to the success of many energy industries.

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Table 1. Economic Indicator: Variations in the Cost of Generation and Production

	Baseload Cost of Production ($/Mwhr)				Peaker Cost of Production ($/Mwhr)			
State	Mean	Standard Deviation	IQR	Opt. Dispatch Savings (%)	Mean	Standard Deviation	IQR	Opt. Dispatch Savings (%)
Alabama	14.74	6.97	9.41	0.0%	40.47	5.85	-	0.0%
Arizona	26.82	16.13	15.28	0.0%	198.18	236.58	260.82	12.8%
Arkansas	21.56	3.07	5.25	0.7%	76.40	50.87	-	3.5%
California	22.97	12.46	9.39	0.8%	165.52	305.64	100.09	33.8%
Colorado	18.50	6.52	9.72	1.6%	219.01	259.93	412.36	42.5%
Connecticut	34.07	12.72	17.35	0.0%	216.75	111.27	162.62	9.8%
Delaware	-	-	-	0.0%	387.51	377.45	582.34	8.6%
Florida	24.68	5.94	8.83	1.0%	276.77	941.38	36.20	10.3%
Georgia	19.41	4.89	6.19	0.0%	61.80	22.63	16.17	3.3%
Idaho	16.06	10.64	16.91	0.0%	-	-	-	0.0%
Illinois	28.42	15.51	15.66	0.3%	117.54	67.26	66.10	30.9%
Indiana	19.51	6.20	6.69	0.1%	80.06	54.81	61.29	3.6%
Iowa	22.29	14.03	12.58	1.5%	77.14	32.24	54.76	4.3%
Kansas	17.17	4.69	9.28	0.5%	75.04	51.13	40.76	14.0%
Kentucky	14.80	3.79	4.49	0.5%	87.82	68.84	37.78	5.6%
Louisiana	25.94	6.05	10.15	1.8%	183.73	25.38	-	0.0%
Maine	17.27	11.20	20.93	0.0%	1125.20	-	-	0.0%
Maryland	19.27	3.45	5.25	0.1%	73.16	25.85	45.63	0.5%
Massachusetts	34.03	18.18	31.56	0.0%	213.92	214.64	252.82	37.7%
Michigan	21.29	5.69	7.96	0.2%	119.99	109.65	51.57	17.6%
Minnesota	26.19	15.16	19.78	0.2%	159.14	168.00	101.83	16.3%
Mississippi	20.25	3.61	6.65	0.9%	152.58	254.73	51.66	3.8%
Missouri	17.67	5.34	10.61	0.5%	89.65	58.08	45.79	22.0%
Montana	12.07	6.16	8.90	0.0%	38.73	4.23	-	0.0%
Nebraska	16.14	9.42	15.54	0.9%	72.64	42.09	32.13	8.2%
Nevada	18.68	3.07	6.12	0.3%	78.80	35.04	67.19	0.0%
New Hampshire	20.01	5.57	9.97	0.5%	332.84	167.09	308.73	6.2%
New Jersey	28.76	8.30	15.33	0.4%	105.42	66.51	82.74	12.3%
New Mexico	27.26	7.23	12.85	0.0%	54.14	-	-	0.0%
New York	27.81	19.68	18.14	2.2%	351.20	801.97	61.14	13.6%
North Carolina	15.42	8.23	10.39	0.4%	103.30	46.84	73.00	2.4%
North Dakota	16.00	5.26	8.34	0.0%	92.46	-	-	0.0%
Ohio	18.94	4.51	5.40	0.7%	175.33	117.41	128.24	5.1%
Oklahoma	20.55	6.75	10.00	0.9%	49.60	7.09	13.68	0.0%
Oregon	18.79	10.20	15.25	0.0%	45.87	-	-	0.0%
Pennsylvania	21.52	7.54	8.20	0.1%	82.27	49.21	39.71	67.5%
Rhode Island	32.26	-	-	0.0%	-	-	-	0.0%
South Carolina	18.91	6.61	9.54	0.2%	96.94	30.73	45.40	6.4%
South Dakota	14.45	8.16	15.66	0.0%	66.21	22.71	32.50	2.1%
Tennessee	13.46	6.48	7.57	0.2%	58.25	18.51	36.34	0.0%
Texas	22.52	7.08	11.23	0.9%	196.95	393.23	73.70	42.4%
Utah	19.47	7.66	12.52	0.1%	-	-	-	0.0%
Vermont	21.65	14.22	28.24	0.0%	119.43	34.73	58.61	0.4%
Virginia	18.37	4.32	7.06	0.1%	82.19	30.25	59.41	0.6%
Washington	14.67	6.29	8.93	2.0%	32.72	7.92	-	0.0%
West Virginia	15.51	1.05	1.71	0.1%	-	-	-	0.0%
Wisconsin	20.59	7.69	15.61	0.4%	90.25	74.04	53.97	8.7%
Wyoming	12.69	2.73	5.25	0.1%	-	-	-	0.0%

