Energy Policy Institute

Center for Advanced Energy Studies

NSF Award #1127970

The Energy Policy Institute

REGIONAL ELECTRICITY TRANSMISSION PLANNING IN THE WEST: WORKSHOP PROCEEDINGS

September 2012

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REGIONAL ELECTRICITY TRANSMISSION PLANNING IN THE WEST: WORKSHOP PROCEEDINGS

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Acknowledgements

The workshop coordinators wish to recognize the Organizing Committee Members who made this workshop possible. Thank you to Dr. Wes Sine (Cornell University) and Dr. Joshua Linn (Resources for the Future) for your time, energy, and perspectives.

We would like to offer a special thank you to the Organizing Committee Chair, Dr. Andrew Van de Ven (University of Minnesota), for the additional participation and invaluable guidance.

We would also like to thank the Transmission Resource Mentors who facilitated the development of the academic presentations:

- Vickie Van Zandt, *ISO New England*
- Brad Nickell, *Western Electricity Coordinating Council*
- Rich Bayless, *Northern Tier Transmission Group*
- Fred Heutte, *NW Energy Coalition*
- John Cupparo, *Pacificorp*
- Bob Anderson, *Western Grid Group*
- Marsha Smith, *Idaho Public Utilities Commission*
- Chris Mensah-Bonsu, *California ISO*
- Sue Henderson, *Xcel Energy*
- Will Hazelip, *Duke Energy*
- Jeff Miller, *ColumbiaGrid*
- Brian Silverstein, *Bonneville Power Administration*

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I. Workshop Summary and Findings *David Solan, Boise State University*

Purpose

The Center for Advanced Energy Studies' Energy Policy Institute (EPI), headquartered at Boise State University, held the workshop *Regional Electricity Transmission Planning in the West* April 26-27, 2012. The workshop was funded through the National Science Foundation's programs for Innovation & Organizational Sciences (IOS) and Virtual Organizations as Sociotechnical Systems (VOSS): Award Number 1127970. The purpose of the workshop was to identify the organizational, procedural, and regulatory barriers to more effective regional electricity transmission planning in the West. In the process of identifying these barriers, the workshop facilitated future research by recognizing the gaps between industry and academia; prioritizing potential research opportunities; and creating collaborative networks among researchers, government, industry, and other stakeholders.

More than thirty invited participants attended the workshop, including representatives from academia, transmission companies, investor-owned utilities, government regulators and public utilities commissioners, stakeholder groups, transmission planners, independent system operators, public power administrations, and grid consultants. Over the course of the two days, IOS scholars presented six papers developed specifically for the workshop and with the input of an individually assigned electricity transmission practitioner. The six papers, which are reproduced in the proceedings, covered

- the public policy organizational environment,
- technologies and transmission planning,
- boundary organizations and institutional innovation,
- insights from complexity science into the dynamics of organizational ecologies,
- high reliability organizations applicability to transmission planning, and
- rules for emergence and insights from the organization of economic clusters.

In addition to the formal presentations, many interactive sessions with a variety of formats took place. There were three "fishbowl" panels and three breakout group sessions, with a diverse mix of the represented groups assigned to each session. All of the participants interacted in two "summary of themes" sessions, and a special closing session on emerging research was held to identify further avenues for follow-on funded research and to ensure continued academic and practitioner collaboration.

Background and Context

Much of the electricity grid was planned, sited, and constructed decades ago. Upgrades and new lines are required to maintain reliability and to bring electricity to load or population centers. Recent mandates for renewables necessitate new lines to be built to connect remote areas where utility-scale wind, solar, and other resources are usually found. The investment needed is at least in the tens of billions of dollars. New transmission lines may run hundreds or even over a thousand miles, crossing federal, state, and local jurisdictions. Each jurisdiction may require a separate approval for a project, depending on its specific geography.

The US system is separated into three interconnections that have very limited connectivity between them: the Western, the Eastern, and ERCOT (Texas). The Western Interconnection covers area from at least fourteen states, two Canadian provinces, and northern Baja California in Mexico. The non-profit Western Electricity Coordinating Council (WECC) has been delegated responsibility for "coordinating and promoting" bulk power system reliability in the Western Interconnection, as well as planning and operating activities (WECC, 2012). Furthermore, WECC has creation and enforcement authority for reliability standards, which derives from an agreement with the North American Electric Reliability Corporation (WECC, 2012a). In terms of electricity planning, WECC is divided into planning sub-regions and committees for resource adequacy, reliability, and transmission expansion. A number of designated stakeholders (e.g., utilities, transmission companies, power generators, government agencies, consumer advocates, tribal organizations, non-governmental organizations, among others) are involved in transmission planning activities and meetings, which are normally open to the public. The utilities do their own planning, and their individual integrated resource plans for generation and transmission are often "rolled up" to the sub-regions and WECC to inform higher level planning. It is important to note that WECC has the authority to plan, but not the authority to enforce implementation of transmission expansion plans. The purpose of WECC's transmission plan is to provide the best information possible so that industry, government officials, and other stakeholders can utilize it and engage in appropriate activities for the good of the region.

However, a frequent criticism of transmission planning is that the reality of what gets constructed and energized does not match the plans. There are a multitude of contextual reasons for the delta between plans and action. In the past, a main reason was that federal and state policies not directed at reliability were not required to be accounted for in planning, so an important driver was sometimes excluded or relegated to secondary status in planning. The Federal Energy Regulatory Commission (FERC) has only very recently required their inclusion in planning through the issuance of Order 1000 in mid-2011, and funding from the American Recovery and Reinvestment Act of 2009 (ARRA) or "stimulus" was provided for an interconnection-wide planning process. The explosion of policies such as state Renewable Portfolio Standards (RPS) that require certain utilities to supply or purchase a given percentage of electricity generated from renewable sources has greatly altered the operational landscape. Electricity flows and the location of resources do not necessarily accord with state geographical boundaries nor the territories of the “balancing authorities” that own a portion of the grid and are responsible for operation in a given location or “balancing area.” Also, the primary source of additional renewable generation in recent years has been intermittent wind, which is not always “on.” Similarly, solar energy is being heavily incented and has comparable variability issues. Both resources are usually developed by third parties or merchant generators that utilities must contract with to purchase the power.

Next, the West is a patchwork of regulation and deregulation for electricity markets and jurisdictions with authority for project approvals. In most states, state public utilities commissions must approve generation and transmission expansion for investor-owned utilities, a major criterion of which is the affordability of projects to be borne by ratepayers. The federal and state governments own a significant percentage of lands in the West, and there are two power administrations that must operate under certain rules derived from their formation in federal law to market power from federally-constructed dams. The permitting of projects is also patchwork. Transmission line permitting and approvals in the West are largely a state or even local jurisdictional issue. Understandably, public opposition to new lines is often strong and influential, whether the motivating factors are concerns over property values, the viewshed, health effects, or impacts on land considered to be of high value (e.g. agricultural, recreational, or historic to name a few). Attempts by the federal government through FERC to gain preemptive or overriding authority over states and localities in permitting have been rejected by the courts.

In addition, the West has traditionally been opposed to the widespread formation of what are known as regional transmission organizations or independent system operators, which have much more authority in terms of operating markets or approving regional transmission lines. Only California has an independent system operator (CAISO) in the West, and CAISO must collaborate with other sub-regions with differing planning cultures and technical capacity. In contrast, the Midwest, Northeast, Mid-Atlantic, and Texas have preferred the formation of voluntary independent system operators or their equivalent, and they have made efforts to forge ahead with initiatives such as tightly integrated regional markets and innovative transmission planning.

Because of the challenges highlighted above, NSF funded the workshop to investigate what insights may be derived from organizational scholars and their interaction with electricity practitioners, and how this interaction may advance knowledge while suggesting improvements to transmission planning.

Findings

These findings derive from the Principal Investigator's (PI) analysis and interpretation of the discussions, presentations, and workshop records and notes (see Appendix for full description of workshop planning and structure). Where appropriate, the presentation or paper that stimulated discussion of certain points is highlighted below for reader referral. It is important to note that the specific paper may not necessarily refer to the finding associated with it; the finding was generated by participant discussion. Any errors or omissions are the fault of the PI.

Transmission planning in the West is at an inflection point. Transmission planning is moving from a state in which planning was formerly bifurcated between planning for operations and forecast planning through economic studies. Because of the demands being placed on planning, the transition must be made from *planning for reliability* to one of *reliable planning* (Schulman), an exceptional challenge in a technical system that operates from a sub-millisecond operational level, to markets organized on hourly and day-ahead increments, to decadal timescales in planning for physical infrastructure. The stakeholders involved in a system in transition must account for not only the *integration of new technologies*, but also new metrics to ensure that it is efficacious in achieving both reliability and policy goals (Kirschen). FERC Order 1000 and the new compulsory Regional Transmission Expansion Planning process funded through ARRA require for the first time that federal and state policy and regulatory impacts – *the policy environment* – be formally accounted for in planning. These new requirements, including the recognition of state RPS and the incorporation of variable generation such as wind and solar, reach far beyond previous planning assumptions (Wilson). Actors in the system are *challenged to innovate* in a sector that is known for being cautious and very slow moving (Lichtenstein), especially as policymakers move rapidly to position their jurisdictions as attractive to the clean energy and information technology industries in the hope of forming *economic clusters* and creating job growth (Marcus). Finally, an improved planning system requires better engagement and understanding of stakeholder interests. In a planning milieu that is blurring boundaries, planners must develop a better understanding of *boundary organizations* and *boundary objects* (Hargrave).

Many of the workshop findings above refer to challenges in transmission planning and potential avenues that are ripe for further research from IOS and VOSS scholars. However, the challenges discussed call for collaborative and interdisciplinary research beyond these specific programs. Scholars must engage not only across academic disciplines but with practitioners and policymakers to get input into developing impactful research questions and appropriate research design. Researchers should adopt the comparative method to examine these complex questions in the electricity sector and across regions. At the same time, researchers should be careful to be informed by other complex systems to avoid the trap of assuming electricity is *sui* *generis*. In terms of specific future research identified at the workshop, the most promising avenues for investigation were in regard to

- renewables integration and innovation,
- stakeholder engagement and boundary organizations,
- maintaining high reliability of the grid while redefining what it means to have an effective planning process and outcomes, and
- better understanding of how policy choices affect decisions and risk in the planning system.

Researchers from the workshop are developing NSF proposals to address at least two of these areas at time of the publication of these proceedings. Finally, future research in these areas will be of value for comparison to other “organization of organizations” that do not have direct hierarchical authority but are charged with coordination, which is important to meeting policy goals and providing societal benefit.

II. Academic Papers

Each of the six speakers was asked to provide a discussion paper and presentation for the workshop. The presenters were charged with developing frameworks to help identify practical lessons based on organizational theories to improve the effectiveness of regional electricity transmission planning. In addition, the scholars were asked to identify basic organizational sciences research agendas that may be relevant to regional planning organizations, providing a foundation for future research in the field. The following abstracts provide a summary of each paper and presentation, and the key frameworks developed to ignite frank discussions regarding decision-making, organizations, and processes in transmission planning. Following the abstracts are the discussion papers.

Abstracts

Elizabeth Wilson, University of Minnesota

Large-Scale Wind and Transmission: Western Challenges and Opportunities

Developing renewable energy resources in the United States also requires developing electricity transmission infrastructure. Across the country, renewable energy resources have been increasing rapidly in recent years, especially wind power. Each state and regional jurisdiction, however, has taken a different approach to connecting new wind turbines to the transmission grid and dispatching electricity from wind. The paper and presentation explore the policies and politics underlying transmission siting and wind integration.

Daniel Kirschen, University of Washington

Technologies for Transmission Expansion

Technological developments (involving concrete, copper and steel but also "smarts") can facilitate the transmission expansion process but can also make it more "interesting." Rather than presenting a catalog of technologies, the paper discusses the types of contributions that technologies can bring and how different technologies can contribute to these goals.

Timothy Hargrave, University of Washington, Bothell

The Role of Boundary Organizations in Institutional Innovation

This paper examines the role of boundary organizations in processes of institutional innovation. These organizations span boundaries between diverse groups, enabling them to identify points of agreement and co-produce solutions to issues of common concern, while simultaneously maintaining boundaries and preserving differences. The paper identifies the reasons that boundary organizations are established, the practices and “boundary objects” they employ, and the conditions under which they are effective.

Benyamin Lichtenstein, University of Massachusetts, Boston

Complexity Science Insights into Organizational Ecologies and their Dynamics: The Case of Electrical Transmission Planning

Complexity science integrates 15 discipline-based methods, theories and/or approaches for exploring the non-linear dynamics that are often present in complex systems and social ecologies. Several of these relatively new tools may offer insights into the emergence and adaptability of social ecologies like projects, organizations, alliances, and multi-stakeholder processes. The premise of this paper is that complexity sciences may help understand and improve the Electrical Transmission Planning process. For example, Complex Adaptive Systems theory has explored the paradoxical findings that although diversity drives adaptability in a social ecology, shared schema are necessary to improve performance. Similarly, NK Landscape models have shown that too much agent interdependence in a system can lead to a 'complexity catastrophe;' however, this can be avoided by increasing coordination or decreasing the frequency of agent interactions. Dissipative Structures theory, Resilience studies and Distributed Control theory have explained how new order emerges and re-emerges in social ecologies, expanding the system's capacity to accomplish tasks and gain efficiencies. Complex Systems Leadership theory provides tools for increasing innovation and emergence in social ecologies. Each of these disciplines are presented, with a focus on how they might be operationalized and applied to the Electrical Transmission Planning process.

Paul Schulman, Mills College

What in High Reliability Organizations (HRO) research might be useful in transmission planning?

With important changes facing electricity systems, transmission planning may well be reaching a crossroad. Major challenges now loom for the future of grid reliability. A distinctive line of organizational research has focused on describing strategies and practices employed by organizations that have successful records in managing hazardous systems reliably. A review of this research and its major findings suggests some useful applications for transmission planning in promoting long-term as well as real-time grid reliability. In particular, this paper argues for an analytical distinction between planning for reliability and reliable planning.

Alfred Marcus, University of Minnesota

Rules for Emergence: Insights into the Organization of Economic Clusters

Four factors in cluster formation that have not been sufficiently recognized in the organizations literature are identified: the capacity to create rules for (i) boundary determination, (ii) benefit-cost allocation, (iii) conflict resolution, and (iv) rule-change. The significance of these factors is illustrated by comparing efforts to create wind energy clusters in Texas and Minnesota.

