Center on Global Energy Policy at COLUMBIA | SIPA

A Quantitative Analysis of Variables Affecting Power Transmission Infrastructure Projects in the US

By **Lewis (Zhaoyu) Wu, Abraham Silverman, Dr. Harrison Fell,** and **Dr. James Glynn**

March 2024

REPORT

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About the Authors

Lewis (Zhaoyu) Wu is a Research Associate at the Center on Global Energy Policy at Columbia University's School of International and Public Affairs. His research centers on energy systems modeling with a particular focus on data science, data curation, data pipeline construction, data validation, and energy systems model calibration, operation, and analysis. Lewis also supports research activities related to energy transition, Net Zero agenda, international trade of critical minerals and energy commodities, and energy policies.

Lewis holds a Master of Science in Data Science from Columbia University Fu Foundation School of Engineering and Applied Science and a Bachelor of Science in Data Science and Computational Physics from the University of California Irvine School of Physical Science.

Abraham Silverman joined the Center as the Director of the Non-Technical Barriers to the Clean Energy Transition initiative. The Non-Technical Barriers initiative is designed to identify major legal and regulatory bottlenecks to the clean energy transition and then provide state and federal policy makers pragmatic solutions to address those challenges. Major focus areas include Legal and Regulatory Barriers at the state and federal level, Market Rules and Economic Incentives, and Social Acceptance & Just Deployment of Infrastructure.

Before joining the Center, Abe served at the New Jersey Board of Public Utilities as the General Counsel and Executive Policy Counsel. Abe's portfolio included developing offshore wind, solar, electric vehicle, energy storage, and interconnection reform programs, along with quantifying and managing ratepayer impacts of the clean energy transition. Abe also led the State's engagement with PJM Interconnection, the regional grid operator for New Jersey, on topics such as implementing New Jersey's first-in-the-nation offshore wind transmission solicitation, resource adequacy, clean energy market design, and transmission policy.

Previously, Abe spent more than a decade at NRG Energy, Inc., as the Deputy General Counsel & Vice President of Regulatory Affairs. Abe supported NRG's power markets team, power plant operations group, renewable development and state retail electricity market programs. Abe also led the company's advocacy at the Federal Energy Regulatory Commission, as well as anti-trust compliance work at the Department of Justice/Federal Trade Commission. Abe has also worked as an associate at Perkins Coie LLP and as a staff attorney at FERC. Abe has a Bachelor's Degree from the University of Maryland and a JD from the George Washington University Law School.

Abe has testified before the United States Senate's Energy & Commerce Committee, the Federal Energy Regulatory Commission, the New Jersey Senate, and is the author of numerous pleadings at the state and federal level, including before the U.S. Supreme Court and various U.S. Courts of Appeals.

Dr. Harrison Fell is a former Senior Research Scholar at the Center on Global Energy Policy at Columbia University SIPA, where he co-leads the Power Sector and Renewables Research Initiative. Dr. Fell specializing in the fields of environmental, energy, and natural resource economics. His recent work focuses on issues related to renewable energy deployment and integration, policy design and assessment of emissions regulations, and electricity market regulations.

Prior to joining CGEP, Dr. Fell was an associate professor (with tenure) at North Carolina State University, an assistant professor at the Colorado School of Mines, and fellow at the DC-based think tank Resources for the Future. Dr. Fell's research has been published in over 25 peer-reviewed journals, including publications in the leading environmental economics field journals and top general interest economics journals. Dr. Fell currently serves on the editorial councils at two of the top environmental economics journals, the *Journal of Environmental Economics and Management* and the *Journal of the Association of Environmental and Resource Economists*. He holds a Ph.D. and M.S. in economics from the University of Washington and B.S. degrees in economics and engineering from the Colorado School of Mines.

Dr. James Glynn is a Senior Research Scholar at the Center on Global Energy Policy. He leads the Energy Systems Modelling Program. He has over 15 years of experience within energy systems analysis, energy technology research, development, and deployment, collaborating with governments, technologists, utilities, suppliers, and energy analysts in the United States, Europe, and Asia. His published work spans the whole integrated energy system, including energy, economy & climate. Dr. Glynn is internationally recognized for his energy systems modeling innovations across hybrid modeling methods, uncertainty methods, and energy security assessments. James currently serves on the Integrated Assessment Modelling Consortium (IAMC) scientific working group (SWG) in climate-related Financial Analysis.

Dr. Glynn's research interests focus on developing and applying integrated techno-economic energy systems models and their interactions with the climate, economy, and society to find resilient pathways to future sustainable development goals. He is an expert developer and user of the International Energy Agency's Energy Technology Systems Analysis Programmes' (IEA-ETSAP) TIMES framework. He has led and actively contributes to the global ETSAP-TIAM developer's group exploring novel developments in TIMES energy systems modeling. His national and global model applications have provided insights into Irish, European, and International energy policy, legislation, and investment decisions in collaboration with a broad range of stakeholders.

He is an EU-commission invited expert in energy systems modeling and a reviewer of the EU

Commission's DG-ENER new energy systems model METIS. He has given expert witness testimony to government committees on carbon capture and storage (CCS), carbon budgets, and net-zero carbon energy systems transition. He has served on the scientific advisory boards for multiple national and European research projects, such as the German DLR BEAM-ME project on high-performance optimization algorithms. He collaborates on numerous international energy-climate networks, including the Integrated Assessment Modelling Consortium (IAMC) and JPI-Climate. He is an affiliate invited member of the IEA-ETSAP executive committee. He has successfully led multiple national and international research & consulting project consortia.

Dr. Glynn's recent publications include: (1) the highest resolution assessment of global rooftop solar energy potential; (2) improving the technical realism of the power sector in integrated assessment models; (3) the impact of future climate on the technical operation of the energy system; (4) the role of direct air carbon capture and storage in global mitigation scenarios; (5) the impact of local air pollution on equitable global decarbonization; and (6) the development of the first zero-carbon energy system pathways for Ireland consistent with the Paris Agreement.

He holds two masters degrees (NUIG, Strathclyde) and a PhD (UCC) in areas related to energy systems analysis across engineering, science, and economics. He has affiliations with the Science Foundation Ireland MaREI Centre in University College Cork (UCC) and the engineering faculty in Imperial College London.

Executive Summary

Upgrading the US electric grid is vital to a successful energy transition. Transmission expansion lowers electricity costs for consumers; speeds deployment of new generation resources; provides economic opportunities for communities; increases system reliability, particularly in the face of extreme weather events; and enables large-scale transfers of power from areas of the country with high renewable energy potential to customers. But experience over the past twenty years has shown that new transmission projects often face extensive delays, impeding or even denying these potential benefits to consumers and communities. In response, policymakers at the state and federal level are considering reforms to transmission finance, cost allocation, siting and permitting, advanced technologies, and other areas to help jumpstart the United States' currently moribund transmission expansion processes.

As part of this process, policymakers and other stakeholders are debating the merits of various transmission planning policies in terms of project success, but the impact of specific variables can be hard to quantify. This can lead stakeholders to rely largely on anecdotal or qualitative arguments to support their positions. The wide variation in the way utilities are regulated and transmission planning processes are implemented across the United States further compounds the difficulty of evaluating the relative effectiveness of different transmission planning policies.

This report, a joint project of the Non-Technical Barriers to the Clean Energy Transition Initiative and the Energy Systems Modeling and Analytic Platform at the Center on Global Energy Policy, Columbia University SIPA, applies a data-driven approach to this policy debate. Using statistical analysis and machine learning models to analyze a dataset from the data company MAPSearch of planned transmission projects of at least 100 kilovolts (kV) conceived between 2005 and 2023, which includes more than 1,300 transmission projects, the report provides a systematic assessment of the impact of key variables on the likelihood that a proposed transmission line will actually be built. The results of this assessment can help those interested in expanding transmission infrastructure understand which variables may be worth prioritizing in a particular geographical area or region, given its unique combination of attributes, needs, and challenges.

The report finds that the most impactful variables to transmission project success include the following:

- **Regional and state support.** Markedly more transmission is being built in parts of the country with strong regional transmission planning programs and state support for transmission, including New York and Texas. Areas characterized predominantly by vertically integrated utilities (i.e., utilities that own generation, transmission, and distribution assets within a given franchise territory on a monopoly basis), particularly in the Southeast and Northwest, have seen substantially less transmission expansion, with the exception of the Southwest, where significant new transmission is in the planning stage.

- **Interstate vs. intrastate.** Transmission projects that cross state boundaries are approximately 7% less likely to reach completion than intrastate projects, though merchant developers are slightly more successful at developing interstate projects than regulated utilities.
- **Project goal.** Transmission projects designed to increase economic efficiency (i.e., where consumer savings exceed the costs of the transmission, on an annualized basis) are largely missing in the Southeast and the Mid-Atlantic region's PJM Interconnection (PJM) market, one consequence of which is that customers in these regions are not enjoying the full scope of potential transmission benefits. This is potentially due to a less mature transmission planning process and less favorable regulatory climate.
- **Choice of utility business model.** Merchant transmission developers are approximately 14% more successful at developing high-voltage direct current (HVDC) projects than traditional regulated public utilities. Vertically integrated utilities, on the other hand, are approximately 10% more likely to succeed at developing reliability projects (i.e., those upgrades needed to address grid reliability violations) than merchant transmission developers and 5% more likely to succeed at developing multi-value driver projects (i.e., those involving more than one purpose).