Table 2. Geographic Indicator: Distribution of Generation Capacity and Demand

	Percent of Total Population Served within Footprint Radius					
State	**1 mile**	**5 mile**	**10 mile**	**15 mile**	**20 mile**	**25 mile**
Alabama	0.4%	7.4%	30.0%	56.6%	74.7%	87.3%
Arizona	0.9%	4.7%	5.9%	59.8%	60.7%	61.7%
Arkansas	0.5%	4.7%	14.9%	37.1%	56.9%	82.6%
California	0.7%	14.2%	23.0%	31.3%	49.1%	55.4%
Colorado	0.8%	10.4%	19.7%	26.6%	51.1%	92.6%
Connecticut	1.9%	32.5%	47.8%	81.9%	98.2%	99.2%
Delaware	1.5%	26.8%	44.6%	83.9%	99.2%	100.0%
Florida	1.2%	17.2%	49.6%	62.9%	87.1%	90.3%
Georgia	0.6%	10.0%	37.5%	57.2%	88.0%	94.3%
Idaho	0.1%	3.9%	13.1%	24.5%	44.6%	85.1%
Illinois	0.9%	11.5%	32.7%	86.0%	95.2%	98.8%
Indiana	0.6%	12.7%	19.4%	68.9%	80.6%	91.4%
Iowa	0.9%	11.8%	26.0%	68.3%	83.0%	89.0%
Kansas	1.0%	17.2%	38.4%	56.9%	89.2%	95.7%
Kentucky	0.7%	15.3%	38.7%	48.4%	55.2%	81.5%
Louisiana	0.9%	19.3%	47.9%	61.9%	80.2%	87.7%
Maine	0.4%	8.4%	30.4%	40.1%	74.4%	82.8%
Maryland	1.7%	22.1%	46.1%	74.2%	95.1%	97.5%
Massachusetts	2.4%	30.9%	50.0%	72.1%	91.5%	95.6%
Michigan	1.1%	13.9%	37.2%	89.3%	96.6%	96.8%
Minnesota	1.4%	13.9%	44.7%	75.5%	87.9%	91.3%
Mississippi	0.3%	6.7%	18.6%	38.9%	51.3%	62.7%
Missouri	0.9%	15.4%	40.7%	73.8%	81.4%	91.5%
Montana	0.1%	5.1%	13.3%	18.0%	30.6%	48.4%
Nebraska	0.9%	5.8%	48.0%	72.4%	83.8%	91.5%
Nevada	1.1%	11.1%	34.3%	39.2%	58.0%	71.5%
New Hampshire	0.6%	11.0%	42.4%	79.7%	99.2%	100.0%
New Jersey	2.2%	19.9%	51.2%	81.0%	98.4%	99.3%
New Mexico	0.3%	2.4%	4.6%	7.3%	12.2%	14.9%
New York	5.7%	24.7%	48.3%	78.7%	94.7%	95.8%
North Carolina	0.7%	11.5%	40.0%	67.4%	86.5%	92.7%
North Dakota	0.1%	1.9%	8.8%	15.5%	19.3%	38.8%
Ohio	0.9%	6.9%	31.2%	56.5%	87.0%	91.2%
Oklahoma	0.7%	12.7%	22.0%	40.9%	52.0%	87.2%
Oregon	0.1%	1.8%	6.4%	14.1%	38.7%	50.6%
Pennsylvania	1.5%	15.8%	58.4%	89.1%	95.5%	98.4%
Rhode Island	2.3%	45.2%	80.0%	84.2%	98.5%	100.0%
South Carolina	0.9%	9.4%	31.2%	78.7%	94.4%	99.9%
South Dakota	0.3%	5.7%	10.5%	15.3%	30.4%	34.5%
Tennessee	0.5%	6.7%	25.9%	47.3%	66.1%	84.0%
Texas	1.1%	14.2%	37.8%	52.6%	80.0%	83.5%
Utah	0.5%	4.0%	6.1%	7.6%	88.2%	92.3%
Vermont	2.2%	13.1%	22.5%	75.9%	98.9%	99.0%
Virginia	1.3%	14.7%	36.3%	75.0%	93.4%	96.5%
Washington	0.4%	2.2%	6.1%	22.9%	38.4%	50.3%
West Virginia	0.6%	12.0%	39.5%	60.1%	72.0%	82.9%
Wisconsin	2.2%	13.7%	39.2%	83.0%	94.4%	94.8%
Wyoming	0.1%	1.4%	4.8%	11.0%	30.6%	41.1%

Table 3. Construction Indicator: Differences in Transmission and Generation Capacity