Large Scale Wind and Transmission: Western Challenges and Opportunities

Elizabeth J. Wilson

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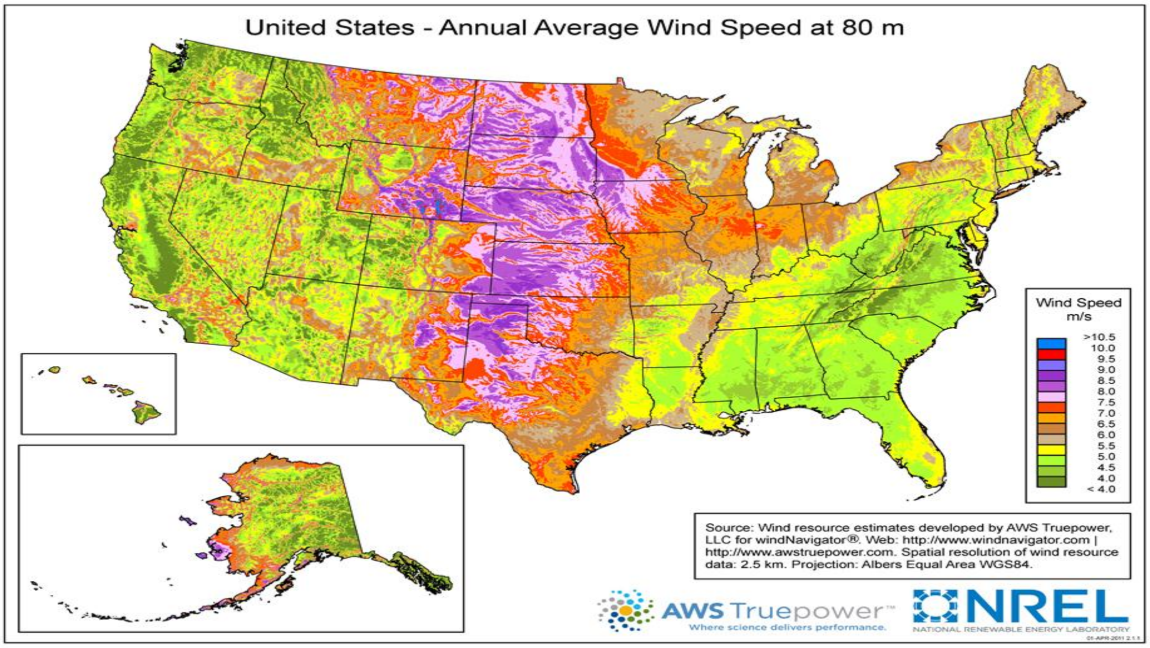
Introduction

Developing large-scale wind energy in the West will require the simultaneous development of new transmission lines and new tools to integrate variable wind power within the Western Interconnect. Wind power development will also require new levels of institutional and organizational coordination across states and electric utilities both for transmission line planning and power grid operation. This paper provides a short overview of the policy and organizational environment for wind and transmission planning in the West and provides an overview of ongoing challenges for large-scale wind development. After providing a brief background of the electric power grid and wind power development in the Western United States, Section 3 outlines the opportunities and challenges for developing wind and related transmission capacity in Western states.

Background

Wind in the West

There are many good wind resources in the West (Figure 1), but as demand for electricity is concentrated on the coast, developing remote sites for renewable energy necessitates new transmission lines. At the end of 2011, over 13,217 MW of wind had been installed in the Western Interconnection, about 30 percent of the 43,635 MW installed in the U.S. (NREL, 2012b) (Table 1). Note that with the exception of WY, the states with the most installed wind are those with the largest populations and electricity demand (CA, CO, OR, WA).


United States - Annual Average Wind Speed at 80 m

Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: Albers Equal Area WGS84.

Figure 1: United States wind resources at 80m, a Class 4 site is equivalent to 7-7.5 m/s. Source: (NREL, 2012a)

Electric Grid

Historically, the power grid was built to connect large-centralized power plants to electricity demand centers. Distributed and variable resources like wind power fundamentally alter this relationship, and its development has been characterized as “regulatory push”—through state-level renewable portfolio standards and tax credits at the state and federal level—rather than as “market pull” driving new transmission line need (Brown and Rossi, 2010; Piszczalski, 2009).

State	MW Wind
Arizona	138
California	3599
Colorado	1800
Idaho	471
Montana	386
Oregon	2305
New Mexico	750
Washington	2356
Wyoming	1412
TOTAL MW	**13 217**

Table 1: Installed wind resources in the Western Interconnection at the end of 2011 (NREL 2012b).

The current electric power system is broken up into three relatively separate regional grids: the Eastern Interconnection, the Western Interconnection and the Texas Interconnection (Figure 2). This structure is further split by regional transmission organizations (RTOs), power grid balancing authorities and control areas, and along utility service territories (Maize, 2008). Vertically integrated utilities continue to dominate the Western U.S. electricity market and with the exception of Oregon, other Western states have suspended electricity market restructuring (California, Nevada, Arizona, New Mexico and Montana) or not attempted it (Colorado, Idaho, Utah, Washington, Wyoming) (EIA, 2010).

The current electric power grid is maladapted to integrate additional renewable power; in part because of the architecture of the current transmission system was not designed to manage variable renewable resources (Bayless, 2012) and partly because of lack of capacity. As wind power curtailments have increased in many areas, as evidenced by the Columbia River Valley wind curtailments in the Spring of 2011 (Klass and Wilson, 2013; Romano, 2012; Wiser and Bolinger, 2011), pressure on building additional transmission lines has increased. Developing transmission to link distant wind resources to demand centers also has energy penalties from both line losses and potential congestion losses. These losses mean that it is often more attractive to develop poorer quality wind resources which are closer to existing transmission lines (Hoppock and Patiño-Echeverri, 2010).

At the federal level, steps have been taken to help rectify this difficulty, but they are currently insufficient. The North American Electric Reliability Council (NERC) helps to ensure reliability and coordinate across the eight regional councils (Figure 3), it does not have the authority to plan new transmission lines (Joskow, 2005). The FERC establishes interstate electricity rates for transmission but it is not able to overrule states when they deny interstate transmission permits, as upheld in the 2009 U.S. Court of Appeals for the Fourth Circuit decision (Dotson, 2010). New FERC Order No. 1000 builds on Order No. 890 and attempts to further encourage additional regional transmission planning, and it also addresses developing transmission to meet state-level policy goals (like renewable portfolio standards), cost allocation for regional projects and non-incumbent status to build transmission lines (Federal Energy Regulatory Commission, 2012).

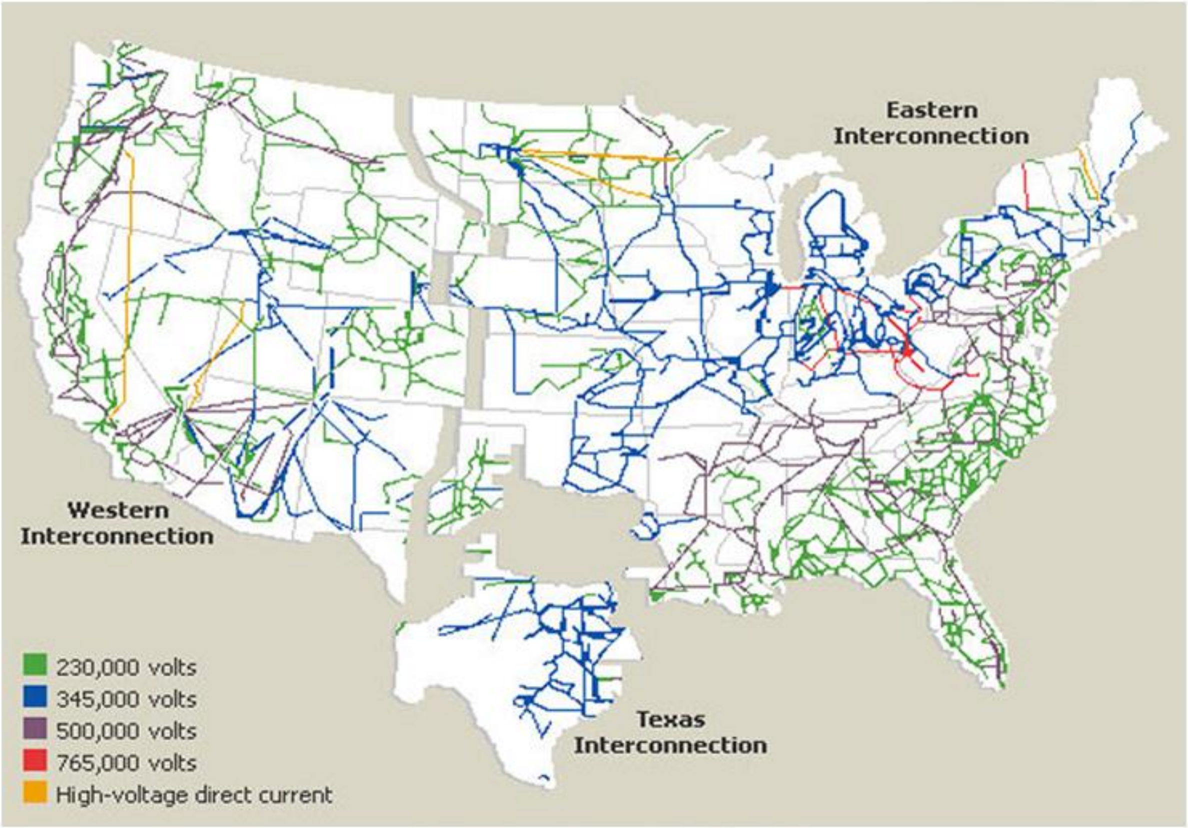


Figure 2: Map of United States showing the Eastern Interconnection, the Western Interconnection and the Texas Interconnection. Source: http://www.powersystemanalysis-guru.info/

How FERC Order No. 1000 will change transmission planning and development in the West is uncertain. While the new regional cost-allocation model could allow for regional benefits to be better incorporated into local projects, historically cost allocation for interstate transmission is tricky and state regulators have often been limited in accounting for only state-specific costs and benefits of transmission projects (AWEA and SEIA, 2009; Western Governors' Association, 2012).

What form future transmission systems will take is also in question. While some propose the construction of a nation-wide “Supergrid” to spur and support renewable development (AWEA and SEIA, 2009) and integration of large-scale wind by decreasing the correlation between wind resources (DeCarolis and Keith, 2006), others advocate for a more distributed grid build out (Rhoads-Weaver and Forsyth, 2006).

While other regions of the country have RTOs to aid in regional transmission planning processes, the lack of a larger regional organization to coordinate planning remains a barrier. Figure 3 shows the current regions for transmission planning today.

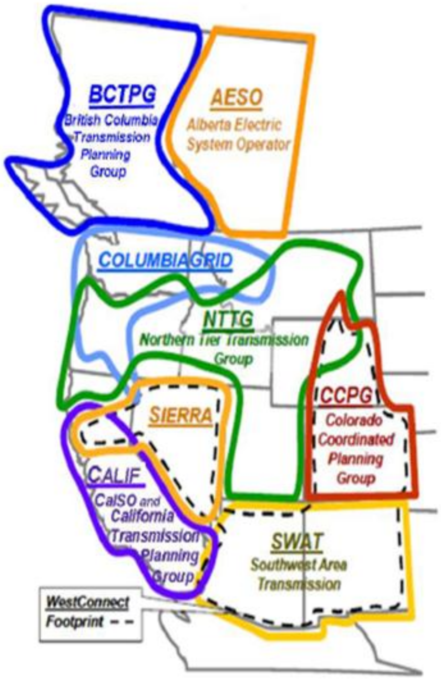


FIGURE 3: Transmission planning in the Western United States in 2012 Note that the planning areas segment many of the proposed WGA transmission line plans. (Western Governors' Association, 2012).

Regional Transmission Planning For Renewable Power Development Opportunities and Challenges

Given the importance of states in the transmission approval process, the state level context is crucial, yet it alone is insufficient for renewable energy transmission planning and development and in the West as many transmission lines will originate in one state and end in another, potentially crossing three to four states in the process. Additionally, most jurisdictions do not require transmission plans to be evaluated separately in state-level integrated resource planning activities (Western Governors' Association, 2012). Figure 4 shows where current wind projects are located and where the current transmission capacity is located.

The need for new transmission is affecting regional planning and coordination and realigning state interests as states are one of the most important “gatekeepers” for planning and approving interstate transmission (Oskvig, 2008). Interstate transmission planning highlights a crucial tension between the needs of regional coordination for transmission capacity planning and development and the state and local nature of planning, line approvals, cost allocation algorithms, and local siting considerations which must incorporate local land use preferences and aesthetics, environmental, agricultural, and historic/cultural considerations. (Brown and Rossi, 2010; Klass and Wilson, 2013).

The regional coordination necessary to develop large-scale renewable energy and accompanying transmission is unprecedented and brings together a set of actors and interests which have not traditionally worked together. Nationally, this conversation is beginning in many different venues. At the Federal level, the Federal Energy Regulatory Commission (FERC) began a series of planning meetings in 2009 to facilitate discussions of national transmission planning (Piszczalski, 2009). Additionally, studies linking wind and necessary transmission have been completed by industry (Utility Wind Integration Group, 2006) and by state, regional, and federal actors (Corbus et al., 2009; Department of Energy, 2006; K. Porter et al., 2009).

In the West, many of the best renewable energy zones are not near any existing transmission capacity (Figure 5). While the Western Governors Association (WGA), through an iterative process with state-level experts has identified the most promising zones future renewable energy development (Western Renewable Energy Zones—WREZ) and mapped potential transmission corridors (Figure 4) (Western Governors' Association, 2009, 2012), it remains to be seen if any will be developed. These Western planning activities (funded through the U.S. Department of Energy) have provided a crucial component in identifying and envisioning renewable energy development and transmission planning needs in the Western states. Creating a regional plan is just the first step and developing WREZ is not well aligned with current regional planning bodies or utility interests (Figure 3).