Introduction

A reliable energy transmission network is vital to the ability of the United States to withstand the impacts of climate change and accomplish the Biden administration's goal of having a national grid run on 100% clean electricity by 2035 (White House 2021). The Biden administration's Infrastructure Investment and Jobs Act of 2021 dedicated $13 billion to expanding and modernizing the US electric grid (IIJA 2021; DOE 2022). In 2022, Congress passed the Inflation Reduction Act (IRA), which includes several provisions aimed at incentivizing the development of electricity transmission infrastructure in the United States. Section 50151 of the IRA allocates $2 billion for the development of eligible power transmission projects located in regions identified by the Department of Energy as priority areas for transmission development, known as National Interest Electric Transmission Corridors (NIETCs). Section 50152 includes $760 million for grants aimed at facilitating the siting of transmission lines (IRA 2022). Together, these two laws mark the largest investment in US power infrastructure in history. Spending these newly allocated funds will require an unprecedented expansion in transmission planning and construction efforts. This study aims to assist policymakers in guiding those efforts by analyzing key factors that affect whether they will succeed.

Numerous studies have examined the viability of constructing and overhauling local and national power transmission systems in the US to accommodate the expansion of renewables and achieve climate goals (Jayadev et al. 2020; Brown & Botterud 2020; Cole et al. 2021; Ghaddar & Jabr 2019). Most of these rely on mathematical models and algorithms, such as semidefinite relaxation of the AC optimal power flow problem with a custom branch-and-bound algorithm and mixed-integer linear programming models with big-M formulation, a hull formulation, and an alternative big-M formulation (Li et al. 2022), to investigate technical feasibility and optimized configurations of various technologies. This literature broadly agrees that a wide variety of non-technical factors can influence the outcome of proposed projects, but tends to exclude those barriers from the analysis.

Literature focused primarily on non-technical challenges facing the development of the US power transmission system, by contrast, tends to rely largely on qualitative analysis. Studies in this group have examined, for instance, the social, planning, permitting, and administrative issues that slow transmission expansion (Schito et al. 2019; Komendantova & Battaglini 2016). Other studies focused on high-capacity long-distance power grids likewise acknowledge potential regulatory, legal, geopolitical, and economic obstacles to promoting power transmission infrastructure development, and the need for appropriate government intervention (Sun et al. 2021; Vakulchuk et al. 2020; Schulte & Fletcher 2020). Additionally, several researchers have applied quantitative methodologies to study transmission delays and cost overruns using meta-analyses of other studies (Pall 2016) or survey data (Pall 2019).

The present analysis bridges this divide by leveraging various statistical methods and machine learning (ML) classification algorithms to better understand barriers that hitherto have been subjected only to qualitative analysis. Quantitative analysis is able to cut through preconceptions about underlying transmission policies and sociopolitical considerations to reveal which factors are actually correlated with successful transmission expansion efforts.

The classification models for this assessment incorporate a collection of parameters including project cost; project transmission capacity; underlying technology (e.g., direct current versus alternating current); project voltage level; whether the project is interstate or crosses regional boundaries; whether an independent system operator or regional transmission organization (ISO) covers the project; whether the project is primarily designed to enhance grid reliability, connect new renewable generation, decrease the delivered cost of electricity, or be a "multi-driver project," which satisfies multiple needs; and whether the primary project sponsor is a traditional public utility or a merchant developer. The derived models were analyzed to identify the most influential variables and isolate the quantitative influence of each variable on the status classification outcome.

Exploratory Data Analysis

The research for this report analyzed US power transmission infrastructure projects across a range of design variables common to all transmission lines to understand which elements were correlated with higher or lower levels of success.

The analysis included all variables that were included in the transmission database. Inputting as many variables as possible allows the ML framework to identify positive and negative correlations that may evade detection when using more traditional regulatory analysis methods. On the technical side, the inputted variables included project size, voltage, number of circuits, length, and underlying technology type; on the non-technical side, they included whether the transmission line crossed state boundaries, the purpose of the project (i.e., whether it was designed to meet reliability standards, interconnect new generation, improve system economics, or a combination thereof), and whether the transmission line was planned in an organized market or as part of an integrated utility. The resulting correlations may prove useful to policymakers interested in spurring the development of additional transmission lines, including through legislative and regulatory efforts in the US Congress (Senate 2023a) and the Federal Energy Regulatory Commission (FERC 2022).

The dataset for this analysis includes US power transmission infrastructure projects with planned or actual in-service dates from 2005 to 2034 from the commercial data provider MAPSearch.[1] The data fields include estimated project cost (million dollars), transmission line length (miles), project origin state, project destination state, voltage (kilovolts [kV]), voltage type, project type, and project objective (Table 1).

[1] The authors wish to thank MAPSearch (https://www.mapsearch.com/) for generously providing the dataset on which this report relies.

Table 1: Description of key data items

<table>
<tr><th>Data field</th><th colspan="2">Description</th></tr>
<tr><td>Line miles</td><td colspan="2">Distance from origin point to end point measured in miles.</td></tr>
<tr><td>Voltage (kV)</td><td colspan="2">The electrical potential/current value of the line measured in kV.</td></tr>
<tr><td>Voltage type</td><td colspan="2">Description of the current and components of the transmission line, such as single, double, AC/DC, underground, HVDC, and underwater.</td></tr>
<tr><td rowspan="5">Project objective (projects can have one or more objectives)</td><td rowspan="2">Interconnection: The purpose is to connect a specific power plant to the grid.</td><td>Renewable: The purpose is to provide transmission capacity for renewable generation.</td></tr>
<tr><td>Fossil generation: The purpose is to provide transmission capacity for fossil fuel generation.</td></tr>
<tr><td colspan="2">Reliability: The purpose is to alleviate an existing or projected reliability need.</td></tr>
<tr><td colspan="2">Economic: Associated with merchant developers leasing out transmission capacity to utilities.</td></tr>
<tr><td colspan="2">Multi-value: Involves economic, reliability, and renewable/generation purposes.</td></tr>
<tr><td rowspan="2">Utility business model</td><td colspan="2">Regulated project.</td></tr>
<tr><td colspan="2">Merchant project.</td></tr>
<tr><td>From state</td><td colspan="2">State where the project starts.</td></tr>
<tr><td>To state</td><td colspan="2">State where the project ends.</td></tr>
<tr><td>ISO name</td><td colspan="2">Project's identified ISO region.</td></tr>
<tr><td>Project cost ($ million)</td><td colspan="2">Total cost of transmission project in millions of dollars.</td></tr>
</table>

Only transmission projects with both a starting point and an ending point located in the US Lower 48 were considered in this study (1,333 total). All dollar values were adjusted to 2023 values using the Producer Price Index from the US Bureau of Labor Statistics. The project unit cost, measured in millions of dollars per kV-mile, was calculated by dividing the inflation-adjusted project cost by the product of power line length and voltage. The capacity indicator, measured in kV-mile, was calculated by multiplying the power line length by the voltage. Unit costs for multi-circuit projects were modeled as the number of circuits multiplied by the number of miles divided by cost.

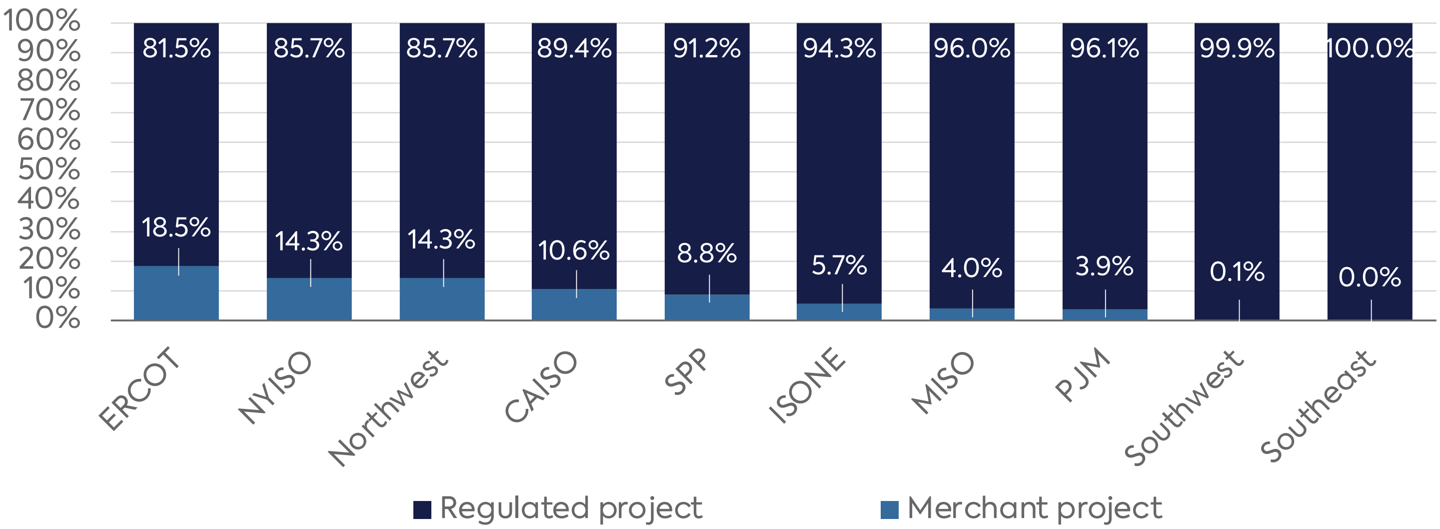
Among the 1,333 transmission projects included in the dataset, around 10% are terminated or on hold (Table 2), with the rest proposed, under construction, or active. The median estimated cost for projects with "terminated/held" status (see Table 2) is $128 million, while the median price for non-terminated projects is about a quarter of that amount, at $33.3 million. The average cost for double circuit projects is 2.28 times higher than that of single circuit projects. The median line miles for projects with "terminated/held" status is 35 miles, which is 21 miles longer than the median line length for non-terminated projects.