	Slope 1988-1998 (Avg. Annual Change)				Difference in Slopes		
State	**Transmission Capacity (Circ. Miles)**	**Net Generation (Mwhrs)**	**Generation Capacity (MW)**	**Sales (Mwhrs)**	**Net Generation-Transmission**	**Generation Capacity - Transmission**	**Sales - Transmission**
Alabama	7.06%	7.01%	1.27%	3.86%	-0.06%	-5.79%	-3.20%
Arizona	1.83%	3.43%	0.47%	4.40%	1.60%	-1.36%	2.57%
Arkansas	1.24%	2.89%	0.02%	5.62%	1.65%	-1.23%	4.38%
California	1.52%	0.36%	-0.24%	1.15%	-1.16%	-1.75%	-0.37%
Colorado	1.48%	1.99%	0.85%	3.48%	0.51%	-0.63%	2.00%
Connecticut	7.43%	-4.90%	-1.39%	0.70%	-12.33%	-8.82%	-6.74%
Delaware	14.76%	-1.48%	2.32%	3.55%	-16.24%	-12.45%	-11.22%
Florida	1.30%	3.93%	2.28%	3.99%	2.64%	0.99%	2.69%
Georgia	4.77%	2.22%	2.13%	4.66%	-2.55%	-2.64%	-0.11%
Idaho	1.54%	7.92%	1.71%	2.52%	6.38%	0.16%	0.98%
Illinois	2.35%	1.32%	0.15%	2.02%	-1.03%	-2.20%	-0.33%
Indiana	0.92%	2.95%	0.35%	3.02%	2.03%	-0.58%	2.10%
Iowa	3.50%	3.06%	0.60%	3.11%	-0.43%	-2.89%	-0.38%
Kansas	0.25%	2.78%	0.33%	3.05%	2.53%	0.08%	2.80%
Kentucky	-2.29%	2.71%	0.54%	4.31%	5.00%	2.83%	6.59%
Louisiana	2.80%	1.19%	0.48%	3.03%	-1.61%	-2.32%	0.23%
Maine	-0.16%	-4.18%	-2.01%	0.39%	-4.01%	-1.85%	0.56%
Maryland	-2.45%	2.99%	1.96%	2.21%	5.45%	4.41%	4.66%
Massachusetts	0.85%	-0.21%	0.00%	0.76%	-1.06%	-0.85%	-0.09%
Michigan	5.72%	0.35%	-0.16%	2.39%	-5.37%	-5.88%	-3.32%
Minnesota	-0.18%	0.88%	0.86%	2.61%	1.06%	1.04%	2.79%
Mississippi	-5.85%	3.62%	0.36%	4.85%	9.46%	6.20%	10.69%
Missouri	-0.70%	2.48%	0.85%	3.23%	3.18%	1.55%	3.93%
Montana	0.03%	0.80%	0.26%	0.13%	0.77%	0.22%	0.09%
Nebraska	1.93%	4.02%	0.72%	3.53%	2.09%	-1.20%	1.61%
Nevada	0.04%	3.13%	2.46%	8.16%	3.09%	2.42%	8.12%
New Hampshire	1.90%	8.60%	5.00%	0.30%	6.69%	3.10%	-1.60%
New Jersey	0.91%	-1.24%	1.03%	0.88%	-2.14%	0.12%	-0.03%
New Mexico	1.00%	1.85%	0.46%	4.27%	0.85%	-0.54%	3.27%
New York	0.84%	0.00%	1.07%	0.39%	-0.84%	0.23%	-0.45%
North Carolina	1.66%	4.24%	0.90%	3.28%	2.57%	-0.77%	1.62%
North Dakota	0.87%	1.54%	0.11%	2.07%	0.67%	-0.76%	1.20%
Ohio	2.84%	1.48%	0.34%	1.89%	-1.36%	-2.51%	-0.96%
Oklahoma	-0.36%	1.62%	0.00%	2.24%	1.98%	0.37%	2.60%
Oregon	0.85%	1.36%	-0.26%	1.66%	0.51%	-1.11%	0.81%
Pennsylvania	4.52%	1.68%	0.49%	1.51%	-2.83%	-4.03%	-3.00%
Rhode Island	-0.78%	6.86%	3.06%	0.84%	7.64%	3.84%	1.63%
South Carolina	1.43%	2.56%	1.90%	3.63%	1.13%	0.47%	2.20%
South Dakota	2.34%	5.19%	1.40%	2.92%	2.85%	-0.95%	0.58%
Tennessee	-2.76%	4.78%	0.41%	2.30%	7.54%	3.16%	5.06%
Texas	4.05%	2.58%	1.17%	3.31%	-1.47%	-2.88%	-0.74%
Utah	2.24%	1.61%	0.75%	4.54%	-0.63%	-1.49%	2.29%
Vermont	2.55%	0.38%	-0.60%	2.10%	-2.17%	-3.15%	-0.45%
Virginia	2.01%	3.84%	1.96%	2.97%	1.83%	-0.05%	0.96%
Washington	1.27%	2.73%	0.70%	0.17%	1.46%	-0.57%	-1.10%
West Virginia	1.48%	1.17%	-0.13%	1.98%	-0.31%	-1.61%	0.51%
Wisconsin	3.17%	1.87%	1.53%	3.13%	-1.29%	-1.64%	-0.04%
Wyoming	3.06%	1.17%	0.59%	0.30%	-1.89%	-2.47%	-2.76%