In the Phase III WGA report presents a series of interviews with utility executives, state Public Utility Commissioners, and Canadian provincial Energy Ministers and provides a stakeholder analysis of opportunities and barriers of Western renewable energy development and transmission planning (Western Governors' Association, 2012). The report finds that most utilities believe that they have enough transmission underway to fulfill RPS requirements for the next decade, are targeting developing renewable resources close to their service territories (and not the WGA WREZ), and, importantly, do not believe that any new RPS requirements or carbon related rules to be forthcoming (Western Governors' Association, 2012). Currently, only one quarter of utilities in the West factor carbon into their utility resource planning and decision making.

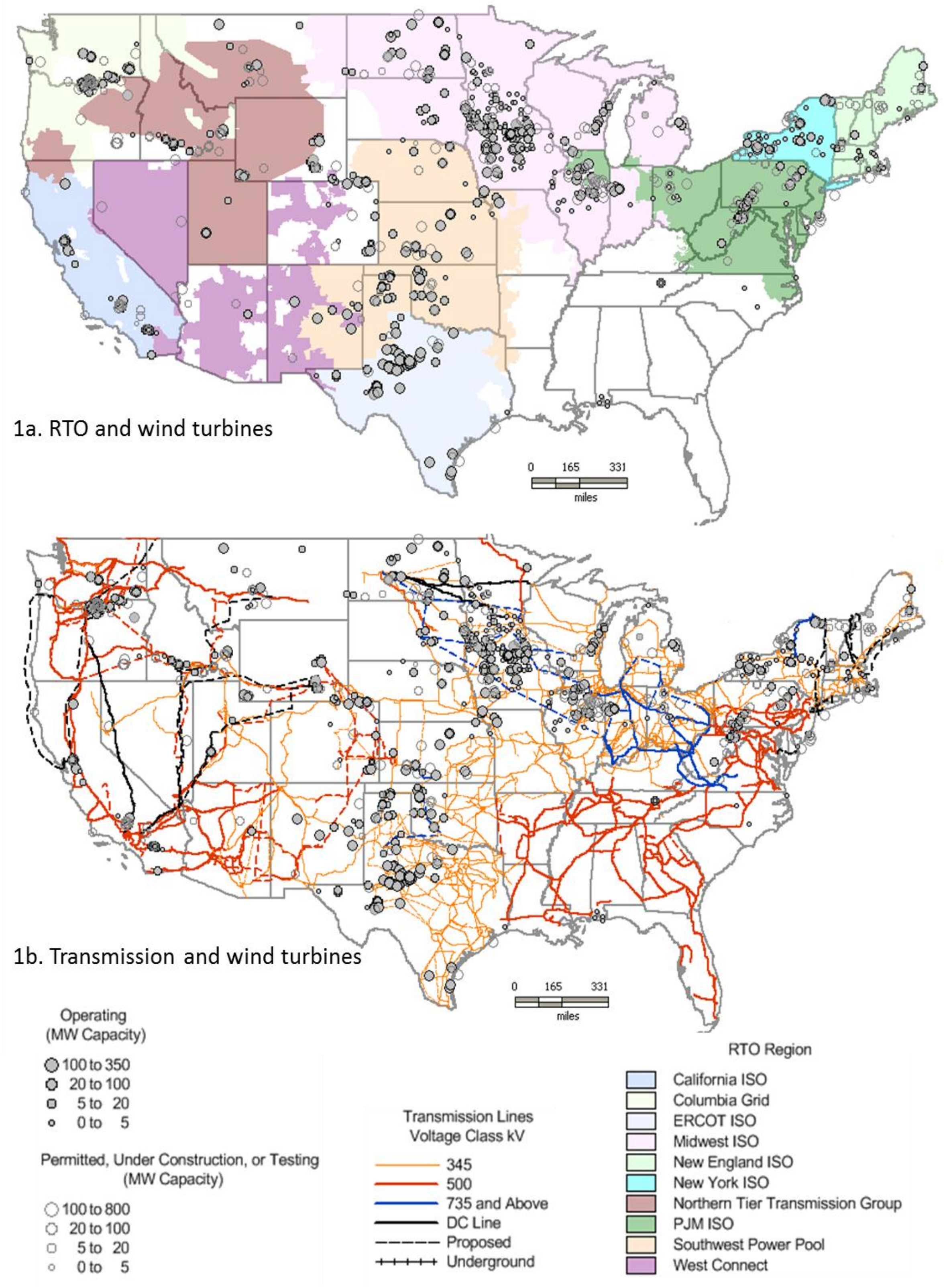


Figure 4. Regional transmission organizations, planned and existing transmission lines, and planned and existing wind turbines in the United States. Wind power is concentrated within some RTO areas (1a) and that proposed transmission lines link to some of the areas with the highest numbers of existing and proposed wind farms. Source: Ventyx Velocity Suite, 2011. From (Fischlein et al., 2012)

Even if utilities were committed to further developing the regional renewable potential, transmission still remains a barrier with two-thirds of utilities reporting that state-level policies and regulations impede interstate transmission planning and construction (Western Governors' Association, 2012). This is exacerbated by messy approval process which engages multiple levels of government without any structure of formal coordination. Additionally, state-level Public Utility Commissions are often statutorily limited in what transmission projects they can approve. Often hemmed in by restrictive and single-state focused definitions of “need”, they are unable to approve a transmission line larger than one that would meet the definable needs of the state’s retail customers (Western Governors' Association, 2012). These issues highlight the obstacles at the utility and the state-level statutory and regulatory changes which are necessary for transmission line development.

Resolving these issues often rests on questions of cost allocation. The long distances and high costs of transmission mean that there could be some states where wind is developed (and there is an economic benefit to wind projects), states where the transmission line passes through (transit states), and states where the wind power is delivered. The transit states may not benefit from the new transmission project and might not want to pay for the transmission lines, “as they may believe they reap neither the economic benefit, nor do they get the renewable power,” (Fischlein et al., 2012).

Transmission development for renewable power also highlights several important political issues. For example, while many Western states have adopted Renewable Portfolio Standards (RPS), several have not and these different policy orientations may highlight deeper divisions on climate policy goals and potentially undermine justifications for regional support for transmission lines. Additionally, transmission for renewable also highlights divisions within the environmental community, while many environmental groups have been strong supporters for renewable energy development, transmission line development for large scale wind deployment is often fractious, with national and local chapters of the same organization often on different sides of the same issue (Greenwald and Gray, 2008).

Discussion and Conclusions

Creating a framework for integrated transmission line planning and development for renewable energy will require new organizations, regulatory approaches, cost allocation algorithms as well as streamlining state approval, siting, and permitting processes. This multi-level, multi-state reorganization of organizations, institutions and incentives integrates existing political interests.

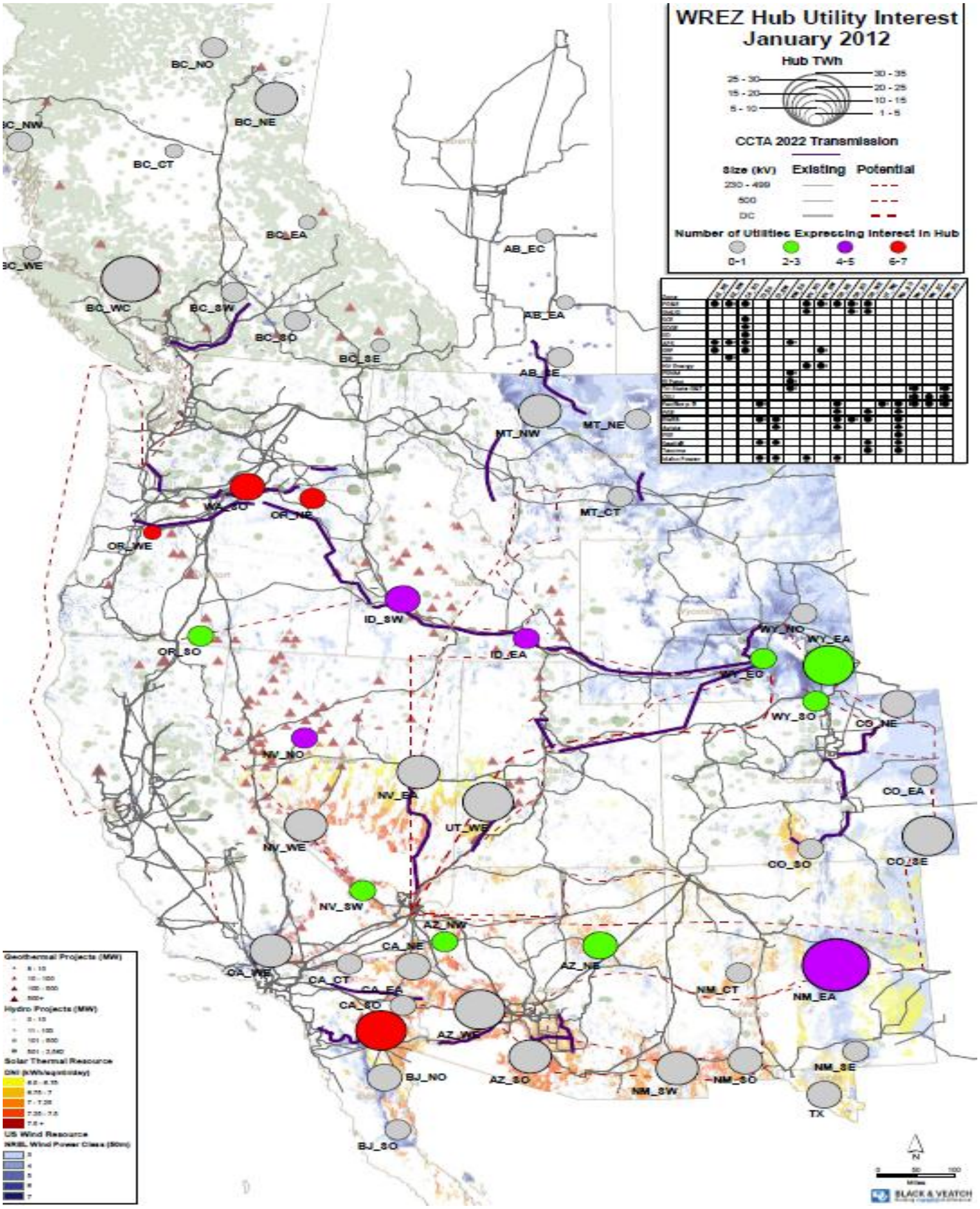


Figure 5: Western Governors' Association Western Renewable Energy Zones and potential new transmission corridor (WGA, 2012). The map shows both potential wind resources (in blue tones) and solar resources (in red/orange tones) for the Western Renewable Energy Zones (WREZ).

In the Western U.S., the future of wind power and renewable energy is linked to transmission. Developing this transmission will require new institutions to facilitate planning within and across states to transport distant wind resources to demand centers and manage the variability of the wind for reliability. While the Western Governors' Association has begun to identify renewable energy zones and needed transmission, they lack the authority to facilitate the regional resource planning necessary for resource development. Current policies and regulatory tools appear insufficient to encourage existing transmission planning regions to consolidate and engage in larger regional planning efforts. The new needs for coordination also highlight the importance of multi-level governance and multi-state coordination as transmission line planning, siting, and development engages many different state institutions (Klass and Wilson, 2013).

The question of transmission development is often framed as one of fairness: Who will pay for the transmission system upgrades? And of equity: Who will benefit from the wind resource? These simple questions highlight multiple divergent interests across the region. These interests—both existing and emerging—are shaping wind power and transmission development and are rapidly changing. Additionally, each state has different interests which are mediated by established rules governing PUC approval and siting process, the interconnection of wind projects, and state-level electricity systems and institutions.

If large-scale wind is to grow to meet a significant portion of Western electricity needs, the transmission dilemma must be resolved at a regional scale. All future solutions must integrate technical needs and political interests into new institutional and organizational configurations which span existing regional interests. Large-scale wind development in the West will depend on re-shaping state-specific institutions and fostering regional cooperation.

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Technologies for Improving Transmission

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Introduction

Until fairly recently, running a power system essentially involved balancing two objectives: providing a reliable electricity supply and keeping the cost of electrical energy low. In short, balancing the fear and the greed. Over the years, electric utilities learned how to provide a satisfactory reliability at a reasonably low cost. Because they were vertically integrated monopolies, they had little or no incentive to innovate and a stasis ensued.

Growing concerns about the environmental impact of the power system in general and global warming in particular have fundamentally changed this equation. We must now strive to balance the greed, the fear and the need to be green. Planning the expansion of a transmission network in a way that satisfies two of these three conflicting objectives is relatively straightforward. Doing well in all three directions at the same time will require innovation. This paper discusses the role that new technologies can play in this process and highlights the inevitable tradeoffs that will be required.

Benefits of Expanding Transmission

Expanding the capacity or reach of the transmission network has three main benefits. First, it increases the global economic welfare by enhancing market efficiency, i.e. by facilitating trading and thus optimizing the use of natural and existing resources. Second, it should improve (or at least preserve[1]) the reliability of the electricity supply, i.e. reduce the number and duration of outages. Third, it should help meet the environmental objectives, such as facilitating the integration of renewable energy sources. However, transmission expansion is costly and almost invariably controversial. We must therefore explore how new technologies can help achieve these same goals either through other means or with a minimum of discontent.

Some of the technologies that we will consider involve major infrastructures (i.e. a lot of concrete, copper and steel). Because these technologies are pretty mature, we can’t expect

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[1] Additional transmission capacity does not automatically enhance reliability because in a network that is economically adapted, the incremental capacity should be used for additional transactions, leaving the reliability level unchanged (at best) (Kirschen, 2004).

major improvement in performance. It is therefore essential to also explore how we can leverage computing, communication and control technologies to achieve substantial benefits are a lower cost and with less environmental disruption. In doing so, we can’t focus exclusively on the transmission network. Instead, we must broaden our scope to the power system as a whole and consider how the application of new technologies in other parts of the power system can help achieve the same objectives as transmission expansion.

More specifically, we are looking for new technologies that will have the following *tangible benefits*:

- Make it less costly to add transmission capacity (i.e. fewer $ per MW)
- Increase the capacity of existing assets (i.e. more MWs without adding new lines)
- Reduce the visual impact of transmission lines
- Reduce the requirements for right of ways.

We are also interested in technologies that can provide more *intangible benefits*, such as making the power system:

- More flexible (i.e. improve its ability to deal with the short term uncertainties caused by stochastic and intermittent renewable energy production)
- More robust to unanticipated changes (i.e. build a system that can adapt to unforeseen changes in its operating environment over the long run)
- More resilient to major disruptions, such as devastations caused by natural phenomena

Adding new lines and increasing the transmission capacity of existing ones will usually provide some of these benefits, but we need to consider whether this conventional approach is optimal or whether the same goal can be achieved through other means.