Table 2: Basic data item statistics

Item description	Item detail	
Total transmission projects collected with complete data	1,333	
Transmission project status	Active: 626 (46.8%) Proposed: 490 (36.8%)	Terminated/held: 128 (9.6%) Under construction: 91 (6.8%)
Whether the transmission project is interstate	Interstate projects: 112 (8.4%) Non-interstate projects: 1,221 (91.6%)	
Whether the transmission project is underground or underwater	Underground or underwater: 108 (8.1%) Surface: 1,225 (91.9%)	
Whether at least one end of the project is in an ISO region	In an ISO region:1,068 (79.7%) Not in an ISO region: 273 (20.3%)	
Project type	Regulated: 1,232 (92%)	Merchant: 109 (8%)
Project objective	Reliability project: 1,176 (88.2%)	
Statistic summary on length for all transmission projects regardless of project status	Minimum: 0.1 miles 1st quantile: 7 miles Median: 15 miles	3rd quantile: 34 miles Maximum: 3,045 miles Average: 44.1 miles
Statistic summary on estimated cost for all transmission projects regardless of project status (cost expressed in 2023 dollar value)	Minimum: $0.3 million 1st quantile: $16.9 million Median: $37 million	3rd quantile: $96.7 million Maximum: $12,390 million Average: $201.7 million
Statistic summary on unit cost (thousand dollars per kV-miles; cost expressed in 2023 dollar value) regardless of project status	Minimum: $0.008 K/kV-miles 1st quantile: $9 K/kV-miles Median: $15.5 K/kV-miles	3rd quantile: $32.2 K/kV-miles Maximum: $1,711 K/kV-miles Average: $35.4 K/kV-miles

Among all ISOs, PJM Interconnection (PJM) has the highest number of projects, followed by Midcontinent Independent System Operator (MISO) and Electric Reliability Council of Texas (ERCOT). ERCOT has the highest percentage of merchant-type transmission projects, reflecting its substantial investments in transmission as part of its Competitive Renewable Energy Zone (CREZ) process.[2] New York Independent System Operator (NYISO) has the second-highest ratio of merchant to regulated projects, followed by California Independent System Operator (CAISO) and Southwest Power Pool (SPP). Meanwhile, ISO-New England (ISO-NE), MISO, and PJM have the lowest percentage of merchant transmission[3] development among the organized market areas, and the vertically integrated (i.e., utilities that own generation, transmission, and distribution assets within a given franchise territory on a monopoly basis) non-market areas in the Southeast and Southwest have effectively no merchant transmission (Figure 1). The Northwestern portion of the US, which is also largely composed of vertically integrated utilities, shows significant merchant investment, however, suggesting that there is nothing inherently inconsistent between vertically integrated utility service territories and aggressive merchant transmission development.

Figure 1: Breakdown of total transmission project type by region (regardless of project status), including market and non-market areas



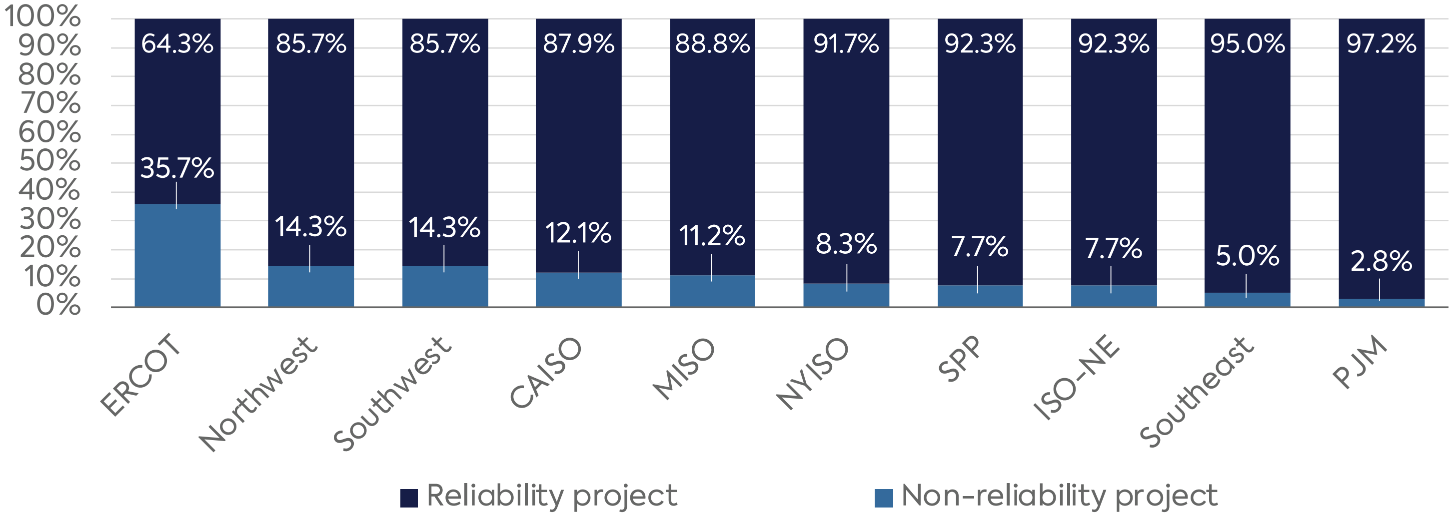
Source: Authors' analysis based on MAPSearch data.

[2] In 2006, the Public Utility Commission of Texas (PUCT) established the CREZ process to build out the ERCOT transmission system to connect wind-rich areas, primarily in West Texas, to load centers. Enabling the new generation to be delivered to load resulted in substantial savings to ERCOT customers (ERCOT 2014).

[3] FERC defines merchant transmission as those "facilities developed by independent entities for which the developer assumes all risks associated with the project and, in return, the developer can charge negotiated rates for transmission service, though the developer cannot pass its risk onto captive customers." Anbaric Development Partners v. PJM Interconnection, 171 FERC ¶ 61,241 at P. 2 (2020), citing TransEnergie U.S., Ltd., 91 FERC ¶ 61,230 (2000).

PJM has the highest percentage of reliability projects aimed at enhancing existing transmission lines, while ERCOT has the highest percentage of non-reliability projects. The remaining regions fall between these two (Figure 2).

Figure 2: Breakdown of total transmission projects by objective (regardless of project status) in different ISOs and non-market areas



Source: Authors' analysis based on MAPSearch data.

PJM has 163 transmission projects planned for construction or currently under construction, the most among the market areas, followed by MISO with 130. Among these 163 planned projects, approximately 96% are for reliability purposes while the remaining 4% are for non-reliability purposes. The number of non-reliability projects drops to approximately 3% when all projects are considered, as shown in Figure 2. This shows that development in PJM is tilted significantly toward reliability projects, especially when compared with any of the other market or non-market areas. The ratio of reliability to non-reliability projects for non-market regions is mixed, with the Southwest and Northwest having robust non-reliability-based transmission development and the Southeast having virtually none. Because non-reliability projects are typically designed to improve system economics (i.e., save consumers money) or meet state public policy needs, the relatively low number of such projects in PJM may suggest that consumers in that market are paying more than necessary. Notably, the market regions with a higher percentage of non-reliability projects all have robust regulatory support for public policy transmission projects. The relative lack of non-reliability projects in the PJM region may help provide further impetus to PJM's ongoing efforts to reform its public policy transmission planning process.[4]

[4] PJM is currently in the midst of a long-term regional transmission planning (LTRTP) stakeholder process that is intended to reform its transmission planning process. https://www.pjm.com/committees-and-groups/workshops/ltrtp.