Table 4. Perception Indicator: Weighted Average of Siting Difficulty

		Weighted Average Difficulty Ratings by Respondent Groups					
State	Total state evaluations	All Groups	Consulting Company	Gov't. Regulatory Agency	Investor-Owned Utility	Public Electric Utility	Other
Alabama	21	5.71	6.81	3.63	7.20	5.64	4.50
Arizona	18	6.21	8.67	8.00	6.00	5.67	3.80
Arkansas	21	5.81	6.64	5.00	6.60	5.20	5.00
California	25	7.73	9.27	8.17	6.00	7.65	5.63
Colorado	20	7.30	8.40	8.00	8.00	5.45	6.80
Connecticut	24	7.66	8.33	8.00	7.60	6.94	8.00
DC	24	7.84	9.06	9.00	8.00	6.95	6.50
Delaware	22	6.57	6.31	8.00	8.00	6.13	5.67
Florida	22	8.08	8.84	8.00	8.50	7.48	7.63
Georgia	22	6.63	7.61	4.00	7.20	6.91	4.56
Idaho	20	6.17	8.00	7.00	6.00	5.25	4.75
Illinois	26	6.38	6.86	5.00	8.00	5.68	5.56
Indiana	20	6.89	7.67	5.00	7.33	7.08	4.67
Iowa	25	6.31	7.23	5.43	7.83	5.71	5.80
Kansas	21	6.21	7.79	5.40	6.60	4.80	5.00
Kentucky	23	6.26	6.63	5.50	7.20	5.93	6.14
Louisiana	21	6.18	8.00	7.00	7.20	4.69	5.83
Maine	25	6.50	7.20	7.00	7.00	6.00	5.67
Maryland	25	7.77	8.13	9.00	8.00	7.63	6.29
Massachusetts	23	7.37	8.88	7.60	8.00	6.39	6.22
Michigan	21	6.46	6.40	4.00	7.67	6.73	6.30
Minnesota	27	7.25	8.29	7.10	7.88	6.70	6.20
Mississippi	21	6.02	8.00	8.00	7.20	4.39	6.00
Missouri	24	6.20	8.08	5.80	7.64	4.73	5.40
Montana	23	6.35	8.00	5.86	7.50	5.38	6.60
Nebraska	19	6.00	7.13	3.00	7.17	4.75	6.20
Nevada	21	5.91	7.91	5.33	6.00	5.27	5.60
New Hampshire	23	7.05	7.50	7.20	7.25	6.94	6.00
New Jersey	26	7.43	7.78	8.75	7.67	6.62	7.30
New Mexico	22	6.82	8.33	7.38	8.00	5.67	6.00
New York	31	7.85	8.53	8.25	8.33	7.30	8.23
North Carolina	22	6.04	6.40	5.00	7.20	5.77	5.11
North Dakota	24	5.04	6.13	2.54	6.88	4.92	5.60
Ohio	24	5.69	6.04	3.00	7.50	5.29	5.17
Oklahoma	19	6.15	8.09	4.00	6.20	4.89	5.40
Oregon	19	6.83	8.00	6.50	6.00	6.80	6.00
Pennsylvania	28	6.61	7.27	8.89	7.17	5.63	6.20
Rhode Island	22	7.17	8.50	8.25	7.75	5.93	7.40
South Carolina	21	6.32	7.63	5.00	7.20	6.36	4.80
South Dakota	23	5.32	6.79	3.69	6.43	4.50	5.20
Tennessee	22	6.31	7.38	3.00	7.20	5.79	5.71
Texas	24	5.70	7.16	2.20	7.00	5.28	4.25
Utah	21	6.82	8.25	8.00	8.00	5.27	6.60
Vermont	21	7.26	7.54	8.75	7.25	6.33	7.00
Virginia	26	7.01	7.65	5.25	8.00	6.76	7.33
Washington	19	7.18	8.57	8.00	6.00	6.75	6.00
West Virginia	21	5.42	5.18	4.00	7.00	4.87	6.50
Wisconsin	29	7.57	8.39	7.44	7.88	7.26	6.11
Wyoming	23	5.84	7.64	5.80	6.67	4.53	6.40

Table 5. Principal Component Analyses Results and Factor Analysis Input Variables

Factor Analysis Input Variables	**PCA Input Variables and Component Loadings**
Economic Principal Component (65% variance explained) ←	-Baseload standard deviation (0.68) -Baseload inter-quartile range (0.66) -Peaker optimal dispatch (% savings) (0.33)
Geographic Principal Component (86% variance explained) ←	Population *unserved* within footprints -10 mile radius (-0.47) -15 mile radius (-0.51) -20 mile radius (-0.52) -25 mile radius (-0.50)
Construction Principal Component (91% variance explained) ←	Difference in Slopes -Net generation — transmission (-0.58) -Generation capacity — transmission (-0.59) -Sales — transmission (-0.56)
Perception Indicator- All survey respondents weighted average state difficulty (standardized)	*None*

Table 6. Factor Analysis: Two-Factor Solution Varimax Rotated Factor Loadings and Communalities.

Variable	Siting Difficulty (Factor 1)	Transmission Demand (Factor 2)	Communalities
Perception Indicator	0.871	-0.112	0.771
Geographic Component	0.684	0.168	0.495
Economic Component	0.639	0.384	0.556
Construction Component	0.079	0.960	0.929
Total Variance	1.640	1.111	2.751
% Variance Explained	41.0%	27.8%	68.8%

Table 7. Regression Predictors: Varimax Rotated Factor Loadings and Communalities

	Public	Environment	Regulation	
	Factor 1	Factor 2	Factor 3	Communalities
Population Density	0.56	0.56	0.20	0.67
LCV Environmentalism Score	0.48	0.61	0.27	0.68
Median Housing Value	0.87	0.07	0.26	0.83
Education (% of population)	0.82	0.05	0.30	0.76
Permitting by Voltage (kV)	0.02	0.11	0.78	0.62
Natural Resources Employment	-0.75	-0.26	0.35	0.75
Type of Siting Authority	0.16	-0.03	0.72	0.55
Number of Siting Agencies	0.14	0.02	0.66	0.46
Land Cover Score	0.03	0.84	-0.04	0.70
% State Forest Land	0.42	0.57	0.25	0.57
Elevation Standard Deviation	0.10	-0.78	0.25	0.68
% Farm Lands	0.31	0.59	0.15	0.46
Variance Explained	24%	23%	18%	65%