Overview of Various Groups of Technologies

Generation Technologies

It is logical to begin our discussion with the generation technologies because the current need to enhance the transmission network stems in large part from changes on the generation side of the system. The most important change has been the rapid development of very large wind farms. Besides being usually located far from the main load centers, the stochasticity and intermittency of these energy sources needs to be compensated by other control resources that can follow the changes in net load at an acceptable cost. Enhancing the transmission network can help operators deal with these problems because the vagaries of renewable generation can be averaged over a wider area and because they are less likely to create significant operating problems when the network is stronger.

For a while it looked like the best location for photovoltaic generation might be on the roof of residential and commercial premises. Since it would then have been located close to the loads, it would have reduced the need for transmission capacity. However, because the installation cost now represents a very large share of the total cost of PV generation, it is likely that the large-scale deployment of PV will also take the form of centralized installations and will also place additional stress on the transmission network.

Changes affecting conventional generation technologies, such as carbon capture and storage, fracking, or even the development of electricity markets can also have a profound effect on the generation fleet. Since the extent of these changes is difficult to predict, they can also have a major impact on the need for transmission.

Transmission Technologies

AC Transmission

AC transmission is still used to move the majority of electrical energy around the country. If it is decided to build a national transmission overlay to facilitate energy transfers between regions, it is likely that this would be done at 765kV, which is a technology that has been deployed for a number of years. Higher voltages are possible (e.g. a 1000kV line has been built in China) but may not be justifiable in the United States. Other technological developments in ac transmission are likely to facilitate the deployment of increased transmission capacity:
In *compact transmission lines,* the conductors of the three phases are held in place more firmly using advanced insulators. This allows for a reduction in the spacing between the phases and hence a reduction in the right of way required for a given transmission capacity (Tsujimoto 1982). Such a line is currently undergoing tests in China.

Transmission towers equipped with *composite cross-arms* are currently undergoing field tests in the UK. On these towers the conductors can be suspended directly from the cross arm because it is made out of an insulating material. These conductors are thus suspended higher because there is no need for the vertical insulator string. This increases the vertical clearance and hence makes possible either an increase in the nominal line voltage or an increase in the allowable sag. Both approaches increase the line’s transmission capacity without requiring higher or wider transmission towers (Kopsidas, 2011).

High temperature conductors are able to carry a larger amount of power without exceeding the maximum allowable sag. Studies have shown that this can be an effective way of increasing transmission capacity without having to build new lines or increase the height of existing transmission towers (Kopsidas, 2010).

DC Transmission

Conventional (i.e. current source) DC transmission is the most effective way to move large amounts of power from point to point. Unfortunately, until a suitable DC breaker is developed, it cannot be used in the multi-terminal configuration that would facilitate its more widespread adoption. Voltage source DC transmission provides more flexibility and the ability to deploy meshed networks, but currently offers a much smaller transmission capacity (Eriksson 2001). The interested reader will find a more detailed discussion of transmission technologies in McCalley (2011) and McCalley (2012).

Control Technologies

A considerable amount of research and development has been devoted in recent years on the applications of power electronics to the control of the transmission network. A number of series Flexible AC Transmission System (FACTS) devices have been proposed. Their ability to improve stability, re-route power flows around network bottlenecks and generally improve the flexibility of the system has been demonstrated using simulation tools. However, besides a few demonstration projects, no such devices have been deployed. The main reason is that their cost is not justified by the benefits that they provide over more conventional ways of operating the system.

Storage Technologies

Battery energy storage is the technology that could possibly completely change the way power systems are operated and hence the need for transmission capacity. However, before that happens, the cost and performance characteristics of batteries still have to improve dramatically. Considering the amount of research underway on various battery technologies, this is not an unreasonable proposition.

If a sufficient amount of battery capacity was distributed around the grid, it would be possible to compensate for the intermittency of renewable sources while at the same time keeping the output of the conventional power plants much more constant. This would result in a leveling of the load on the transmission network and hence in a reduced need for transmission expansion. In other words, the utilization factor of the transmission network could be dramatically improved from its current low level. Distributed energy storage would also improve the utilization of the available transmission capacity through another mechanism. A substantial fraction of the available transmission capacity is always set-aside as a security margin for dealing with sudden line outages. This form of preventive security is required because there aren’t enough fast control resources to stabilize the system after an outage has occurred. Distributed energy storage could provide these corrective action resources and thus free up this reserve transmission capacity for carrying energy (Department of Energy, 2012).

Demand-side Participation

Encouraging electricity consumers to shift their demand over time using price signals or other mechanisms provides a form of “virtual energy storage”, which has the advantage of having a much lower investment cost than all the current technologies that provide “real” storage. (Storing dirty clothes for a few hours is much cheaper than buying and installing batteries!). The potential for controlling the power system using resources from the demand side will grow as more smart meters are deployed and as the number of plug-in electric vehicles increases. While demand side technologies are attractive because their cost is low, it is not yet clear what how much of an impact they will have because their potential depends not only on technological developments but also on public acceptance and participation.

Monitoring Technologies

To ensure the reliability of the transmission network, operators must know what its current state is and how big a security margin they should keep to prevent unavoidable sudden faults and failures from causing widespread outages. Unfortunately, the size, geographical extent and complexity of the power system makes this task fairly complex and the results are somewhat inaccurate. For example, the apparently simple task of keeping a safe distance between the conductors of a transmission line and the vegetation growing below that line turns out to be quite complex. The distance that these conductors sag as more power flows through them depends on the ambient temperature, the wind speed and the wind direction, factors that can vary quite significantly over the length of a major transmission line. On the other side, the height of the vegetation depends on the temperature and the rainfall at each location over the last few years. To be on the safe side, operators will tend to use conservative estimates that reduce the capacity available for transmitting energy.

Improvements in the hardware and software used to assess the state of the system can therefore improve the reliability of the system or to operate the transmission network closer to its limits (i.e. “sweat the assets”). These improvements can also give operators the tools and confidence they need to operate reliably a power system spanning a much wider area and thus take advantage of an increased geographical diversity of renewable energy sources.

Computing Technologies

Studying a power system using computational models for planning and operating purposes yields significant benefits in terms of cost, reliability and the ability to integrate more renewable energy sources. Developments in computing technologies thus enhance the tools that transmission planners have at their disposal. In addition to the regular improvements in CPU speed, development in parallel processing and optimization algorithms are particularly useful for power system planning because they allow planners to:

- Consider more options
- Consider each of these options under a wider range of scenarios
- Increase the geographical scope of their studies
- Improve the fidelity of their studies by using more detailed models
- Consider a longer planning horizon
- Consider how the electricity supply system might be affected by developments in other industries (gas, transportation, ..).

Because planners have the ability to study possible solutions under an increasing range of conditions, the candidates that emerge will be more robust as conditions inevitably change. This robustness, however, extends only to the scenarios that are considered. We have to accept that if conditions turn out to be vastly different from what was anticipated (i.e. a “black swan” event occurs), the network might turn out to be poorly adapted in terms of one or more of the economic, reliability or environmental performance criteria.

Conclusions: Deploying New Technologies

Technological developments can and will help support the development of the transmission network in ways that balance the conflicting objectives of economics, reliability and environmental impact. While some of the technologies described above are fairly mature field and probably can’t support major breakthroughs, others (particularly those involving the deployment of computing and communication) could yield substantial benefits at a reasonable cost.

One question that we should discuss is how to facilitate or accelerate the development and deployment of the most promising new technologies. The barriers seem to be mostly institutional:

1. Regulated utilities do not have much incentive to try new things: they are under pressure to keep costs low and don’t want to be blamed for poor reliability. Can we design robust incentive mechanisms that will provide long-term improvements through the adoption of new technologies?

2. In our current unbundled industry structure, some new technologies need to be deployed by one party but will provide benefits to another (e.g. flexible generation, storage, demand response). Can we create market mechanisms to make it happen?
3. The implementation of some new technologies creates winners and losers. How can we get around the opposition that this will create?

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The Role of Boundary Organizations in Stakeholder Processes:

Implications for Transmission Planning

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For Proceedings of the

Organizational Sciences Workshop on

Electricity Transmission Planning Organizations

Energy Policy Institute

Center for Advanced Energy Studies

Boise State University

April 26-27, 2012

Introduction

Regional transmission planning increasingly has become a contested process involving stakeholders with diverse viewpoints about the very purpose and meaning of the grid. A recent report by the Western Grid Group captures this when it lays out "business as usual" and "clean energy vision" scenarios, and states that a choice must be made between them because "the two alternatives require different infrastructure, different grid operations, different grid planning and different utility regulation." Similarly, the statement of need for this workshop notes that the "diversity of stakeholders" comprising regional planning groups are "attempting to protect current grid stability while simultaneously developing recommendations for integrating renewable energy transmission within these grids."

Processes for reconciling the perspectives and interests of transmission planning's diverse stakeholders already have been established. The Western Electricity Coordinating Council (WECC) received funding stimulus funding to establish an interconnection-wide transmission planning process known as Regional Transmission Expansion Planning (RTEP) which includes broad stakeholder participation. Of course, the workshop itself is a multi-stakeholder collaborative process for addressing regional transmission issues.

Boundary Organization Theory

The purpose of this paper is to introduce boundary organization theory as a framework for structuring thinking about how to make transmission-related stakeholder processes and organizations more effective in establishing practices and arrangements which are acceptable to diverse parties.

Groups with competing yet interdependent interests coordinate their activities and co-create new, mutually acceptable practices and arrangements through boundary spanning activities (Aldrich & Herker, 1977; Tushman & Scanlan, 1981). Carlile (2004) finds that these activities include knowledge transfer practices, which establish a common language for communicating information across syntactic boundaries; knowledge translation practices which cross semantic boundaries and enable identification of differences in understandings; and knowledge transformation practices which cross pragmatic boundaries by co-producing new understandings, practices, and solutions based on identification of common interests.

Boundary spanning actors employ boundary objects (Star and Griesemer, 1989; Carlile, 2002; Bechky, 2003b), which are artifacts which "[sit] in the middle" (Star 1989, p. 47) between groups of actors embedded in different contexts, and can be shared by these groups to jointly address issues of common concern while maintaining their distinct viewpoints (Star & Griesemer, 1989; Carlile, 2002). Boundary objects include artifacts such as databases, templates, diagrams, maps, and models. Effective boundary objects are recognizable to actors embedded in differing logics, yet at the same time have a conceptual generality and interpretive ambiguity which gives them “different meanings in different social worlds” (Star and Griesemer, 1989: 393). This interpretive flexibility enables actors to use and adapt boundary objects to their own ends, while at the same time the broader recognizability of boundary objects enables these actors to share them and work together (O’Mahony & Bechky, 2008; Franks, 2010). Bechky finds that an effective boundary object enables the actor to place new “knowledge within her own locus of practice in such a way that it enhance[s] [her] understanding of her work world, enabling her to see that world in a new light” (2003: 321).

Boundary organizations are structured spaces in which diverse groups address issues and problems of common concern. They have been discussed extensively in the science and technology literature (Guston, 1999, 2001; Miller, 2001) as well as in natural resources management (Carr & Wilkinson, 2005; Franks, 2010), but rarely in organization studies (but see O’Mahony & Bechky (2008) for an exception.) Boundary organizations provide one means by which opposing actors use boundary objects to manage institutional pluralism. They are able to occupy an intermediate subject position (Bourdieu & Wacquant, 1992; Oakes, Townley, & Cooper, 1998; Maguire & Hardy, 2004) at the boundary of diverse groups (O’Mahony & Bechky, 2008) because they have established legitimacy and a strong reputation with these groups and have established lines of accountability to them (Guston, 2001). Boundary organizations are relatively durable spaces which enable long term relationship building (Franks, 2010) and can be used to address ongoing tensions and issues (O’Mahony & Bechky, 2008; Carr & Wilkinson, 2005; Cash, 2001).

Boundary organizations are both boundary spanning and boundary maintaining: They provide a space in which opposed groups can produce integrative or transformative new logics, practices, and arrangements in areas where their interests and identities converge, yet at the same time enable these groups to preserve their differences in areas in which their interests and identities diverge (Miller, 2001; O’Mahony & Bechky, 2008).

Characteristics of Effective Boundary Organizations: Evidence from the Literature

The existing literature points to a number of characteristics and practices of effective boundary organizations. I now briefly present these, organizing them by type of boundary practice (knowledge transfer, knowledge translation, and knowledge transformation.) I recognize that there is no single set of practices which will be effective under all circumstances; the “right” approach to boundary work is a function of context. Nevertheless, the literature does point to a number of general attributes and practices that are broadly robust.

Knowledge transfer: The ability of the boundary organization to successfully establish a structured space in which parties with opposed interests collaborate depends upon it possessing numerous characteristics. Of foremost importance is the boundary organization's reputation. To succeed in "cross-domain orchestration", the boundary organization, its key personnel, and the processes it establishes all must be seen as credible by its many diverse audiences (Miller, 2001; Cash, 2002). In the absence of such conditions, stakeholders will not feel safe in sharing information and perspectives or engaging earnestly in collaboration. When they are trusted by participants, boundary organizations are able to remove restrictions on the types of conversations that occur among stakeholders (Carr and Wilkinson, 2005).

To ensure that they maintain relationships of trust with stakeholders, boundary organizations must of course be truthful and transparent, and work to ensure that stakeholders perceive the collaborative process as fair. This requires boundary organizations to successfully negotiate the tension between accountability and independence: They must both take account of the perspectives and interests of important stakeholders, yet at the same time maintain the prerogative and ability to change the agenda (Franks, 2010; Guston et al, 2000). Once the boundary organization has established credibility with and independence from its diverse stakeholders, it can begin to guide these stakeholders' efforts to find a common language for collaboration (Franks, 2010).

Knowledge translation: As noted, effective boundary work involves knowledge translation, or the surfacing of differences in the meanings that stakeholders assign to their shared vocabulary. Miller finds that in the international climate change negotiations, the UNFCCC's Subsidiary Body for Scientific and Technological Advice (SBSTA) enables policy makers and scientists to understand each other and find agreement by revealing "the tacit and often value-laden assumptions" of each (2001: 491). Similarly, Carr and Wilkinson's (2005) study of Australian agricultural extension agents finds that these agents enabled diverse stakeholders to "interrogate each other to understand other perspectives on resource management issues and potential solutions" (2005: 261).