Figures 3a–3d show transmission data for each of the FERC Order No. 1000 planning regions, normalized for the hourly peak load of each region. Normalizing by hourly peak load allows one to see the number of transmission additions within each region relative to the amount of load served by that region. Active projects (i.e., those that are already in service) are plotted against the total number of both kilowatt-miles and projects to show how successful each region has been historically at building transmission. In order to examine the likely degree of success for each region going forward, the same data is plotted for projects that have been planned or are currently under construction.

Figure 3a: Number of active transmission projects by region divided by the region's peak hourly load, 2019–23

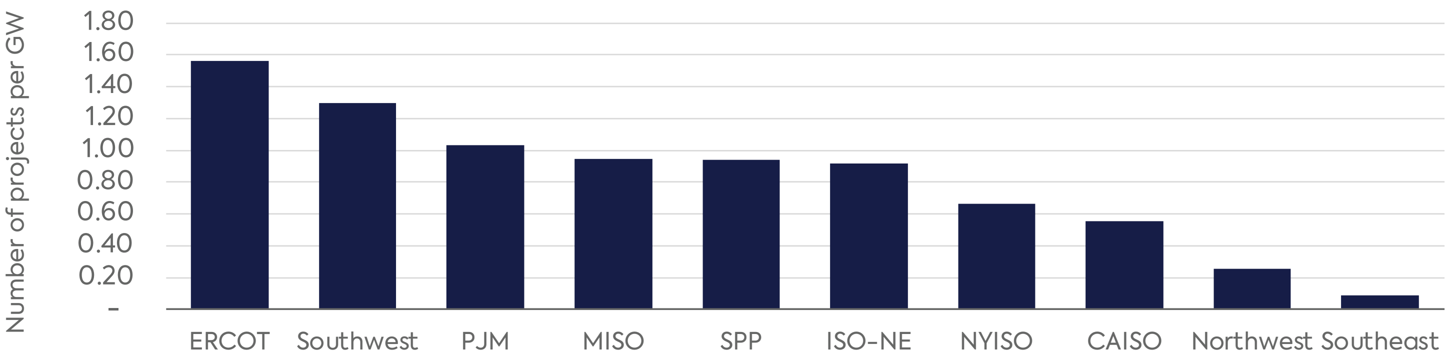


Figure 3b: Aggregated kV-miles of active transmission projects by region divided by the region's peak hourly load, 2019–23

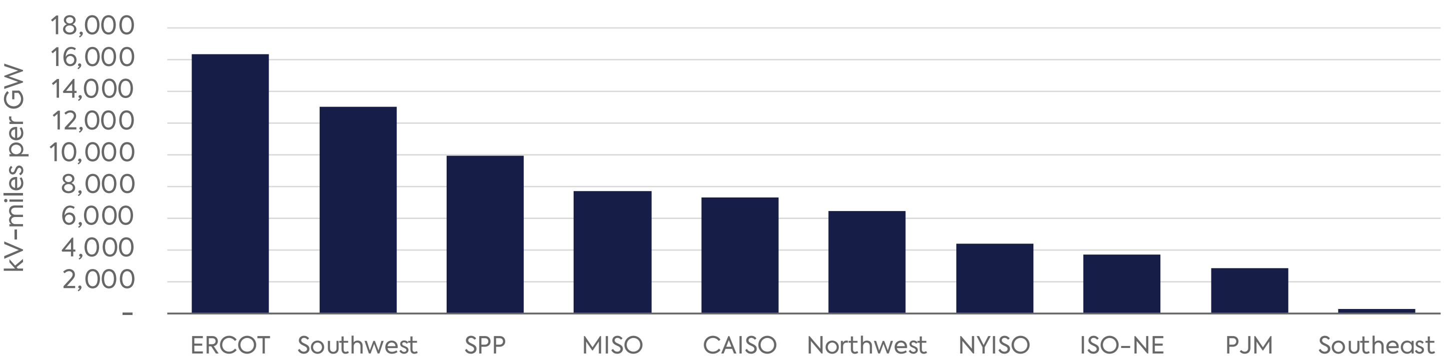


Figure 3c: Number of transmission projects that have been proposed or are under construction by region divided by the region's peak hourly load, 2019–23

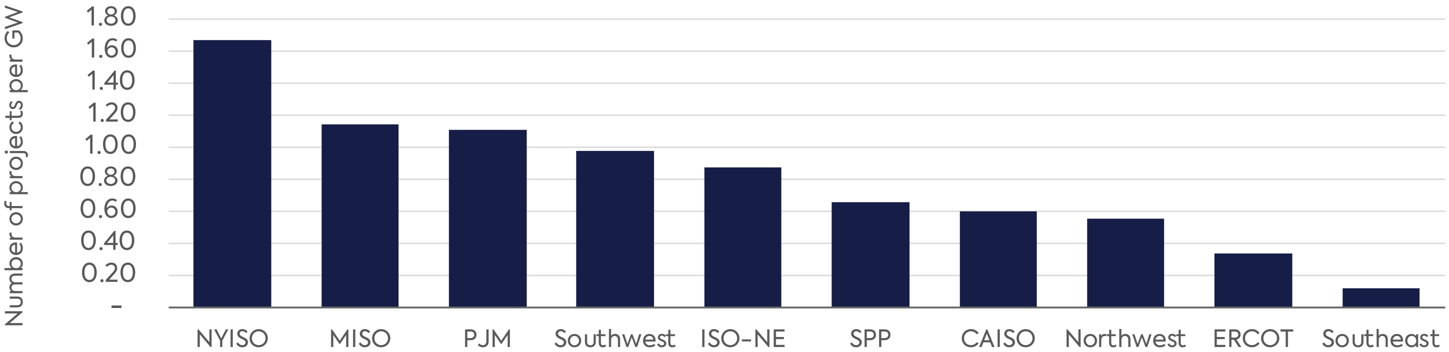
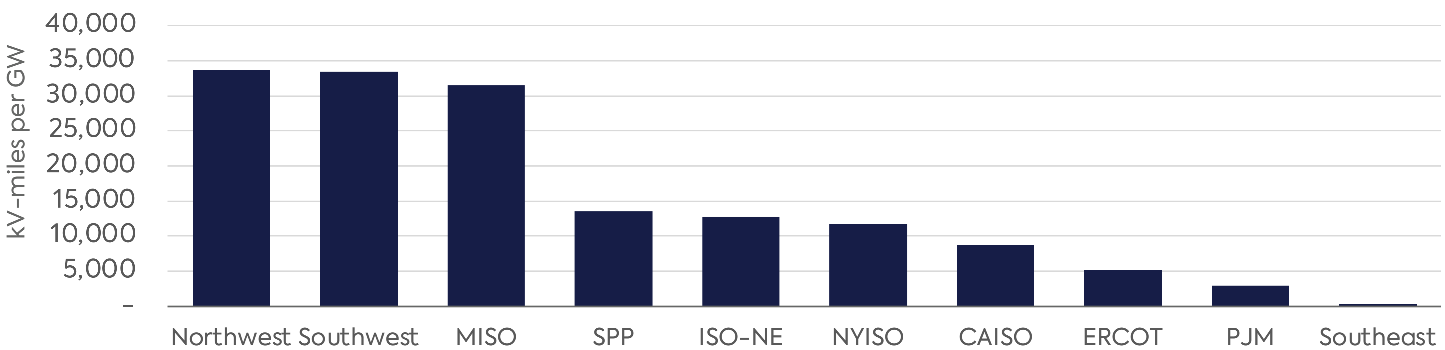


Figure 3d: Aggregated kV-miles of transmission projects that have been proposed or are under construction by region divided by the region's peak hourly load, 2019–23