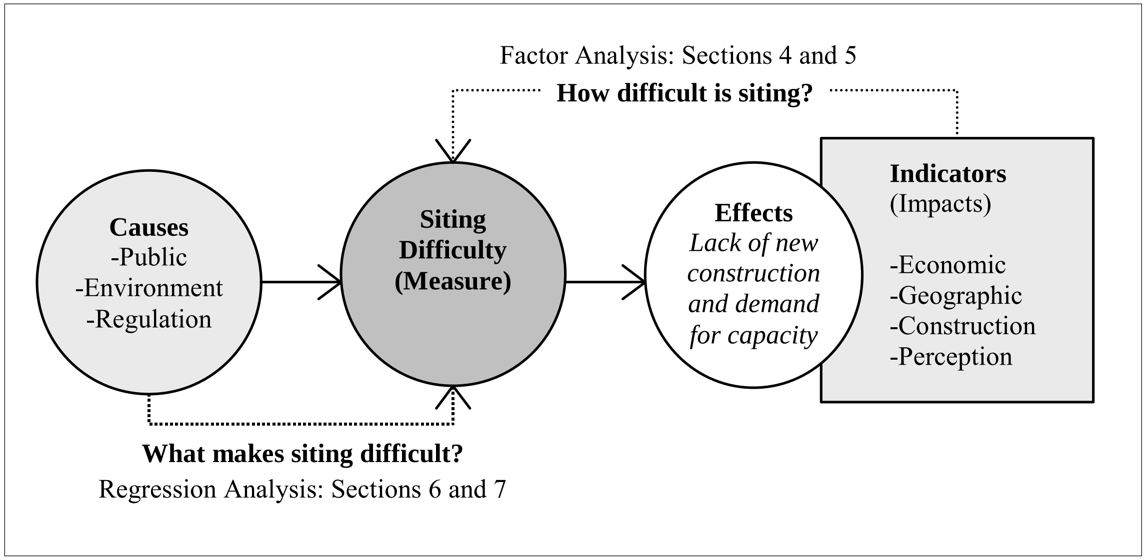

Figure 1. Diagram of causes, effects, and indicators of siting difficulty

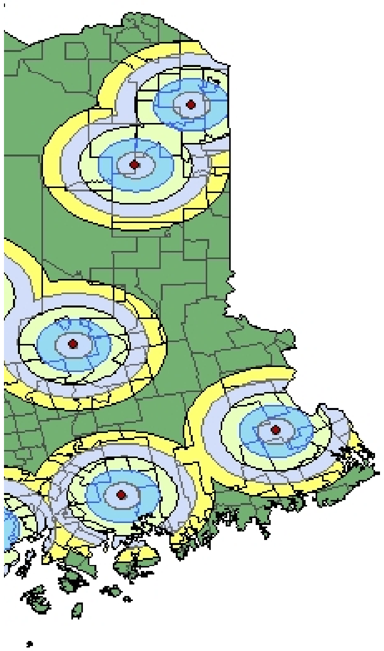

Figure 2. Illustration of GIS footprint model for generating plants in Maine

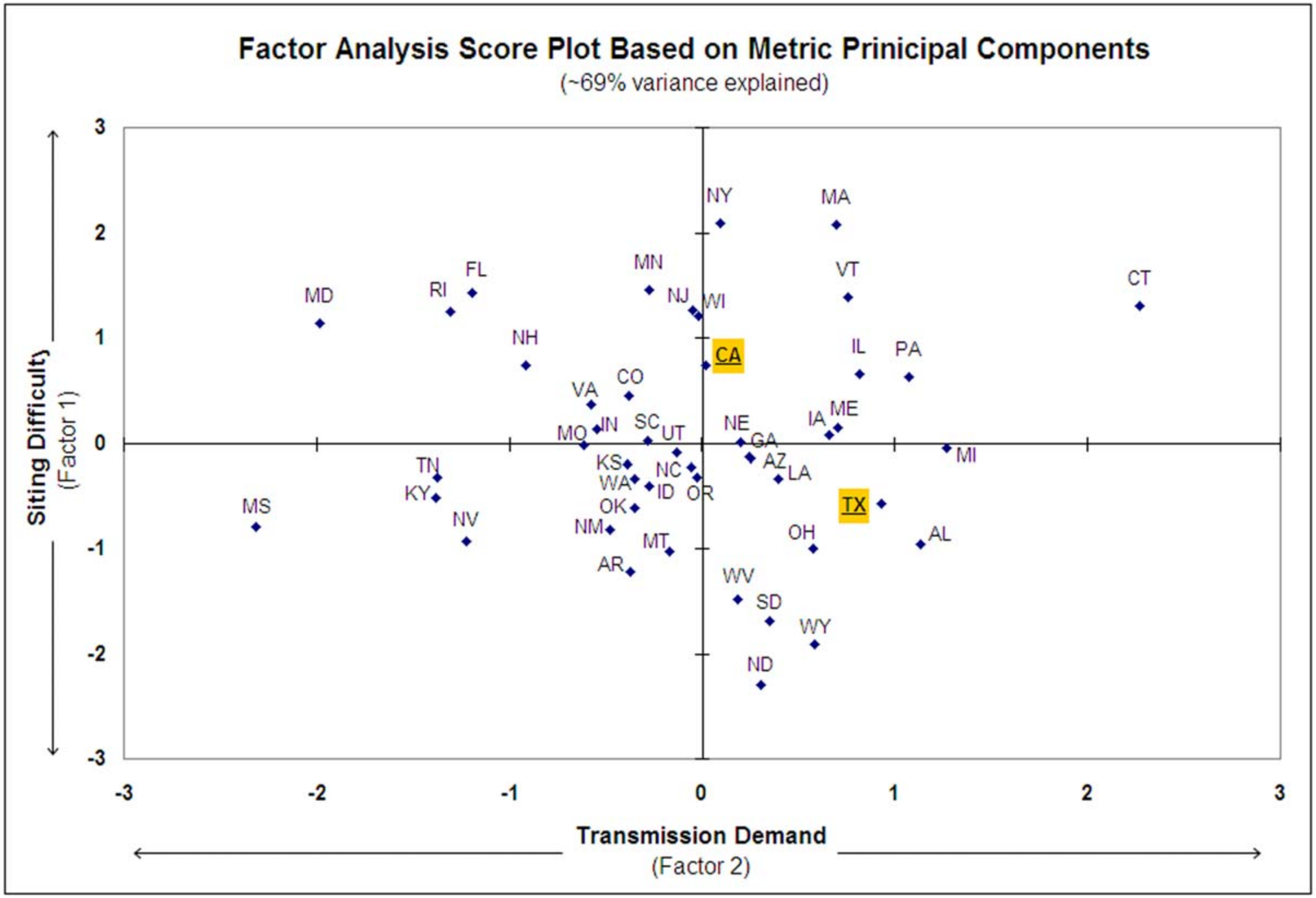