Knowledge transformation: Boundary work is pragmatic and political; boundary organizations help stakeholders to not only bridge language differences but also co-create new, mutually satisfactory practices and arrangements. They do so by using rather than denying difference – by providing space for experimentation, learning, and the co-production of new knowledge (Guston, 1999), which involves stimulating and making use of creative tension between opposed sides (Miller, 2001).

Knowledge transformation is more likely when the boundary organization does not try to control production but rather facilitates it by providing a structured space (O'Mahony & Bechky, 2008). Boundary organizations establish the boundary objects around which other actors collaborate and the ground rules for how these objects are used, but are more likely to be effective when they allow stakeholders to surface and explore their own assumptions and ideas, identify their roles and tasks for themselves, and establish the technical direction of their work. When stakeholders control production in this way they become more invested in the collaborative process and more likely to see it as legitimate. Franks (2010) finds that when the agricultural experiments of Dutch environmental cooperatives were most successful when they "incorporate[ed] local knowledge derived from alternative perspectives", and university scientists constrained themselves to monitoring and assessing local approaches rather than imposing solutions.

Pietri and colleagues provide a cautionary tale which shows that boundary organizations can undermine themselves by trying to control the use of boundary objects. They find that when the Ocean Science Trust excluded stakeholders from the conduct of a study of alternative approaches to decommissioning offshore oil rigs, it unintendedly gave these same stakeholders grounds to question the study's legitimacy.

Boundary organizations tend to be more effective in addressing problems when they view knowledge transformation as an ongoing process of continuous adaptation to changing circumstances, interests, and information. This view of boundary work is consistent with the adaptive governance paradigm in natural resource management, which takes the view that under conditions of complexity and uncertainty, collaboration between parties with diverse interests requires ongoing collaboration because policies must be continuously negotiated and renegotiated (Brunner et al, 2005; Ostrom, 2010).

Of course, boundary organizations are more likely to be effective when they possess the capacity to research new ideas which surface. Miller finds that SBSTA has been effective in serving the international climate change policy process in part because it continuously "give[s] rise to expert advisory committees, scientific assessments and/or research management agencies" (2001: 483).

Conclusion

As transmission planning shifts from a predominantly technical process to a stakeholder-driven process, new ideas – even those of great economic and technical merit – will be adopted only if they embody the viewpoints and satisfy the interests of many diverse and sometimes competing stakeholders. Boundary organizations provide durable, structured spaces in which these stakeholders can work together to continuously, adaptively create and re-create mutually satisfactory technologies, practices, and arrangements. This paper has briefly described some of the features of effective boundary organizations. The lessons offered here apply not only to existing transmission planning boundary organizations such as WECC, but also at the many other boundaries within the transmission system – for example, at the boundary of federal and state jurisdictions, or in facility siting processes which bring together community and business representatives.

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Complexity Science Insights into the Electrical Transmission Planning Process:

Options for Integrating Renewable Energy into the Grid

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An NSF IOS Project organized by the Center for Advanced Energy Studies' (CAES) Energy Policy Institute (EPI), located at Boise State University – April 2012

Introduction

The complexity of the electric grid is remarkable but understandable considering the task of bringing electricity to every city and rural area across the U.S., with full availability at every time of day at exactly the level and amount needed by each specific household. From the perspective of electricity suppliers and grid operators, this requirement of providing universal and uninterrupted service gives rise to a major challenge of integrating wind and solar energy into the grid. That a challenge is due to the contrast between reliability – the core design principle for the electric grid, versus the variability of energy production from wind and solar sources, i.e., solar generates energy in the daytime, and the majority of wind power is generated at night. The good news is that renewable energy technology has made great gains in innovation and price efficiencies; this along with the fact that renewable 'supplies' are free and non-polluting makes them highly attractive to the consumer market. Still, the variability of these sources plagues their integration into the grid.

Fortunately these variances can be well managed through deploying a 'smart-grid' design across the electric transmission grid. Smart-grid technology has advanced significantly in the past 10 years, and now city-wide smart-grid information systems are able to integrate a wide range of renewable sources of energy, as well as local, distributed-source and co-generation facilities to a city-wide electric grid. These technologies, however, require greater capacity and slack for variation within the transmission lines, to be managed by an advanced information technology system. Such additions require significant capital investments; their expense can be justified only by reducing other aspects of the planned expansions of electrical transmission lines. According to some, this trade-off has led to a slow-down in the integration of renewable energy onto the grid, along with the concomitant losses in clean-tech employment and potential decreases in greenhouse gas pollution.

From the perspective of organization science (the academic discipline underlying management) this challenge is not unique; in a generalized form it is seen whenever a new innovation appears within a highly complex industry like electrical generation. This is especially true when the proposed technological and social benefits are based on new frames and assumptions that are distinct from the current institutional system. Thus the integration of a new social innovation like renewable energy is difficult because it requires a shift in the values that underlie current economic analyses as well as the current bases of resource allocation (i.e.**,** institutional power) in large utilities.

Although a good deal is known about how such value shifts can lead to institutional change (see Hargrave, this volume) and collective action (see Marcus, this volume), in this case the innovation challenge is magnified due to the sheer complexity of the environment in which the new innovation is emerging. Specifically electricity generation is an industry environment of dynamic networks comprised of many diverse players that are inter-dependent and 'co-evolving' across the business landscape. This complexity is amplified due to the multiple and overlapping areas of regulation across the system, as well as by the stream of innovations that address technology problems at all levels of the transmission process. One approach for encouraging these new innovations and dealing with the underlying problems is to understand the principles of complexity in the environment. The present paper takes this approach by applying recent insights from complexity science to the dynamics of electricity transmission planning.

Complexity science is a set of disciplines that incorporate emerging methods from biology, computational science, mathematics, thermodynamics, complex systems thinking and interdisciplinary social theory; each of these methods seek to explain the non-linearity and threshold behaviors that are endemic to a dynamic "social ecology" (Sawyer, 2005; Goldstein, Hazy, & Lichtenstein, 2010). Social ecologies are networks of sustained relationships in a human environment; these relationships emerge and are sustained when the needs of network participants (actors, agents) are satisfied by the resources and contributions that other actors provide, thus creating a web of interdependence and mutuality across all agents in the ecology. In more formal terms, a social ecology is a bounded network of interdependent human agents and entities with shared schema and needs that exist in a symbiotic relationship that allows for the generation of mutual benefits and resources. In a general sense these benefits and resources that are generated and exchanged include: access to basic needs, goods and services, trust/friendship, information/entertainment, and various forms of social, financial, and knowledge capital. Complexity science is the study of these social ecologies – how they emerge, adapt, and evolve.

My application of complexity science is focused around the particular social ecology, namely the network surrounding the Western Interconnection of the U.S. electrical grid, managed by the Western Electricity Coordinating Council [WECC]. The impetus for this analysis is a recent workshop that included individuals representing the entire scope of this social ecology – executives and managers from large utilities, government agencies (Federal, State, and Regional) and industry associations, as well as a group of academics from engineering, public policy and management. This meeting – *NSF IOS Organization Sciences Workshop on Energy Transmission Planning* – was designed by the CAES, a project of the Idaho National Labs located at Boise State University. The present paper is a formalization of my presentation at that two-day conference.

Complexity of the Social Ecology in and around the Electric Grid

A good example of the environmental complexity of electricity generation was provided by Gardner and Lehr (2011) in their analysis and recommendations for wind energy adoption in the Western section of the electric grid. One of the key recommendations in their report was for 'Increased Coordination Among Relevant Parties' (page 40-41), a recommendation that is an important first step in managing complexity. In that context they provide a list of the relevant parties, a list that helps appreciate the breadth and diversity of players in this social ecology:

> Every study examining transmission analyzed in this paper…discussed the importance of increased coordination and cooperation amongst relevant parties. More specifically, relevant parties in terms of renewable energy projects and transmission integration include:
>
> 1. resource planners;
> 2. sub-regional and interconnection-wide transmission planners;
> 3. transmission developers;
> 4. federal land use agencies;
> 5. renewable energy developers;
> 6. state, provincial and federal regulators;
> 7. balancing authorities; and
> 8. environmental organizations.

A thoughtful reading of this list reveals that each of these eight 'parties' is itself a complex social ecology; for example looking at item #7, the Western Governors' Association identifies 38 distinct *balancing authorities* within WECC; a recent report on renewable energy zones in the West (related to item #5) identified 123 renewable energy source projects with a combined transmission distance of 34,301 miles.[2] This complexity is also seen in the processes involved; a good example is resource planning (item #1), which was accomplished by 16 large public utilities in 2007-2009.[3] Looking at just one of them, the Integrated Resource Plan [IRP] developed by PacifiCorp (2011; http://www.pacificorp.com/es/irp.html), reveals over 300 pages of unique analyses on regulations, portfolio standards, resource needs, loads and load balancing, sourcing options, portfolio modeling and evaluation, price projections, production costs, and capitalization requirements. This information then needs to be summarized and into aggregated with the IRPs from the other 15 utilities across the region to form a 'base case

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[2] Mills, A., A. Phadke, and R. Wiser. 2010. Exploration of Resource and Transmission Expansion Decisions in the Western Renewable Energy Zone Initiative. Berkeley, CA: Lawrence Berkeley National Laboratory, February. http://eetd.lbl.gov/ea/emp/reports/lbnl-3077e.pdf.

[3] Barbose, G. and Larson, P., 2010. Developing demand- and supply-side resource assumptions for the 2010 TEPPC study: Utility input needed. Presentation at the Western Resource Planners Forum; San Diego, CA. Lawrence Berkeley National Laboratory. http://www.wecc.biz/Planning/TransmissionExpansion/RTEP/06212010/Lists/Presentations/1/2b%20-%20Western%20Integrated%20Resource%20Plans%20-%20Barbose.pdf

scenario' – an initial set of assumptions from which a Transmission Planning Reference Case can be initiated.

Summarizing these issues, the field of electricity generation includes at least two distinct categories of complexity, namely (a) multiple layers/players in the ecology, and (b) many overlapping processes and issues that each player has to engage with [See Table 1]. In a formal sense, it is not just the number of different players in the ecology that makes it complex, although keeping track of the various agencies involved in the approval of a new large transmission project can be a significant task in itself. Nor is complexity limited to the challenge of each process that occurs in the ecology. Instead complexity refers to the degree of interdependence across elements in the system, i.e. the degree to which the actions of one entity in one layer or process can impact the dynamics within another, thus generating constant change with high uncertainty and the chance for unexpected emergent outcomes.

A good way to consider this difference is to compare two common things: an airplane and mayonnaise (Cilliers, 1998). The former is *complicated* – an airplane has upwards of 1,000,000 parts organized into systems across multiple layers of operations, designed to provide completely predictable and totally reliable outcomes. In contrast, mayonnaise is *complex*. Although it is made of only two ingredients,[4] together they create an emergent outcome that is completely unpredictable from the properties of each. Whereas modern management is ideally suited for complicated situations, its tools are not well designed for complex dynamic systems like electricity generation.

Complexity science is an alternative approach for understanding the complexity of dynamic social ecologies; for the past 20 years complexity science has generated insights for scholars studying organizational transformation (Goldstein, 1988; Anderson, 1999; Lichtenstein, 2000), innovation (Cheng & Van de Ven, 1996; Brown & Eisenhardt, 1997; Fleming & Sorenson, 2001), and institutional emergence and change (Chiles, Meyer, & Hench, 2004). Of the 18 or so distinct disciplines of complexity science (Lichtenstein, 2011; also Maguire, McKelvey, Mirabeau, & Oztas, 2006), several of them shed light on the dynamics of this social ecology. In the present paper I will review two of these disciplines –Agent Based Modeling, and the NK Landscapes model – to explore how leading-edge research in these areas sheds light on the complexity of electrical generation planning.

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[4] Mayonnaise is made from oil and eggs.

Agent-Based Modeling and its Insights into Electricity Generation

Perhaps the most well-known of the complexity sciences is Agent-Based Modeling – the highly sophisticated computer simulations in which autonomous agents, armed with just one or a few 'rules', organize themselves into emergent, nested groupings that are stable over time. This computational "self-organization" is what most authors present as "complexity science" (Lewin, 1992; Waldrop, 1992; Axelrod & Cohen, 2000; Johnson, 2001); such computational aggregation is at the heart of a related class of complexity simulations, NK Landscape models (Kauffman, 1993; Levinthal, 1997; Levinthal & Warglien, 1999; Sorenson, Rivkin, & Fleming, 2006). Here I introduce 'agent-based modeling,' a method that has been significantly advanced by the work of Holland (1995; 1998), Murray Gell-Mann (1994), Kathleen Carley (1990, 1999; Carley & Prietula, 1994; Carley & Svoboda, 1996), and others. One very relevant application of agent-based modeling has been achieved by Leigh Tesfatsion (2011); she and her colleagues at Iowa State University have developed an open-source, agent-based model of the electrical grid.[5] After more than a decade of research, her team has gained valuable insights into the underlying dynamics of the electrical grid, with results that contradict the assumptions from normal economics and which have significant policy implications for all stakeholders in the system (Li, Sun, & Tesfatsion, 2011; Li & Tesfatsion, 2011; Tesfatsion, 2011).

As Tesfatsion explains (Tesfatsion 2011: 14-15), agent-based models [AMBs] are like "wetware culture dish experiments," being boundaried and controllable situations in which repeated experiments can be run that may yield a range of results. In the most advanced edge of the work, which is well represented in her lab, "each agent in an ABM is a software program encompassing data as well as methods that act on these data;" thus, agents are semi-autonomous and interdependent in the same way that human agents are. These agents learn, adapt, communicate with each other, and make decisions that are based on an "action domain" – a finite number of possible supply offers that are continuously updated due to agent learning. Because each agent's data and methods are 'encapsulated' – partially or completely hidden from fellow agents – their behavior is "imperfectly predictable from the viewpoint of other agents in their computational world;" like the real world, market players cannot see each others' strategies before they are enacted.