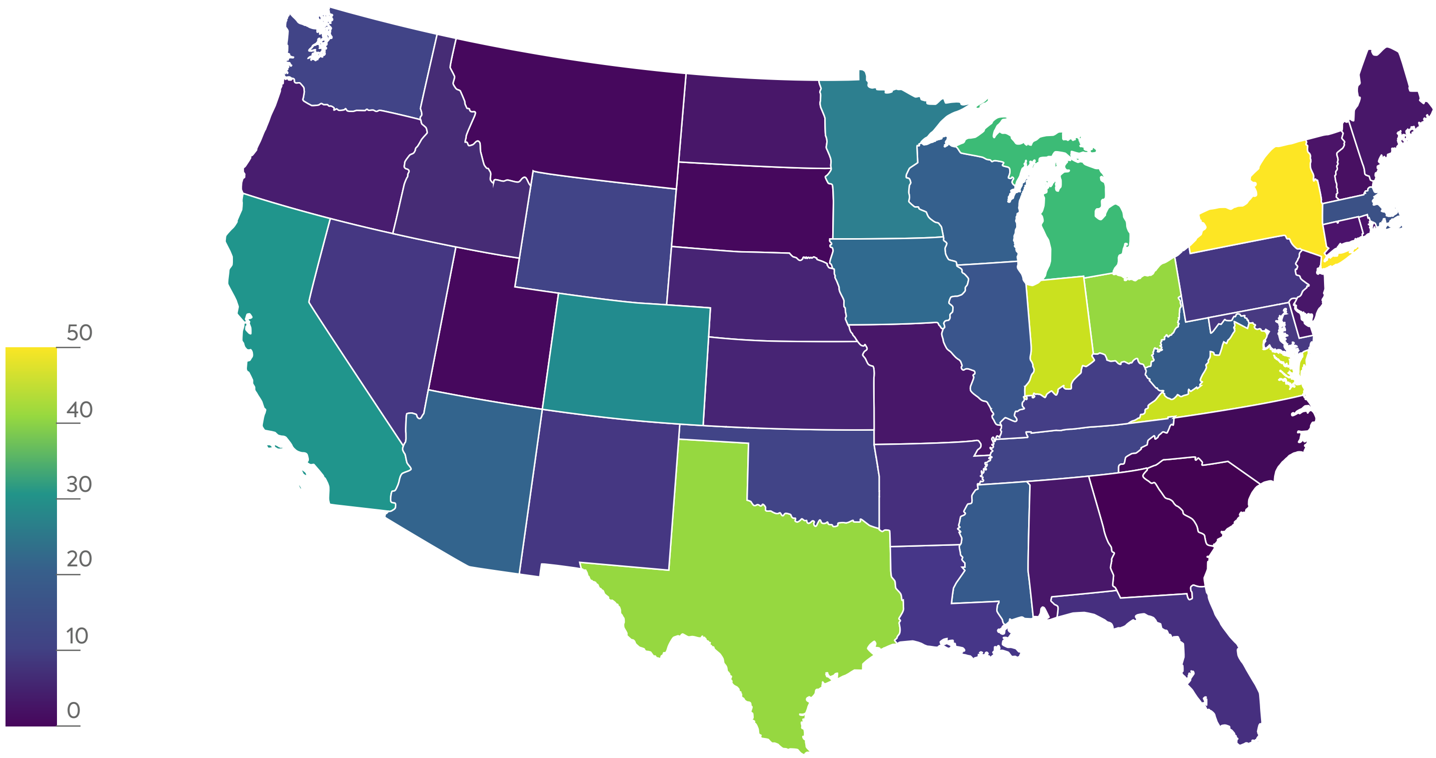
Note: Peak hourly load is measured in gigawatts (GW).
Source: Authors' analysis based on MAPSearch data and Energy Information Agency Hourly Grid Monitor.

This analysis demonstrates that, relative to its size, ERCOT has built and placed into service the most new transmission of any market. Among the total number of projects in ERCOT, 78% are currently in service, making ERCOT the ISO with the highest percentage of active projects. Most of these active projects are reliability projects dedicated to improving the current state of the region's electrical grid and existing transmission lines, while around 30% provide transmission capacity for renewable generation. This relatively high percentage of renewables-focused transmission development is consistent with ERCOT's embrace of proactive transmission planning, which combines planning for system reliability, reduced costs for consumers, and the addition of new generation resources to the grid. Many of these renewable projects belong to the CREZ project group, which includes a significant portion of transmission projects in ERCOT (ERCOT 2018).

Meanwhile, ERCOT is significantly behind other regions in terms of the number of projects that have been proposed or are currently under construction, possibly because of political dynamics in Texas over the past few years that have resulted in less-favorable attitudes toward renewables development or because ERCOT has already built a significant portion of its economic transmission potential.

From a state-by-state perspective (Figure 4), Texas has the most active transmission projects, almost three times more than the second- and third-ranked states of Virginia and Ohio.

Figure 4: Number of projects proposed or currently under construction for each state in the US Lower 48



Source: Authors' analysis based on MAPSearch data.

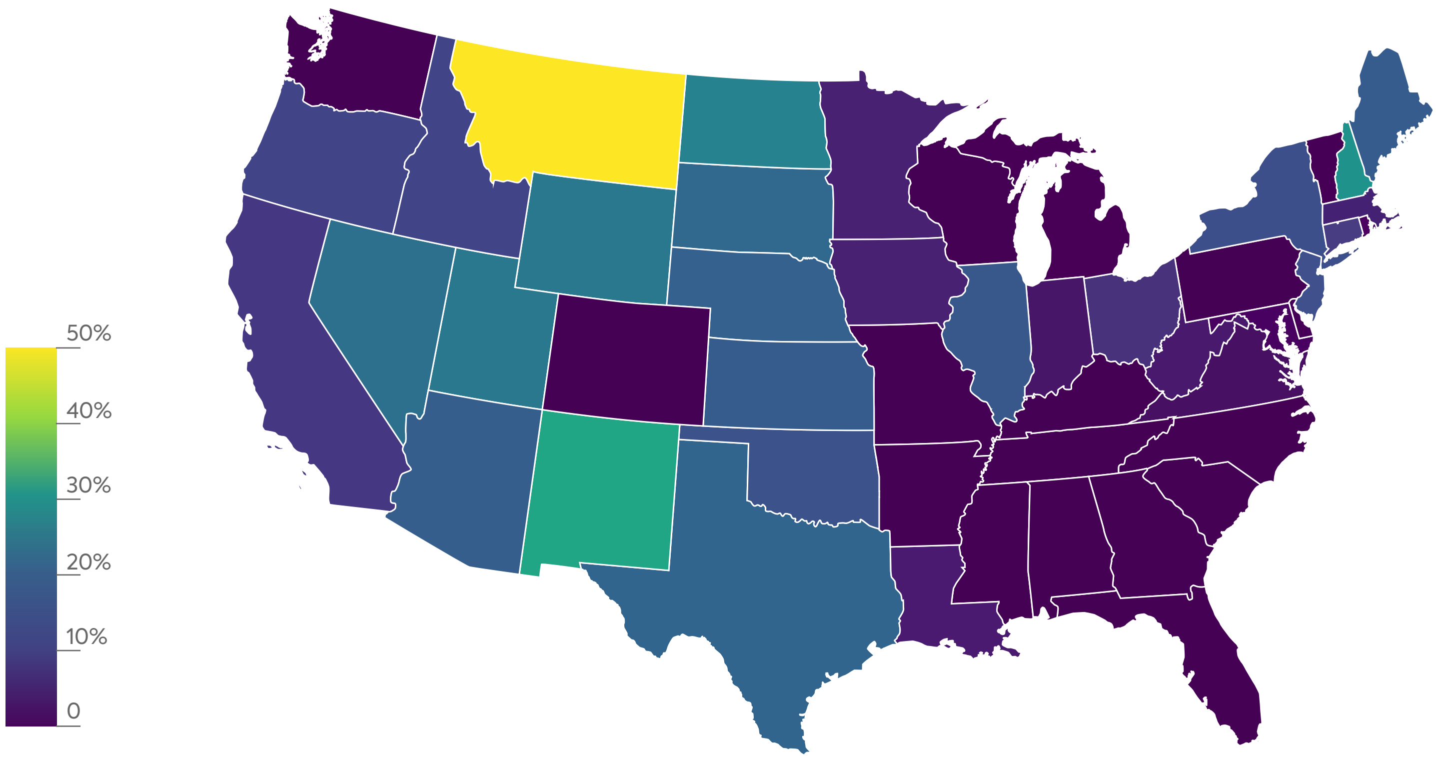
New York State has the highest number of planned transmission projects with 50, of which 48 are proposed and two are currently under construction. In fact, NYISO leads the nation in the number of proposed transmission projects normalized for hourly peak load (Figure 3c). Notably, the New York Public Service Commission, the lead energy regulator for the State of New York, has relied extensively on NYISO's public policy transmission planning process, and the concentration of projects under development in New York demonstrates that state regulators can drive transmission planning and investment. New York has also been a leader in siting and permitting reform for transmission projects, which is in keeping with the state's focus on proposing and constructing new transmission (Shalhoub 2021). Moreover, because NYISO is a single-state ISO, its transmission projects tend to be shorter, which this analysis shows to be positively correlated with outcomes. NYISO's geographically smaller footprint also accounts for why NYISO falls down the list when proposed/under-construction projects are measured on a kV-miles basis (Figure 3d).

States in the Southeast, including North Carolina, South Carolina, Florida, Georgia, and Alabama, have hardly any proposed or under-construction transmission projects. The Southeast is last on most transmission expansion metrics, including both active and proposed/under-construction transmission projects. Moreover, the region has virtually no merchant transmission investment and relatively little non-reliability investment. The few non-reliability projects in the Southeast are equally split between economically justified and interconnection-related projects. The lack of transmission development in the Southeast stands in sharp contrast to the lighter-colored regions of the country on the map in Figure 4 (i.e., those with more transmission development currently underway), which tend to span states that are part of restructured markets with a FERC-imposed obligation to engage in transmission planning for both reliability and economic efficiency (i.e., where consumer savings exceed the costs of the transmission, on an annualized basis) or have seen extensive state support for new transmission. Of course, correlation with competitive markets does not necessarily imply causation, and it is always possible that other factors, such as rate of load growth over time or the fact that vertically integrated utilities may elect to build new generation resources instead of transmission resources, account for the differences.