Figure 3. Factor plot of state transmission demand and siting difficulty scores

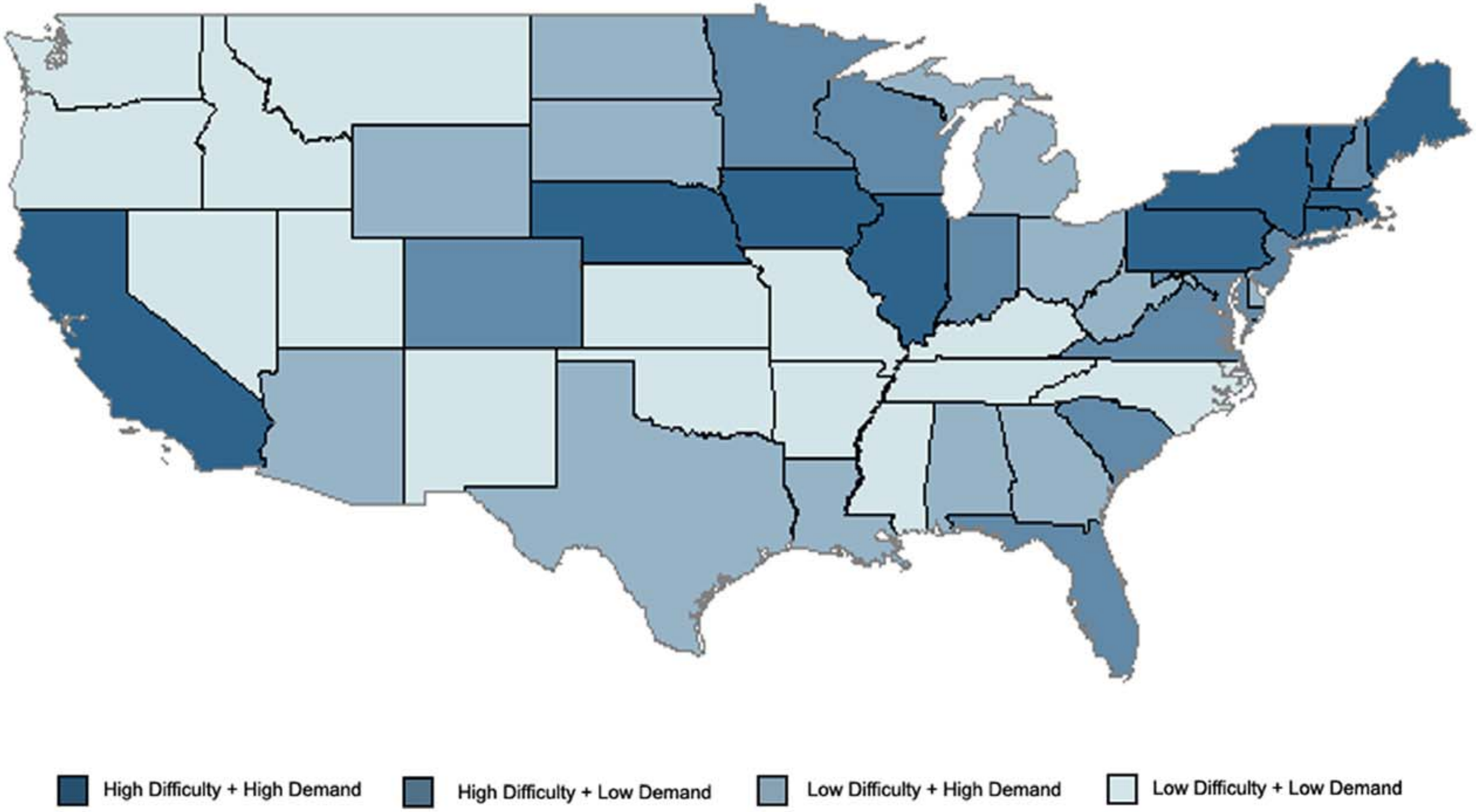

Figure 4. National map of state siting difficulty and transmission demand

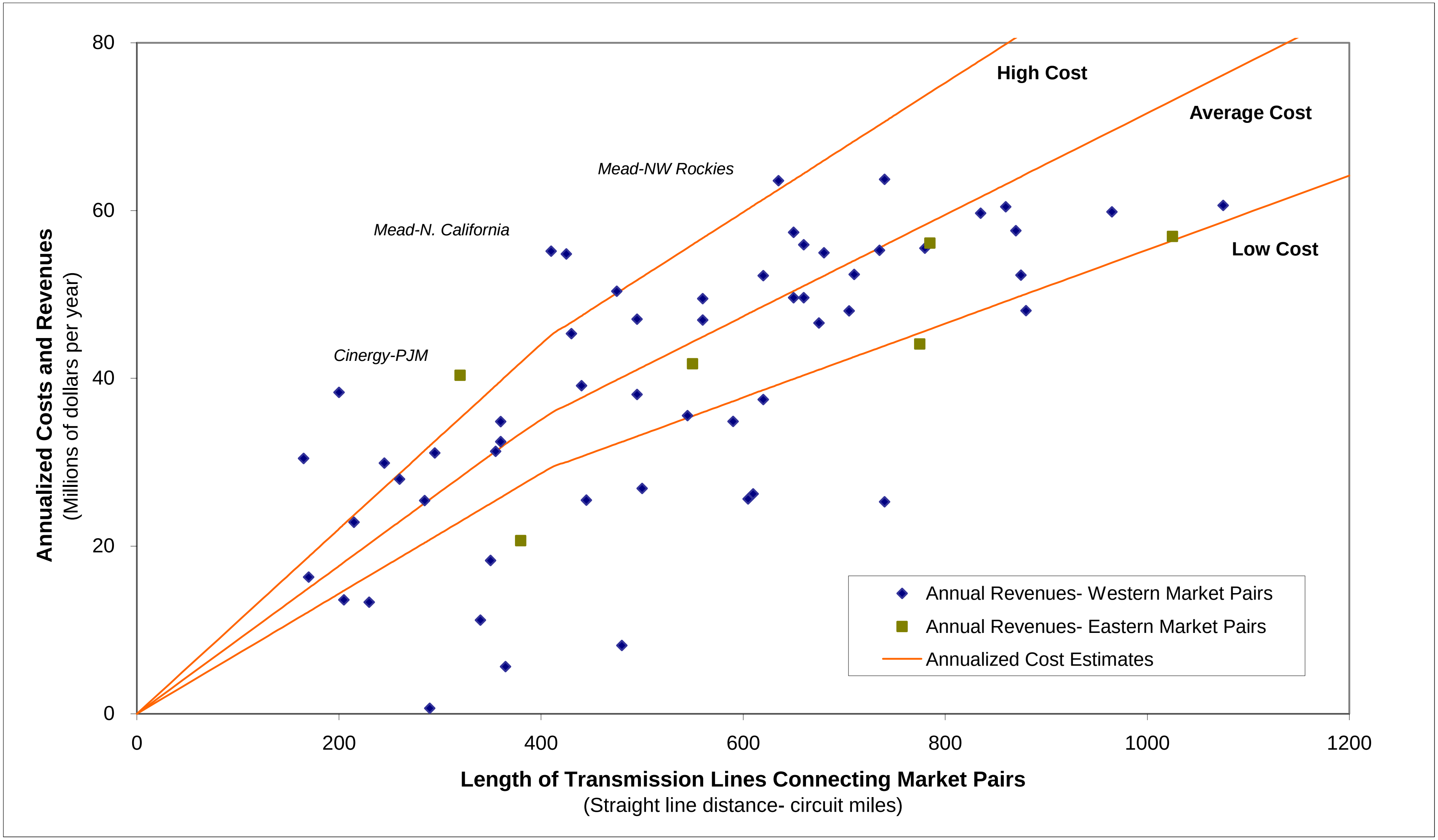