The basic experimental paradigm is a social ecology of electricity producers ('generating Companies' – GenCos) and utilities that purchase and distribute electric power across the grid ('load serving entities' – LSEs). As in all models of this kind, five GenCos and five LSEs are situated within a network of energy needs (market-based demand) and supplies (projected

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[5] Their project is called AMES – Agent-based Modeling of Electricity Systems; http://www2.econ.iastate.edu/tesfatsi/AMESMarketHome.htm. The computational simulator is based on the well-known '5-bus model' that underlies all engineering-based studies of the electrical grid.

generation amounts given known parameters). A number of important details make the simulation remarkably parallel to the empirical reality,[6] including the integration of FERC's goal to have regional power markets adopt *locational marginal prices* [LMP] to settle the differences between supply (price) and demand (cost) when congestion and other obstacles slow down the balancing of power across the entire grid (i.e. the 5-bus model). In all these ways, the agent-based model provides a remarkably accurate simulation of real-world competitive patterns within a regional Independent Service Operator [ISO] (Li & Tesfatsion, 2010). Such patterns are often opaque due to their complexity; ABMs thus become an ideal method for theory-developing experiments that can be replicated across a wide range of initial parameters (Anderson, 1999; Boisot & McKelvey, 2010; McKelvey, 2004).

The main finding in these studies is that under circumstances that appear to favor 'free-market' activities of pricing and exchange, GenCos will learn how to substantively increase their own profits well beyond the 'marginal costs' that are prescribed by FERC. They accomplish this through the reporting of higher-than-true marginal costs, a process they describe as "economic capacity withholding" (Li et al., 2011: 7), and through reporting lower-than-true maximum capacity.[7] At the same time, this also raises the net surplus collections to the ISO, proving more revenue for the regional grid operator. Overall, this covert strategy benefits both sets of powerful agents in the social ecology, at the expense of consumers and under the radar of regulators. The effects of this strategy are well-known as they report, "For example, in 2008, ISO net surplus collections ranged…to $2,660,000,000 in the Mid-Atlantic States;" even more importantly the simulation proves that these large institutions play a very lucrative role in creating "market conditions that are *unfavorable*" to market efficiency (Tesfatsion, 2011: 17). The fact that such perverse learning occurs even within regulated markets suggests that a new system of governance may be necessary to take some market power away from the large utilities and redirect it toward a more decentralized source of consumer interests.

An intriguing additional findings sheds light on the lack of incentives that utilities have in pursuing programs that would decentralize energy generation and provide market revenue to individual homes that produce energy (e.g. through local wind, solar, and distributed energy generation). Such consumer-favored moves can create more apparent variance in demand (mainly through ongoing decreases in usage). However, the ABM studies show that GenCos

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[6] For a very readable description of their methods and assumptions, I recommend Li, Sun & Tesfatsion, 2011. Their comparability of the model to real-world empirical data is strongly proven in a number of studies design to test that question – see Li & Tesfatsion (2010).

[7] They describe (page 6): "As depicted in Figure 4, this supply offer consists of a reported marginal cost function MCRi (pGi) = aRi + 2bRi pGi defined over a reported operating capacity interval [CapLi, CapRUi]. GenCo i's ability to vary its choice of a supply offer from ADi permits it to adjust the ordinate aRi, slope 2bRi , and upper operating capacity limit CapRU I for its reported marginal cost function in an attempt to increase its daily net earnings." (my bold).

profits are *minimized when customers have some control* in their purchase of electricity, i.e. when there is a higher price-sensitivity of demand. In contrast, GenCos maximize their profits when electricity is considered a commodity whose price doesn't affect its demand – we will pay for electricity even if costs go significantly higher. This finding, that large utilities are not incentivized to help consumers decrease their usage and increase their individual control over electricity, is worrisome for advocates of a green economy. This is especially true in an environment that is demanding less regulation, rather than more.

A different but no less valuable approach for gaining insights into the dynamics of energy markets can be gained by examining the complexity science model of NK Landscapes.

Applying NK Landscapes to Electricity Generation

The model of NK Landscapes, popularized by Kauffman (1993) and brought to organization science by Levinthal and his students (Levinthal, 1997; Gavetti & Levinthal, 2000; Gavetti, Levinthal, & Rivkin, 2005) among many others (McKelvey, 1999; Ganco & Agarwal, 2009), provides a computational framework for exploring how a network of interdependent agents adapt and change over time. The basic components of the model are the number of elements *N* – these can be agents, traits, decisions, etc.; and the degree of interdependence across elements *K* – which refers to their mutuality of influence, i.e. how changes in one element cause changes in another and so on. These two dimensions interact to create a 'performance landscape,' a simulation outcome that identifies which combinations of N and K produce the highest and lowest performance for the agents in the model.

NK landscape simulations have been effectively used to study innovation. For example Fleming and Sorenson (2001) used patent data to show that the most effective new inventions were ones with a high number of components *N* but only a moderate degree of interdependence *K*. Separately, Rivkin and Siggelkow (2003) have identified the ideal balance of search and stability in organizational design, as well as the problems that accrue when multiple search strategies are happening at the same time (Siggelkow & Rivkin, 2006). These studies and others have identified a number of proven 'facts' from the model; conceptually we can apply these regularities (propositions) to help simplify the complexity of decision-making in the social ecology of electricity transmission.

A central finding from these studies regards the performance effects of interdependence, which have been shown to follow an 'inverted U' relationship. That is, interdependence initially increases adaptability and performance in the system; however beyond a certain threshold more interdependence decreases performance. This decrease continues until a second threshold is reached, when the level of interdependence becomes so great as to cause a "complexity catastrophe" whereby the entire system 'locks up' – no element is able to adjust or move due to its high interdependence across the entire network (McKelvey 1999).

Applied to electricity transmission planning this result warns against too much reciprocal dependence in the decisions of entities across the network. Although complex decisions have to be correlated, enforcing only a moderate degree of interdependence allows the ecology as a whole to remain adaptive. Furthermore, given the choice of increasing the number of entities in the system versus having existing entities become more interdependent, NK landscape theory shows that the former is more adaptive then having more interdependence because those increases, while providing more 'democratic' and interactive decision-making at a micro level, end up limiting the flexibility and adaptability of the ecology as a whole. This counter-intuitive finding has some intriguing implications for energy policy, and for advocates of renewable energy.

Another important finding from NK landscape models regards interdependencies in alliances and other collaborations, a highly relevant context that had been virtually unexplored until recent work by Aggarwal, Siggelkow and Singh (2011). Their aim was to explore how this context of mutual gains differs from the much more commonly studied context of competitive strategy, in which firms are rewarded (with higher performance) by increasing 'exploration' and innovation activities. In contrast, these complexity researchers found that in arenas of collaborative action with shared outcomes the most effective performance accrues through better governance that increases coordination across the partners. They (Aggarwal et al., 2011: 725) summarize this unexpected finding:

> …as interdependencies increase, coordination becomes increasingly important;…with increasingly dense interactions, coordination becomes paramount in explaining performance. [E]xploration is always important but becomes less so with higher degrees of interaction. [I]n an inter-organizational setting, coordination may actually become more important than exploration. Exploration per se, when not coordinated, can backfire.

Thus, forms of coordination matter a great deal in the outcomes of an ecology of shared innovation like electricity transmission. In particular they find that in these situations the most effective governance mode is a 'self-governing' strategy in which alliance partners focus first on the outcomes to the alliance, and only then focus on maximizing their own firm-level outcomes. The research also shows that in networks of highly interdependent entities, short-term governance benefits do not always translate to long-term effectiveness of an alliance; instead, short-term trade-offs are sometimes necessary to insure long-term performance gains for all partners in the collaboration. In sum their research shows that collaborative and coordinated decision-making can mitigate the dangers of high interdependence, allowing firms and alliances to continuously innovate without compromising their ability to adapt to a dynamic landscape. In contrast to the current economic frameworks that emphasize the autonomy and profit-maximization of individual firms, these studies show that performance of all firms in an alliance can increase in the long-term through an approach that emphasizes coordination and shared governance.

Finally, a recent insight from McKelvey and his colleagues (McKelvey, Li, Xu, & Vidgen, 2010) suggests an even more radical method of coordination across a network, i.e. in situations that go beyond limited alliances. They start with a detailed examination of the presumed NK landscape 'fact' that too much interdependence will cause a complexity catastrophe across the system; however in their analysis they show that a complexity catastrophe is not a theoretically proven fact but is only an *artifact of the simulation* design. They explain that since agents in the simulation interact *at every tick of the system* (at every time period), the NK model assumes that agents communicate *very frequently* with each other. Such high-frequency interaction reflects strong-tie networks; however, according to longstanding theories of innovation networks the most common drivers of innovation are in weak-tie networks, i.e., social ecologies in which agents interact rarely (infrequently). How can the NK landscape model be 'tuned' to reflect this more entrepreneurial context of weak-tie interactions, and how does that alter the findings from NK landscape theory?

To answer these questions, the research team incorporated (programmed) a new dimension of interaction into the model, namely frequency of interaction, *F*. The result of this single change is dramatic: At a certain threshold of lower-frequency interactions the complexity catastrophe no longer occurs: "[N]ot only do we see the disappearance of a complexity catastrophe, we see instead that increasing K [interdependency] has just the opposite effect: the fitness [of the system] increases" (McKelvey et al., 2010: 19). Thus, in complex social ecologies like electricity transmission, higher levels of interdependence do not have to lead to a locking up of the entire system; instead, higher performance can aggregate, *as long as* the agents reduce the frequency of their interactions down to 1-2 times/year/agent, thus maintaining an entrepreneurial, weak-tie environment.

In sum, applying these computational models to the energy grid leads to a number of intriguing proposals for improved innovation, including reducing the overall interdependency across agents, using shared governance to improve coordination in alliances, and decreasing frequency of agent interactions in order to preserve an entrepreneurial weak-tie network of innovation.

Opportunities for Further Research

Beyond ABM and NK Landscape models, complexity science provides many additional avenues for improving the process of electricity transmission planning. For example Holling and his colleagues have developed integrated models of ecosystem resilience, which explain how social and natural ecosystems remain adaptive to environmental and socially-caused change (Holling, 2001; Folke et al., 2004; Walker et al., 2006; Liu et al., 2007). The resilience work also features a model of ecosystem 'flip' – how and why ecosystems can rapidly transform into new and often less adaptive regimes of behavior when they lack the key ingredients of resilience. Such models might be applied to explore how to integrate renewable energy onto the grid, through a 'flip' in values and perspectives that underlie the current economic and political structures of the electric grid.

Another example is complexity models of emergence and order creation that are based on dissipative structures theory (Prigogine & Stengers, 1984; see Lichtenstein, 2000; Chiles et al., 2004; Plowman et al., 2007). These approaches explain the dynamics of emergence that lead to the creation of new systems, new companies, and new communities of organizations. Such models might be applied to the rise of a clean-tech economy, as well as to better understand the obstacles that clean-tech companies face when starting up in conditions that are "unfavorable" to pure competition because large utility market power reduces the economic inefficiency of the market (Tesfatsion, 2011: 17).

Other intriguing examples include how power-law dynamics (Andriani & McKelvey, 2007, 2009; Boisot & McKelvey, 2010) could explain the disproportionate influence of large utilities on the electric grid, and how Complex Systems Leadership Theory (Uhl-Bien, Marion, & McKelvey, 2007; Hazy, Goldstein, & Lichtenstein, 2007; Uhl-Bien & Marion, 2008) might be used to help catalyze social movements which are aiming to increase the amount of renewables onto the grid.

Even the two disciplines that I've summarized in this paper, Agent-based modeling and NK Landscapes, provide many directions for further study. Examples of research questions that stem from the findings reviewed here include:

- What governance options are most effective for reducing the biased advantages that accrue to large utilities and ISOs on the grid?

- How can GenCos profits be maintained (not minimized) when consumers gain more control in electricity purchases (i.e. in the presence of higher price-sensitivity of demand)?

- Without increasing regulations, how can utilities and GenCos to be incentivized to integrate more renewable energy into the grid?

- In electricity transmission planning, how can interdependence across entities be reduced while maintaining an appropriate level of distributed decision-making?

- When does (and does not) greater regulation across entities and levels serve to increase the long-term benefits of electricity generation?

- How can entities reduce the frequency of their interactions, and to what degree will this reduce the complexity and interdependence across the social ecology?

Further questions could easily be developed, but pursuing even a few of these could generate a good deal of insight into the electricity transmission planning process.

In addition to the potential content of these studies, my aim has been to highlight the value of complexity science in exploring the dynamics of decision-making and action around the electric grid. One aspect of this value, exemplified in the computational models of complexity presented in this paper, is the ability to experiment with a wide variety of parameters within a consistent frame that is realistic but without risk, i.e. these models simulate real-world dynamics without requiring unpredictable experiments in real communities (Sawyer, 2005). Another value of complexity science, exemplified in my introduction, is the power of viewing the entire process as a social ecology, a biological/systemic frame that can benefit from a host of insights from complexity research in similar contexts – e.g. Holling (2001), Prigogine (Prigogine & Stengers, 1984); Holland (1998); Bak (1996; Bak & Chen, 1991); Guastello (1995, 1998); Strogatz (2003); Sawyer (2005); and more. As such, complexity science may provide a sound basis for understanding the dynamics of electricity transmission planning.

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What in High Reliability Organizations (HRO) Research Might be Useful in Transmission Planning?

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Abstract. With important changes facing electricity systems, transmission planning may well be reaching a crossroad. Major challenges now loom for the future of grid reliability. A distinctive line of organizational research has focused on describing strategies and practices employed by organizations that have successful records in managing hazardous systems reliably. A review of this research and its major findings suggests some useful applications for transmission planning in promoting long-term as well as real-time grid reliability. In particular, this paper argues for an analytical distinction between planning for reliability and reliable planning.

The author would like to thank the staff at the Energy Policy Institute (EPI) for providing me the opportunity to write this paper in connection with EPI's Workshop on regional electricity transmission planning. Great help with this paper was provided by three Transmission Resource Mentors (TRMs): Brad Nickell, Director of Transmission Planning for the Western Electricity Coordinating Council, Chris Mensah-Bonsu, Regional Transmission Engineering, California Independent System Operator and Jeff Miller, Vice-President, Planning, Columbia Grid. These were wonderful mentors. They gave very generously of their time and offered often stunning insights as they labored to educate the author in the complex issues of transmission planning. But, as the saying goes, "against stupidity even the gods contend in vain." All the errors and insufficiencies in this paper are certainly my own.