Further, the relative success of planned transmission expansion in the Northwest and Southwest regions shows that markets are not the sole answer. These regions, with their vertically integrated utilities, perform well against other regions when measured by kV-miles of proposed/under-construction transmission projects per gigawatt of peak hourly load, but are in the middle of the pack when measured by number of projects per gigawatt of peak hourly load. This discrepancy can be attributed to the expansive geographic distances and proliferation of large (500 kV and larger) long-haul transmission lines in the Northwest and Southwest regions.[5] Thus, while the two regions have comparatively fewer planned/under-construction projects, those in planning are large. Montana, for example, has long been a priority area for merchant transmission developers seeking to take advantage of the state's rich wind resources. About half of the transmission projects in Montana are merchant transmission projects, making it the state with the highest ratio of merchant projects relative to non-merchant projects. Whereas merchant projects comprise just over 10% of all transmission projects in the Midwest, most states in the Southeast region have only utility-sponsored regulated transmission projects (Figure 5).

[5] See, e.g., PacifiCorp's transmission expansion program, https://www.pacificorp.com/transmission/transmission-projects.html.

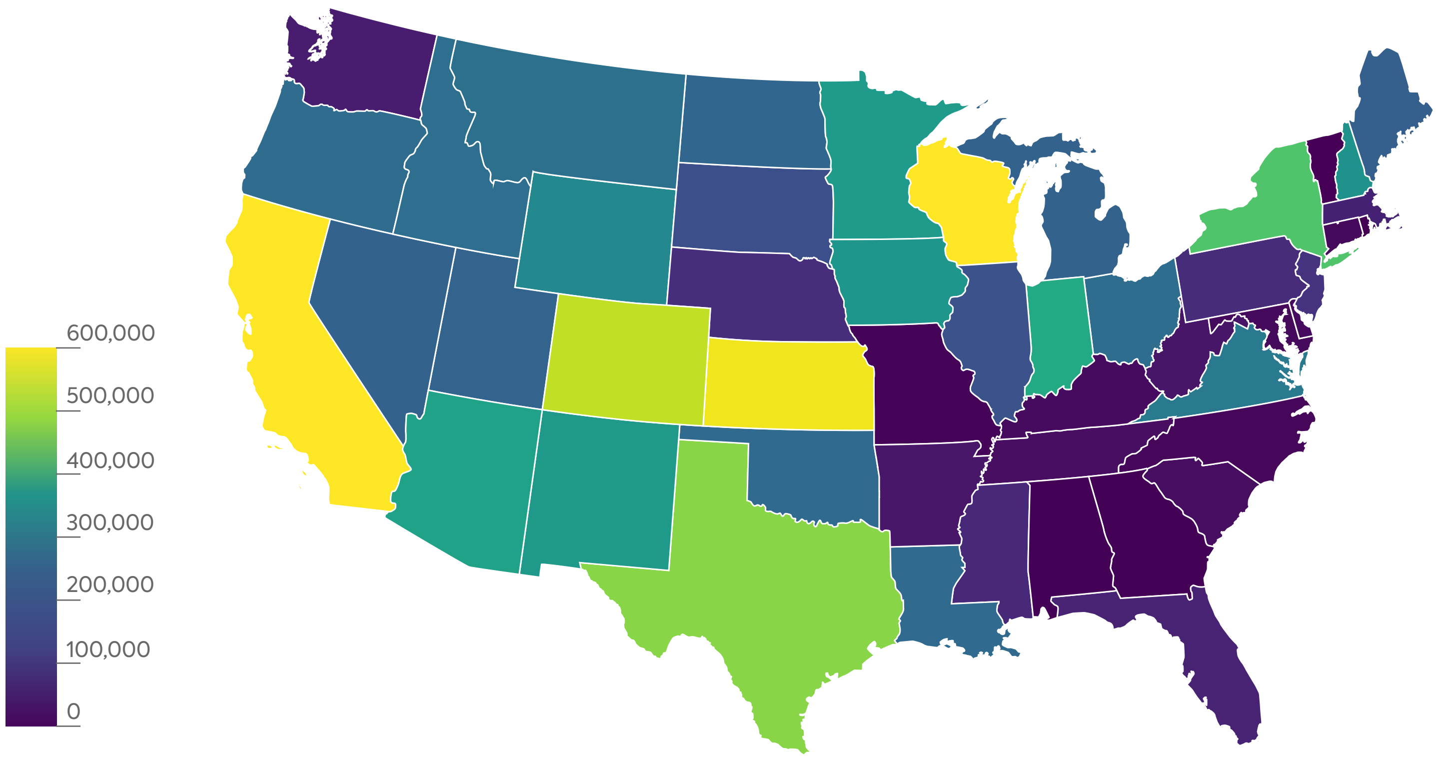
Figure 5: Percentage of merchant projects for each state in the US Lower 48



Source: Authors' analysis based on MAPSearch data.

Viewing the spatial distribution of the projects in terms of kV-miles of non-terminated transmission projects (Figure 6), it is clear that much of the activity follows the high wind electricity production region stretching from Texas to Minnesota. California and Wisconsin also have high cumulative project kV-miles. The Southeast region is seeing comparatively less development. Analyzing historical hourly load data from the Electricity Information Administration for various regions between 2012 and 2022, it can be observed that regions with a high average load growth rate do not necessarily have more planned power transmission infrastructure projects than regions with a lower load growth rate. For instance, the average hourly load growth rate for the Southeast is higher than that for the Southwest, yet the latter region has more planned projects. Thus, while it is not possible to conclusively rule out the non-utility business model or regulatory planning factors, the Southeast's lack of transmission expansion cannot easily be explained by load or population growth. Other contributing factors could include the region's relatively low level of renewables penetration compared to the Southwest.

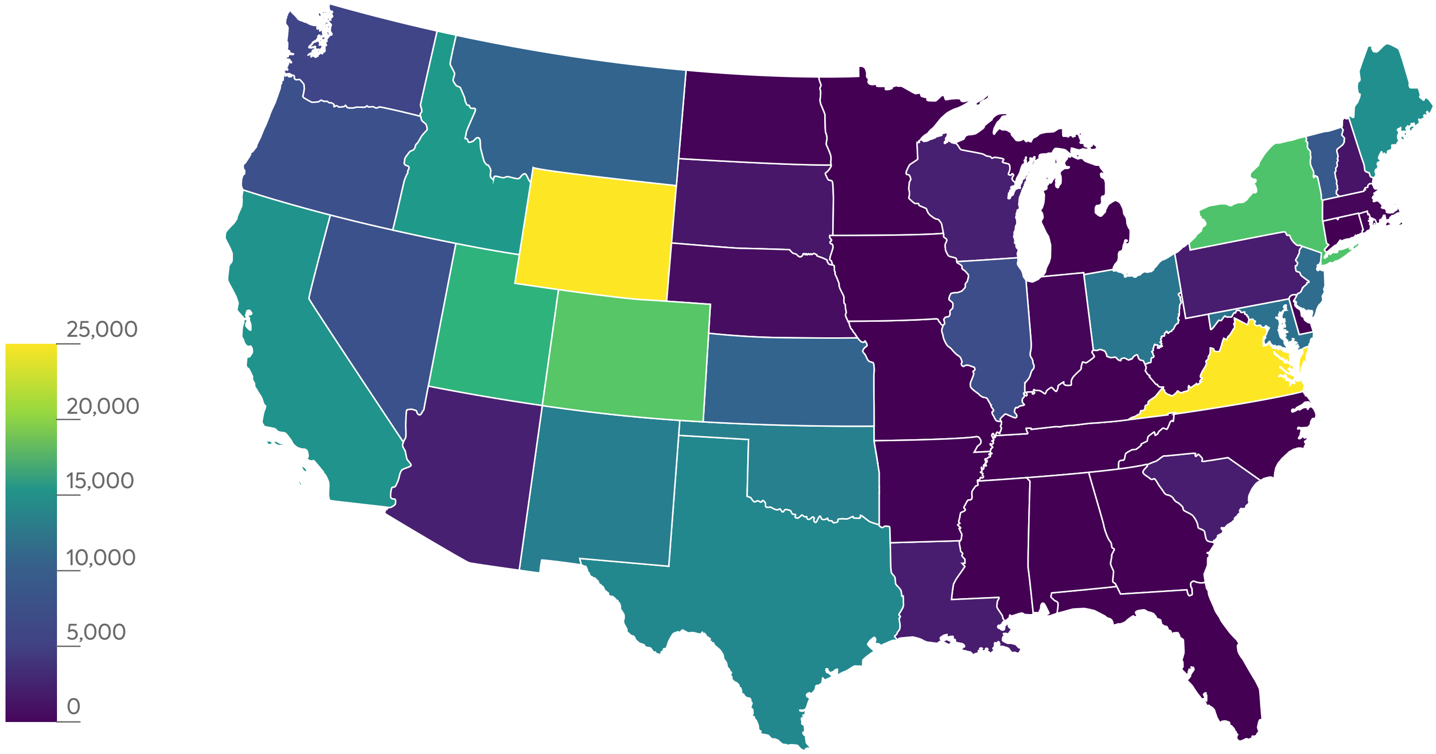
Figure 6: Aggregated non-terminated transmission project kV-miles for each state in the US Lower 48



Source: Authors' analysis based on MAPSearch data.