Figure 5. Estimated revenues and costs for hypothetical transmission lines connecting market pairs

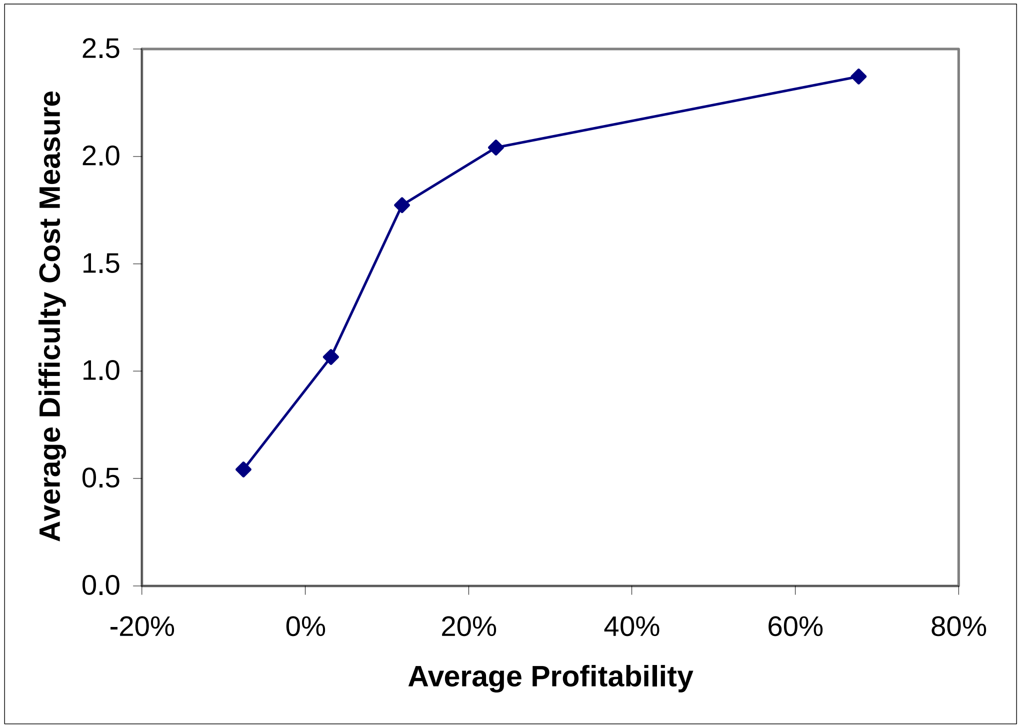

Figure 6. Relationship between estimated profitability and total siting difficulty of transmission lines connecting market pairs