Introduction

It seems clear that on many fronts impending crossroads appear likely for grid reliability. Electricity restructuring and future distributed generation continue to enlarge the number of grid “players” -- many with motives diverging from grid reliability (Wu, Zheng and Wen, 2006). State renewable portfolio standards (such as California’s RPS requirement for 33% renewable electricity procurement by 2020) demand incorporation into grids of intermittent and remote energy resources (CAISO, 2011). Smart grid technologies and pressures for transmission and distribution automation raise additional reliability challenges. All of these make transmission planning an even more critical element in future grid reliability.

Yet to meet these challenges not only will plans have to cope with grid connectivity of more complexity and scale, but the planning process as an organized activity may itself have to evolve. Addressing reliability challenges while at the same time incorporating new stakeholders and their diverging economic interests may well require some significant organizational adaptations and innovations.

Implications of HRO Research for Transmission Planning

The HRO Perspective

Two decades ago a group of researchers undertook to study a set of very unusual organizations. They included the U.S. Navy aircraft carrier the USS Carl Vinson, the Pacific Gas and Electric Company’s Diablo Canyon Nuclear Power Plant in San Luis Obisbo, CA, the Federal Aviation Administration’s air traffic control center in Oakland CA and, later, the California Independent System Operator, the organization that managed the entire high voltage electricity grid in the state of California. Each of these organizations had the challenge of managing and operating technologies that were capable of failing with catastrophic effects.

These organizations operated within very unforgiving environments – there was hardly any political or economic tolerance for failure. They were expected not only to safeguard the safety of their operations but also to provide highly reliable outputs: military capability and readiness, electricity availability and safe air traffic management at all times, including peak periods of high demand.

The original research into these “high reliability organizations” was based on extraordinary access extended to researchers who spent months or longer observing their operations under a wide variety of conditions and interviewing hundreds of personnel at all levels, from top management to control room operators and maintenance workers on the shop floor (LaPorte and Consolini, 1991; Schulman, 1993; Roe and Schulman, 2008).

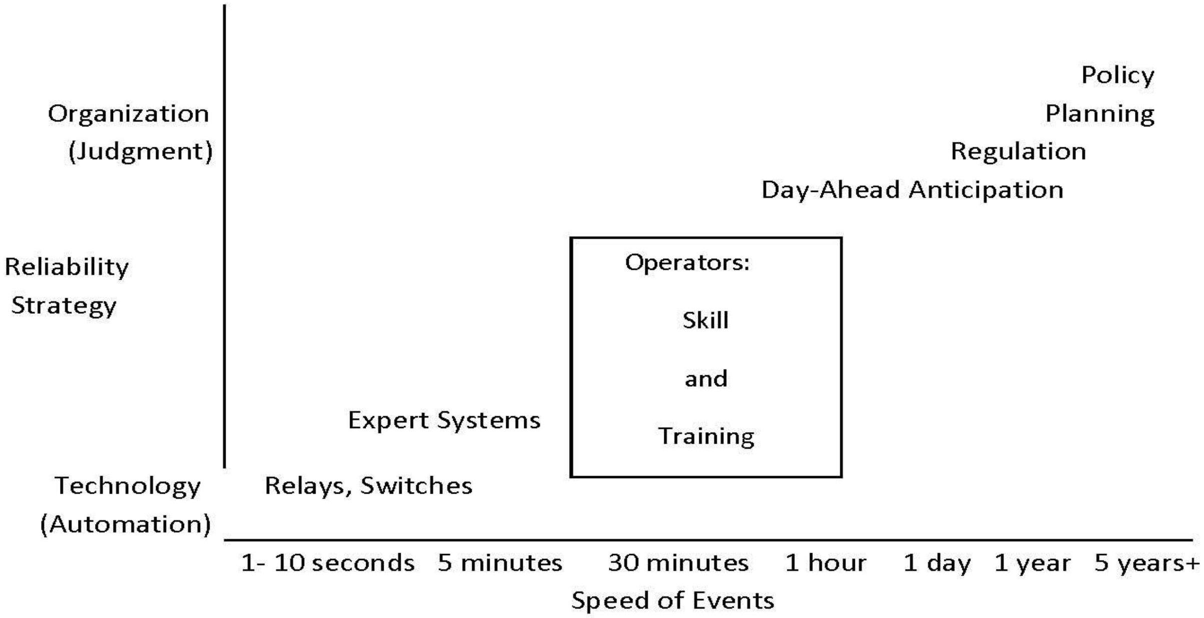
These organizations displayed a number of distinctive features. They are detailed, along with the major findings of this research, in APPENDIX A.

While work planning was an important feature of the observed HROs and day-ahead generation scheduling is critical in CAISO, the time horizons of planning in these organizations did not approach the 10 to 15 year frame for transmission planning in the Western Region. Nevertheless there are important connections between high reliability organizations research and long-term transmission planning.

A "Unified Theory" of Reliability?

It is possible to frame a continuum of reliability requirements and strategies ranging from operations to planning, and even including regulation and policy. This continuum can be arrayed across two dimensions: (1) the *speed* of system events which need to be managed for reliability and (2) the *strategy* appropriate to manage these events reliably[8]. The speed of events can run from fractions of a second (the physics of electrons) to 30 seconds, 1 to 5 minutes, one hour, a day, a year or, in the case of transmission planning, 5 to 10 years or more. The other dimension is the strategy approach for reliability, ranging from technology (in the form of automation) to organization (highlighting human decision-making and judgment). Consider a reliability continuum along these two dimensions shown below in Figure 2:

Figure 2: A Grid Reliability Continuum: Speed vs Strategy



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[8] I am indebted to Brad Nickell, Planning Director at WECC for suggesting these dimensions.

When things happen at the speed of electrons, then fast acting switches and relays that can respond faster than humans are a fundamental strategy for reliability. At slower speeds (under 1-minute) automated special protection systems, such as Remedial Action Schemes, can provide protective reliability through automated pre-planned action.

As action and reaction speeds lengthen (above one minute) expert systems, such as CAISO's real-time market analyzer (RTMA) can consider tens or even hundreds of grid variables and offer continually updated market "solutions" to optimize power prices and transmission routes through automated dispatching instructions.

But here the pattern recognition skills of operators begin to match the speed of grid events. At time periods lengthen from 5 minutes to one day, reliability is managed by operators *at the speed of judgment*. At a day ahead, schedulers and outage coordinators have a prominent role in promoting the reliability of energy supply. As response time frames lengthen from one year to 5 years, regulators and regulatory agencies promote reliability through standards and inspections. From 5 to fifteen years transmission planning and public policy lay long term frameworks for reliability.

The points along this time/strategy reliability continuum are connected. Policy and planning meet, for example in FERC's TPL standards. Further, as Chris Mensah-Bonsu, regional transmission engineer at CAISO observed, "Anything that happens in planning ends up in ops." The focus of much planning is to improve reliability in operational time and strategy. Planning may be directed toward congestion relief, toward enlarging transmission capacity to cope with projected load increases or to deploy new technologies, in line carrying capacity, for example, that can also improve grid reliability.

At the other end of the continuum, the trips of automated switches and Remedial Action Schemes can also impact ops by leaving operators with grid configurations they must appraise quickly and adjust to in order to stabilize the grid and restore full grid capacity (AESO, 2009).

From their position near the center of the grid reliability continuum, operators not infrequently must buffer and compensate for technical design errors through work-arounds, such as their strategy of biasing load forecasts in RTMA in order to "tune" its dispatching decisions. From the other direction, operators also buffer errors or insufficiencies in day-ahead scheduling or outage planning, as well as develop compensatory strategies for regulatory, policy and longer-term planning "errors" as well.

The grid reliability continuum can highlight mismatches in speed and strategy that may threaten reliability. Clearly, putting operators in positions where they have to engage in pattern recognition and make decisions time periods of a minute or less will undermine human cognitive capacities and result in "forced errors" in judgment.[9]

So too regulation, planning and policy judgment can be too slow to keep up with new technologies or with evolving challenges to grid reliability in population shifts, electricity demand or economic conditions. But regulation and policy might sometimes be too *fast* to allow for grid planning to promote reliability at its speed of deliberation, judgment and approval. Brad Nickell, Director of Transmission Planning at WECC, listed policy as one of the least stable and predictable elements in the planning environment, less predictable and stable than demographic changes and economic cycles. Even regulatory decisions might shift rapidly and undercut planning priorities and forecasts.

Serial vs. Parallel Connections along the Continuum

A recent article on "safety chains" describes the dangers of treating layers of defensive protection as comprising a serial chain (Jonegjan, Jonkman and Vrijling, 2012). The problem with a serial connection is that it breaks or fails at its weakest link. The authors suggest instead that the elements of safety should be treated as running in parallel to one another.

A similar argument can be made with respect to the reliability continuum. If the continuum is treated as a serial connection between separate and independent processes, then error at any one point will ramify widely throughout the chain. A planning error will affect operations, as will technical design errors in automated or expert systems. But if there is cross connection between these processes the outcome can be *more* reliable than the weakest part. Cross connections allow for compensatory, interactive and supplemental reliability among different sections of the continuum

This parallel connection can occur by involving operators in transmission planning as both consultants and clients. Similarly engineers who design technical systems can spend time in control rooms learning first-hand the challenges operators face. Cross-talk between planners, policy-makers among regulators with each other and with operators can also enhance reliability at all portions along the continuum.

In particular, such cross-over contacts can help protect against errors of misestimation, mis-specification and misunderstanding throughout the continuum of reliability speeds and

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[9] The error proneness of "fast thinking" in human beings has been highlighted recently by Nobel Prize winning psychologist Daniel Kahneman (2011).

strategy. It is these errors that high reliability organizations spend a great deal of time and effort to prevent (Schulman, 2004). From this perspective applying high reliability theory to transmission planning suggests a useful distinction between *planning for reliability* and *reliable planning*.

Planning for Reliability vs. Reliable Planning

Why is reliable planning distinct from planning for reliability? Planning for reliability is about the identification and selection of desirable transmission outcomes that promote grid reliability. But reliable planning is about the process of planning itself – a process for selecting appropriate means for achieving those high reliability outcomes (or any other policy objective) in electrical grid management. It is one thing to make trade-offs between competing objectives in planning – environmental, economic and reliability improvement. It is quite another to have confidence that planning objectives and the transmission assets once implemented will actually work as expected to achieve the policy objectives agreed-upon. As such, reliable planning is both an implementation and a subsequent grid management problem.

Planning for reliability entails promoting those transmission outcomes which will protect or add to reliability in grid operations and performance. Again, meeting FERC guidelines, coping with increased load, relieving grid congestion or facilitating new technologies in transmission systems are all issues to address in planning for reliability.

But another aspect of reliability is reliable planning itself. This refers to the process of planning and the degree to which it is conducted with protections against errors of misestimation, mis-specification and misunderstanding. Is planning itself sensitive to potential errors in forecasting, does it seek to understand the actual needs of operators, and does it accurately anticipate how new transmission assets will actually perform in practice?

Reliability theory suggests general errors to avoid in reliable planning:

A. Errors of underestimated uncertainty. These are errors of overconfidence and overplanning – planning to a level of false precision relative to forecast accuracy, cost estimation and implementation capability.

B. Errors of risk avoidance. These are errors of delay, inaction or omission.

C. Errors of optimism and reduction; asking the wrong questions and answering them precisely. (Kahneman, 2012; Mitroff and Silvers, 2009).

Another element in reliable planning is to preserve reliability at the speed of judgment; that is, again borrowing from high reliability theory, to protect operator zones of competence and keep them out of precursor zones, where skills and judgment might be degraded. Here planners can apply what we have come to call the operator reliability test (Roe and Schulman, 2008). The test consists of four questions to ask of proposed plans and technical designs:

- Do they increase system volatility?
- Do they reduce operator options?
- Do they eliminate alternate performance modes?
- Do they threaten to push operators into their precursor zone?

If the answer is yes to any one of these, some careful re-thinking is called for.

There are additional process safeguards in transmission planning that enhance its reliability as a process. One, given the possibilities of forecast error (in load, economy and policy) is strategies to maximize decision retrievability. CAISO has yearly plan “reconfirmation” processes and Columbia grid has yearly planning “assessments” to test and reconcile planning commitments with actual developments as they unfold. Another related strategy is to “shallow out” if possible the trajectory of sunk costs. High start-up costs can “capture” decision-makers in spirals of escalating commitment, rigidifying their decisions and magnifying errors.

In general, given its unusually long time-frame, reliable transmission planning must mean planning for surprises. This means assessing the operational implications of new transmission assets if they don’t perform as expected. Will higher capacity lines, for example, mean larger consequences for grid volatility if they operate under curtailments or if as part of a RAS scheme, they trip off (Newman, Carreras, Lynch and Dobson, 2008)? In this era of complexly inter-connected infrastructures, to what vulnerabilities will new transmission assets be subject, and which will they impose onto other infrastructures that depend on them, such as telecoms and transport (Luiijf, Nieuwenhuijs, Klaver, Van Eeten, and E. Cruz, 2012).

Conclusion

Planning for reliability or any other policy objective is founded on the assumptions that stakeholders make about planning options and their actual connection, once implemented, to the achievement of objectives. Reliable planning requires that stakeholders understand where they are with respect to risk, uncertainty and ambiguity surrounding transmission options and likelihood that new assets, once implemented, will actually achieve their objectives.

Reliable planning parallels in important ways the connection between reliability and markets. At the beginning days of CAISO a control room banner read: “Reliability through Markets.” This banner came down quickly at the onset of the energy crisis. The banner should have read “Markets through Reliability.” It takes reliability as a starting point – a *background condition* – for the bargaining among market interests (generators, distributors and users) to arrive at and consummate transactions through the grid. Grid reliability therefore is not primarily the *outcome* of market competition, it is the *starting point*, the underlying requirement for market competition. So too is reliable planning the underlying requirement for the selection of policy objectives in relation to the grid.

Many electricity system “practitioners” seem to regard stakeholder acceptance as the validation of the transmission planning process. But in reality stakeholder acceptance of a plan is only the *start* of a validation process -- a process that ends when transmission assets are in place and *perform as expected*. This requires that planners and stakeholders have not misestimated, mis-specified or misunderstood the options they have chosen. This is the ultimate cognitive foundation for high reliability management.

It’s important to talk about solving political and collective action problems in securing transmission plan acceptance. But without reliable planning none of the collective objectives are themselves secure. All stakeholders, including grid managers, could potentially find themselves worse off for engaging in the process.