For terminated transmission projects, Wyoming and Virginia have the highest cumulative project kV-miles (Figure 7).

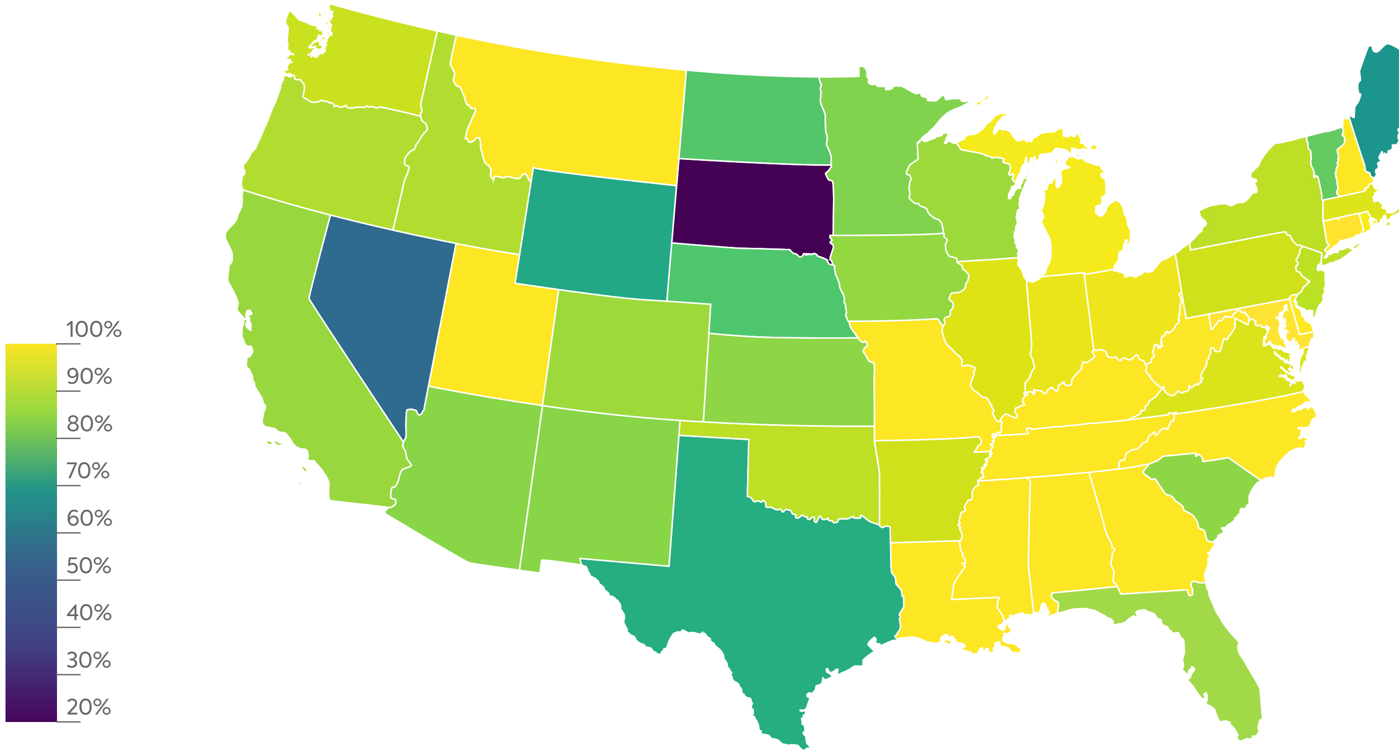
Figure 7: Transmission projects that were terminated or held, as measured in kV-miles, for each state in the US Lower 48



Source: Authors' analysis based on MAPSearch data.

Most of the projects across the Lower 48 states are reliability projects. The ratio of reliability projects to economic projects varies significantly, however. Utilities in the Southeast, for example, build transmission almost exclusively to meet reliability needs. In the middle of the country, by contrast, only approximately 80% of projects are for reliability, while the remainder are for other reasons, including economics and connecting new generation to the grid (Figure 8).

Figure 8: Percentage of reliability projects among all transmission projects in each state in the US Lower 48



Source: Authors' analysis based on MAPSearch data.

PJM projects declined in terms of total kV-miles over the course of the study period. As shown in Figures 3a and 3b, PJM has the third-highest number of projects among all FERC planning regions, normalized for hourly peak load. In terms of the total number of kV-miles normalized for peak hourly load, however, PJM falls to ninth out of the 10 regions under study. PJM project decline appears to coincide with regulatory changes enacted by FERC in 2013, which exempted certain local transmission upgrades, referred to as "supplemental projects," from competition. Supplemental projects, which are typically below 230 kV and within a single PJM zone, are not required to undergo the same competitive bid process as larger multi-zone or higher-voltage projects. Because these projects are subject to less regulatory scrutiny and oversight, there are allegations that utilities are preferentially selecting them to escape regulatory review, which is currently the subject of litigation before FERC.[6] This report's findings related to PJM align with those of other PJM observers (Wayner 2023; ACEG 2023; Peskoe 2021).

[6] Complaint of the Office of Ohio Consumers Counsel, FERC Docket No. EL23-105-000, raising concerns about the prevalence of supplemental projects.

The preceding analysis highlights the importance of regulatory policy. States that engage in proactive regional transmission planning that takes into account economic efficiency and/or public policy transmission needs tend to be more successful in planning and constructing new transmission than those that do not. Figure 8 highlights how proactive transmission planning in MISO, including its multi-value projects[7] and subsequent long-range transmission planning efforts, and ERCOT's CREZ lines have successfully driven increased investment in transmission. By comparison, PJM and the Southeast, which have typically not engaged in public policy transmission, have a significantly higher ratio of reliability-only projects. This has important implications for consumers, who are likely missing out on transmission projects that would improve market efficiency.

[7] For a detailed description of the MISO MVP process, see https://www.misoenergy.org/planning/multi-value-projects-mvps/#t=10&p=0&s=Updated&sd=desc.

Project Status Classification Modeling

To derive the statistical impact of different factors on the likelihood that a proposed transmission project will succeed, classification models were formulated based on the project datasets from MAPSearch. All transmission projects were divided into two classes according to their project status, "terminated/held" and "non-terminated/held," and were represented as 0 and 1, respectively, to establish the condition for a binary classification setup in the model.

The following features were constructed as key variables for the classification model based on the data items from the database (Table 1): inflation-adjusted unit cost ($ million/kV-mile); whether the project is underground or underwater; whether the voltage type is HVDC or AC; whether the project type is merchant or regulated; whether the project objective is reliability, renewable interconnection, economic, or multi-value; whether the project crosses state or regional borders; and whether at least one end of the project is within an ISO region.

Preprocessed data was split into training data (80%) and test data (20%). Sample stratification was applied during the data split to ensure that both the training and test datasets contained a comparable percentage of projects with different labels, preventing unevenly distributed data from causing prediction bias in the classification results. The random forest classifier was used for project status classification. The random forest classification algorithms provide mathematically well-defined feature importances, enabling a statistical assessment of the impact of each variable on transmission project status. The partial dependencies were calculated between selected factors and the success rate of the transmission project, allowing for an understanding of how much in percentage terms each factor contributed to the project success rate. Partial dependence reflects the average probabilistic effect of each variable on the status of the transmission project.