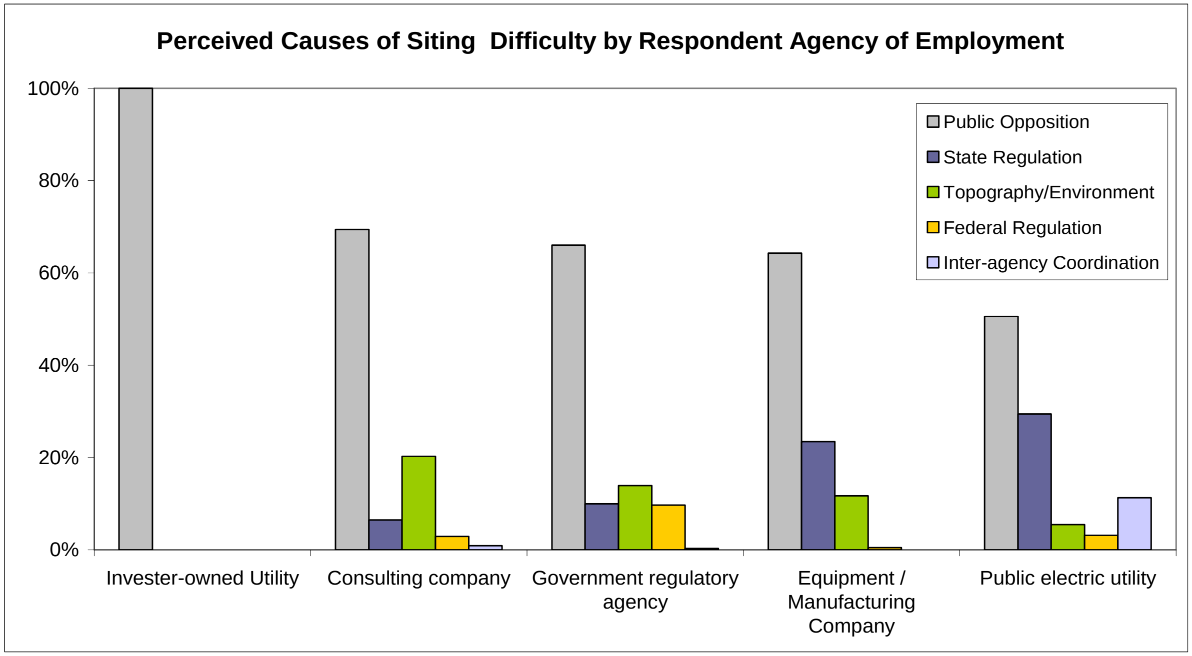

Figure 7. Perceptions of dominant siting constraint by respondents’ employment

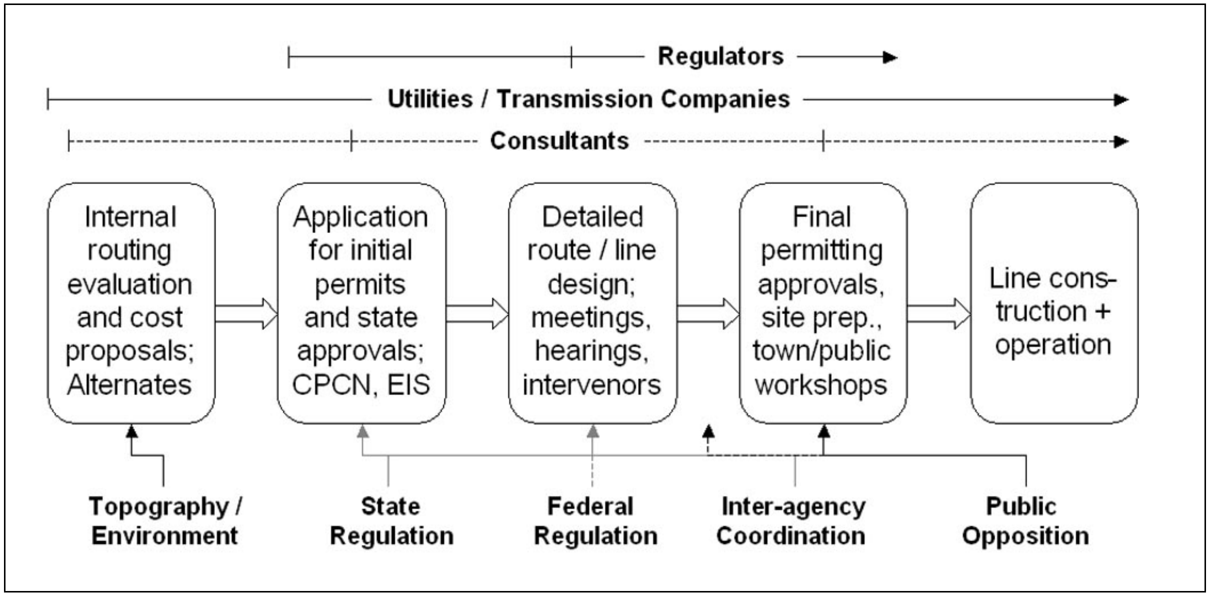

Figure 8. Diagram of transmission line siting process with timing of stakeholder involvement and causes of siting difficulty