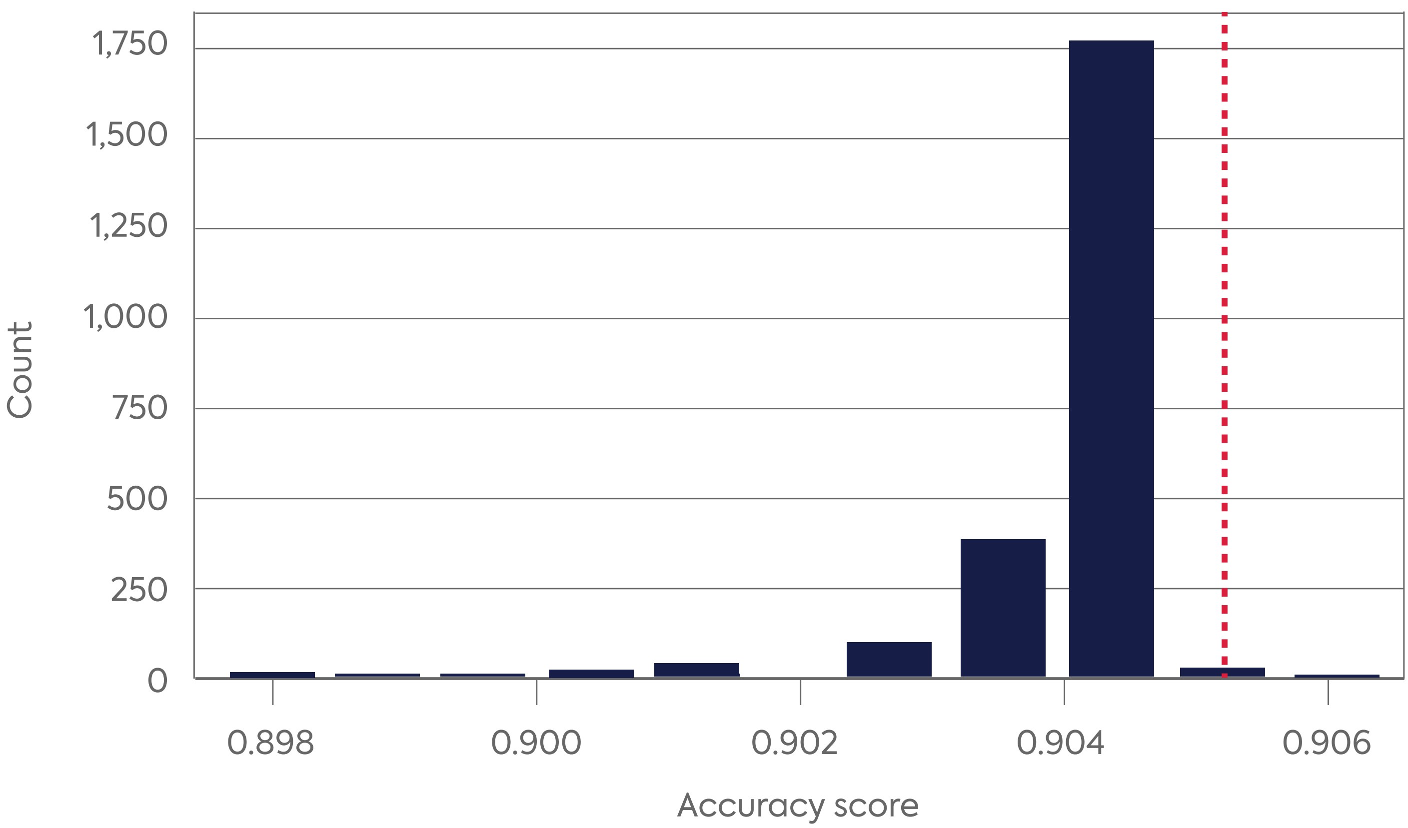
The random forest classifier can also help calculate feature importance, enabling a statistical assessment of the impact of each variable on transmission project status. The algorithm has an explicit mathematical formulation for feature importance, which is measured by the mean decrease in Gini impurity within each decision tree in the ensemble. Gini impurity can be expressed as

$$Gini(D) = 1 - \sum_{i=1}^{k} P_i^{2}$$

Where D represents the dataset and *p* represents the probability of data being classified as class i among the total number of k classes at a given splitting node. Once the Gini entropy value is calculated for each selected factor, it is used to compare each feature's impact on project status.

After fine-tuning the hyperparameters of the random forest classifiers, the classification model with the best performance was determined. Validating the model prediction accuracies for the random forest classifier involved conducting permutation tests with 2-fold cross-validations with 1,000 iterations. The accuracy score of the model running on the original dataset was compared with the distribution of accuracy scores of the same model evaluated on the randomly permuted dataset. The classifier reaches a higher accuracy score when fitted on the original dataset compared with the permuted dataset. The resulting accuracy score was 90.5% with a p-value of 0.015, indicating that the accuracy scores derived from the models that were trained by the original datasets are statistically significant at a confidence level of around 99% (Figure 9).

Figure 9: Permutation test with 2-fold cross-validations with 1,000 iterations on the fitted random forest classifier



Note: The red dashed line represents the accuracy score of the model running on the original dataset without the permutations.

Source: Authors' analysis based on MAPSearch data.

Based on the classifier, the partial dependencies for each categorical non-technical factor were calculated (Table 3). The variable of whether the project voltage type is HVDC had the highest absolute value of partial dependence with a negative sign, implying that on average transmission projects with HVDC voltage type are around 11% more likely to be terminated or held. Projects planned for construction underground/underwater are on average around 6% more likely to be terminated or held; interstate transmission projects are expected to be 7% less likely to succeed; and double circuit lines are approximately 2.5% less likely to be successful than single circuit transmission projects, though the sample set is largely composed of single circuit projects, making the correlation relatively weak.

Table 3: Partial dependence of each categorical variable

Categorical variables	Partial dependence evaluated at the mean
Whether the transmission project is underground or underwater	-6.3%
Whether the project voltage type is HVDC	-10.9%
Whether the project is for reliability	0.9%
Whether the project is for renewable interconnection	1.1%
Whether the project type is for economic	-0.7%
Whether the project is multi-value	-2.4%
Whether the transmission project is interstate	-7.2%
Whether at least one end of the project is in an ISO region	-0.6%

To investigate the different patterns for regulated and merchant projects further, the data was divided into two groups based on project type. One group contains utility-sponsored regulated projects while the other contains merchant projects. The classifier was run on each of these two groups with the same model parameters. Partial dependences for each variable were derived for both groups of project data (Table 4).

Table 4: Comparison between the partial dependences for variables of both merchant and regulated project groups

Categorical variables	Partial dependence evaluated at the mean for merchant projects	Partial dependence evaluated at the mean for regulated projects
Whether the transmission project is underground or underwater	-24.5%	-14.8%
Whether the project voltage type is HVDC	3.7%	-10.6%
Whether the project is for reliability	-10.17%	0.5%
Whether the project is for renewable interconnection	3.6%	1.9%
Whether the project type is economics	-1%	-4.1%
Whether the project is multi-value	3.5%	-1.6%
Whether the transmission project is interstate	-5.2%	-8.6%
Whether at least one end of the project is in an ISO region	-1.8%	-0.9%

Major changes in sign and absolute values were observed for the partial dependence values of several categorical variables, including whether the voltage type is HVDC, whether the project is for reliability, and whether it is a multi-value driver project. HVDC projects are about 14% more likely to be terminated if they are utility-sponsored regulated projects; reliability projects are about 10% more likely to be terminated if they are merchant projects; and multi-value driver projects are about 5% more likely to be terminated if they are regulated projects.

Conclusion

The US power grid is highly fragmented, with states and regions having different regulatory approaches to transmission planning, support for renewable energy, and openness to various utility business models. This analysis of over 1,300 transmission projects finds substantial geographical differences in the amount and type of transmission being built in the United States, as well as the type of transmission preferred.

The report also observes substantially more new transmission within organized electricity markets (ERCOT and MISO in particular) that have engaged in aggressive proactive transmission planning than in market regions such as PJM, which has not prioritized long-term transmission planning. California and Wisconsin were found to be key players with substantial cumulative project kV-miles. Both states have aggressive clean energy goals and have deployed substantial amounts of new renewables over the past decade.

States in the Southeast (North Carolina, South Carolina, Georgia, and Alabama), by contrast, show little activity in terms of proposed or ongoing transmission projects and an almost complete absence of projects designed to lower consumer costs or meet state public policies. The dearth of transmission in these FERC-jurisdictional areas may reflect the important role that FERC's transmission planning requirements play in organized market regions, and their lack of successful transmission expansion may provide additional impetus for FERC's ongoing efforts to mandate new transmission planning processes, which are designed in part to spur cost-effective transmission and improve competition in the generation sector (FERC 2022).

The analysis finds that crossing state boundaries is associated with a 7% decrease in the likelihood of project success. This supports the predominant narrative that grid planners struggle to cross state or regional boundaries, despite the strong body of research from the Department of Energy (DOE 2023) suggesting that cross-grid connections improve reliability and reduce consumer costs. It also reveals a clear area where transmission development is breaking down, potentially due to the fact that cross-state transmission projects require multiple state approvals on cost and siting, which creates more opportunities for regulatory failure. Based on this important finding, policymakers may wish to prioritize interregional planning efforts, including, potentially, by mandating additional interregional transmission connections (Senate 2023a) or improved regional transmission planning processes (Senate 2023b).

The classification model also demonstrates intriguing dynamics among different types of transmission project developers. Merchant transmission developers demonstrate a 14% higher success rate in developing HVDC projects compared with traditional regulated public utilities. This difference suggests that developing direct current technologies may benefit from the particular expertise of merchant transmission developers specializing in HVDC technologies, a point that has important implications for the debate over whether policymakers should allow utilities to maintain the "right of first refusal" over new transmission facilities, which typically favors incumbent interests (Howland 2023).

By contrast, regulated public utilities exhibit a 10% greater likelihood of success in constructing reliability projects and a 5% greater likelihood of success in constructing multi-value driver projects, suggesting that incumbent utilities may have an advantage in constructing reliability-based projects. Additionally, the decision to build underground transmission lines corresponds to a noteworthy 6% increase in the average likelihood of termination or delay.

Congress, FERC, the DOE, and several state governments have indicated their interest in jumpstarting transmission planning efforts, citing the enormous financial, reliability, and carbon-reduction potential of new transmission investment. While debates around transmission competition and the virtues of vertical integration are unlikely to end, this report suggests that interested policymakers could benefit from focusing on tried-and-true regulatory models—in particular, embracing long-term regional planning processes and state policies that support new transmission.

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