APPENDIX A - Schulman

Basic Findings in High Reliability Organizations Research

Some of the basic features of HROs are detailed in Table1 below:

Table 1

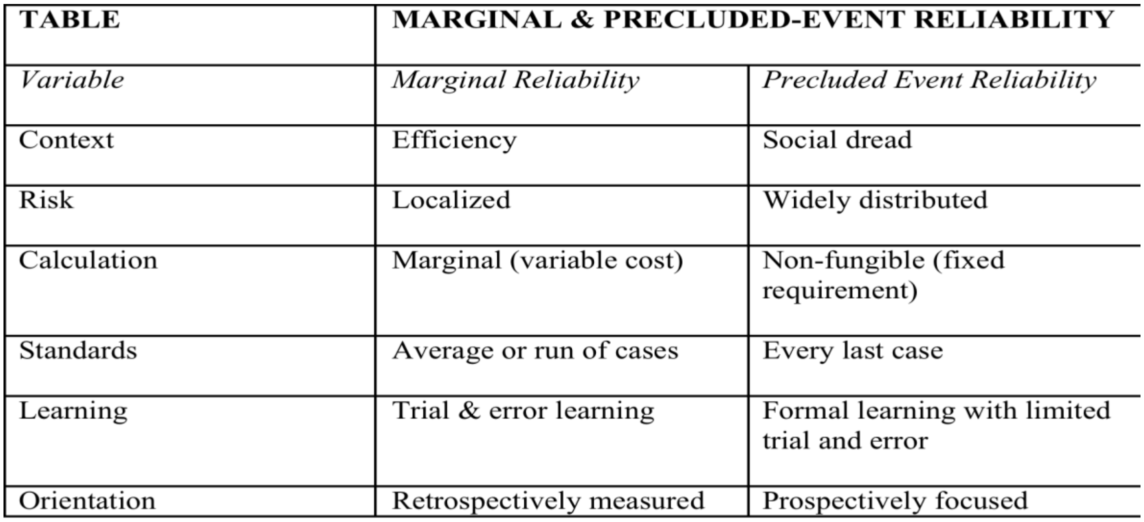


TABLE	MARGINAL & PRECLUDED-EVENT RELIABILITY	
Variable	*Marginal Reliability*	*Precluded Event Reliability*
Context	Efficiency	Social dread
Risk	Localized	Widely distributed
Calculation	Marginal (variable cost)	Non-fungible (fixed requirement)
Standards	Average or run of cases	Every last case
Learning	Trial & error learning	Formal learning with limited trial and error
Orientation	Retrospectively measured	Prospectively focused

The managers and higher executives in these organizations did not treat reliability as a marginal property. They did not consider trading-off a measure of reliability as a variable cost for a measure of overall expense reduction, increased speed or efficiency. Instead, they managed to a standard which we called "precluded event" reliability. (Roe and Schulman, 2008). They identified a set of events which simply must not happen, at any cost. These events they tried to preclude deterministically rather than probabilistically. That is, they were concerned with preventing them in every last case, not over the run of cases or for the "average" case. Reliability expenses related to precluding these events were treated as fixed or baseline requirements for their organizations to operate.

One reason was because often they existed in highly regulated and watchful environments that constrained these trade-offs. Regulation also protected these organizations from strong market competition that would have put pressure on them to cut costs or prices. Any competitors would be subject to the same regulatory constraints.

The operation and management of these organizations was conditioned more by a public dread about failure than by pressure for competitive efficiency. The risks were not confined to one operating unit but were widely distributed throughout the organization and beyond. It's no surprise that most of the HROs were either public agencies or highly regulated monopolies.

In addition, the executives, managers and employees of these high reliability organizations all treated reliability as an indivisible and perishable organizational property. They tried constantly to improve reliability on all fronts. The managers especially seemed to “run scared” about their operations -- often they expressed the view that if they didn’t maintain a continuous search for improvement, they might fall into complacency and lose the reliability they had already attained (Weick and Sutcliffe, 2007).

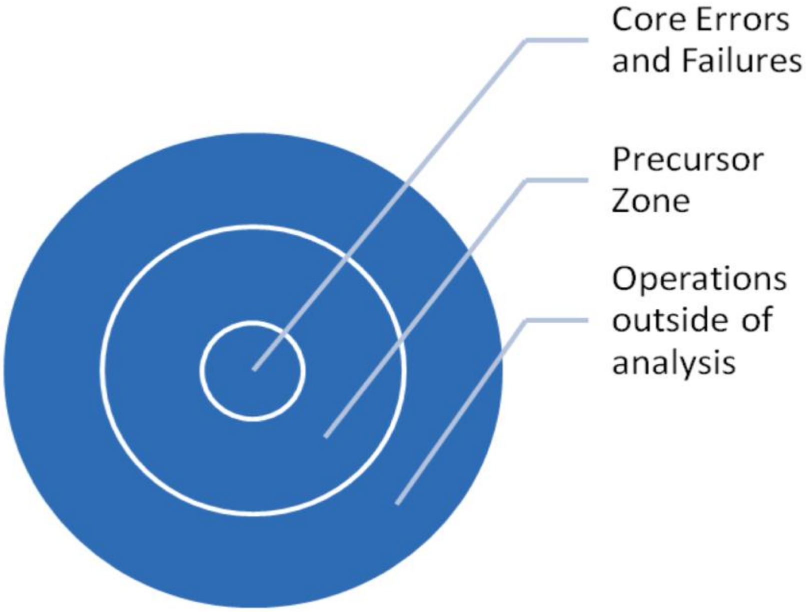
This holistic concern with reliability even penetrated into what might seem like peripheral activities – the cleanliness of work spaces and work benches, even the management of cafeteria operations. A general well-orderedness in these organizations seemed to be associated in the minds of managers and workers alike with the critical reliability these organizations were seeking to maintain.

Finally, a key property of the precluded event reliability orientation was that it was prospective. For the many managers, operators and employees we spoke to, their organization was only as reliable as the first accident or failure out ahead, not the many successful operations behind them. This was in stark contrast to many conventional organizations that define their reliability through past performance, an approach that can lead to complacency and overconfidence.

In fact HROs seem to achieve reliability and safety not through their valuation of these as positive goals per se, but negatively through a strong aversion to misunderstanding, misperceiving or mis-specifying key elements of their operation. In an organization greatly concerned about representational errors everyone can be a “partisan of the neglected perspective”. Even though trial and error were sharply bounded, these were strongly committed learning organizations. As a maintenance department head in a nuclear power plant, said to his staff after signing off on a new procedure: “don’t let people think that this technology can’t still surprise them” (Schulman, 1993).

Each organization had major investments in fail-safe devices, back-up redundancies or automatic shutdown systems to keep its precluded event from happening.
But, in addition, through careful analysis each of the HROs had identified precursor accidents or conditions that could lead through a chain of events to a dreaded core accident.

Figure 2



They organized operations around rules, procedures and training to keep themselves out of this precursor zone. All of the organizations drew a bright line around this precursor. In most of them operators as well as managers could veto actions that would place them in this zone. Nuclear control operators can refuse to allow maintenance operations on operating reactors which would place them in this zone. They can shut down reactors when precursor conditions arise. Air traffic controllers can officially refuse to accept responsibility for maintaining aircraft separation when conditions threaten safe operations – as they did once when a software test mandated by the Federal Aviation Administration test got out of hand -- threatening to pre-occupy their attention. Their declaration stopped the test right away.

The relentless search for improvement in these organizations led them constantly to do new failure and worst-case analyses and often to enlarge the precursor zone outward to include additional unacceptable operating conditions, thereby adding new layers of reliability enhancing protections.

In addition to the analyzed precursor zone conditions, the HROs attempted to protect their reliability still further by keeping operations away from uncertainty. In most of the organizations there were prohibitions against performing operations which had not been fully analyzed. In formal terms, risk assessors and probability analysts generally distinguish *risk*, where both probability and potential losses are calculated, from *uncertainty*, where one or both of these are unknown. HROs tried to keep operations from being performed under uncertainty. Uncertainty was given a formal status in these organizations, including specific language to identify it as a condition, and specific procedures and prohibitions to prevent operations within it. In nuclear power plants, for example, the term is operating “outside of analysis” a prohibited condition and a formal violation of Nuclear Regulatory Commission regulations. In other HROs complaints by control operators that they are in “unstudied conditions” have to be taken seriously and addressed by upper management.

So here were some surprising contrasts we found between HROs and many conventional organizations we had studied. The prospective pessimism we observed about error and failure was quite different from many of the optimistic reliability assessments that dominated many other organizations, assessments founded on past success. Many of these organizations highlighted safety awards they had received for employee low accident rates in prior years. In the HROs there was never a blind trust that Murphy ’s Law had been suspended, nor an acceptance that few slips, trips and fall were synonymous with reliability and safety.[10] Instead there was a constant emphasis on improving reliability across many fronts and renewing mindfulness among all employees (Weick and Roberts, 1993).

Instead of a focus on the punishment of error at the individual worker level, HROs considered operational error to be a *system* issue. They were more interested in understanding the cause of the error, learning about it and then redesigning it away through training or procedural corrections and revisions. We found an extra-ordinary level of ownership of procedures in the HROs, down to the shop level, by those who carried them out. Individual workers were encouraged to initiate procedural revisions to correct their errors and limitations.

From all of this a general proposition emerges from our HRO observations and assessments. Basically it’s that high reliability is not synonymous with invariance in organizational operations. Instead high reliability is a result of the management of fluctuations in key organizational processes and relationships. It’s the containment of fluctuations, rather than their elimination, that is the key to high organizational reliability (Schulman, 1993). Fluctuations in mindfulness, for example, are contained by strategies to “renew the fervor” when mindfulness starts to decay. Fluctuations also occur in levels of inter-departmental credibility and trust.

The precursor and uncertainty zone strategy distributes veto powers around in high reliability organizations to control operators, engineers or even maintenance officials when they deem conditions or proposed actions to be “unsafe”. But to exercise these options requires that these

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[10] It is ironic that shortly before the explosion and fire on the Deepwater Horizon, BP and Transocean officials had visited the rig to present a “safety award” to the crew.

individuals and their departments have credibility in the eyes of other departments in the organization. It's the same with trust. People have to trust that others also share their same reliability goals. Without credibility and trust the planning and coordination of complex tasks, among specialized departments with specialized skills could not be achieved. As one department head told us: "every day is a new day in interrelationships and holding onto trust. It never gets institutionalized." Finally, ambiguity can develop in communications and in shared understandings of plans and proposed actions. Reinvestments must be made in sustaining a common pattern in what psychologist Karl Weick has called "sensemaking" among organizational participants (Weick, 1995).

Managers of HROs knew that these fluctuations could and would occur in their organizations. Reliability was never an accomplished end for these organizations, never completed once and for all.

An Alternate Reliability Approach at CAISO

As later research on high reliability proceeded it became increasingly evident that the HROs we were describing were extremely rarified, unusual organizations. For the most part they were self-contained organizations with a great deal of control over their internal operations. They had production or service technologies that were well understood. When we looked carefully at the California Independent System Operator (CAISO) we found some significant variations in the earlier HRO pattern (Roe and Schulman, 2008). CAISO was a networked organization, with many players in its production process outside of its organizational boundaries and immediate control. Table 2 below highlights some comparisons:

Table 2: Classic HRO vs. Network Model of High Reliability

Classic HRO	**Network HRO**
Standardized raw material; repetitive problems	Unstandardized materials; large problem variety
Formal deductive principles cover system behavior	Important role for experiential and tacit knowledge
Command and control of system inputs and outputs; low input, process and output variance	High input variance; low output variance; high process variance
Action within analysis	Improvisational actions
Action under anticipation	Major role for real-time action
Control through formal design	Operational redesign

There really are at least two approaches to high reliability we've uncovered. In a classic HRO – the nuclear power plant – the inputs (operating conditions, resources, demand for service) were under strong control by the organization. Guns, gates and guards physically insulated the organization. All the incoming resources: equipment and materials were subject to "nuclear standards" and carefully tested. Personnel were also carefully screened, including psychological testing. Even electricity demand was under plant close control – the plant could be taken off line by operators if they were not satisfied that operating conditions were outside on the precursor zone. The low input variance they were able to achieve led to low process variance that is, operating activities followed standard procedures and anticipatory analysis. This all led to low output variance, that is, the high reliability they sought in their operations.

For CAISO, on the other hand, input conditions and resources are far different. They can't control or very accurately predict the state of the electrical grid. The grid can assume many different configurations. Load shifts considerably throughout the day and across the seasons. Weather makes a major impact on grid conditions – storms can disrupt key sections of transmission line. Generators can go offline for a variety of unpredictable reasons. Further the generators themselves vary widely in their reliability, generating capacity, and the speed with which they can ramp-up to full generation. The electrical system is filled with non-standardized parts. Yet CAISO must manage the grid with very low output variance – load and generation must closely match hour after hour, voltage and frequency must be kept within narrow limits.

These narrow output variations are the reliability standard for CAISO. How can an organization translate high input variability into low output variation? The answer is with *high process variation* – enough flexibility to cope with a wide variety of shifting conditions. Operators were able to shift performance modes as circumstances required – from highly anticipatory proceduralized operation when conditions were stable to real-time focused responses during unstable or stressful conditions under which options were invented and improvised. As one dispatcher confided during an interview: "sometimes you have to know when not to follow the rules."

Another way to contrast the two types of organizations is to return to the fluctuations described earlier. In classic HRO the fluctuations are managed within a "bandwidth" of acceptable variations mapped out by prior, anticipatory analysis. But for CAISO, fluctuations often had to be managed through active, real-time analysis.

We found in CAISO operations an alternate approach to high reliability. Here the organization presented a robust service reliability to the outside world by means of internal operational resilience in the face of widely varying, even surprising grid conditions. This networked approach was really a resilience dependent reliability. Again the classic HRO is organized around standardized raw material and repetitive problems. The resilience focused HRO confronts unstandardized raw material and a large variety in operating problems. The classic HRO has command and control over its input conditions and achieves low output variance though low process variance. The resilience dependent HRO has high input variance and achieves low output variance through higher process variance.

The classic HRO operates under well established design principles expressed in formal models that cover most important aspects of its operation. These are embedded in the formal procedures followed in the organization. In a resilience dependent organization like CAISO, some of the behavior of the system is understood and recognized as tacit knowledge, gained through experience. Operators may be forced to operationally re-design the formal designs of technical systems, through “work-arounds” or other adjustments and adaptations.

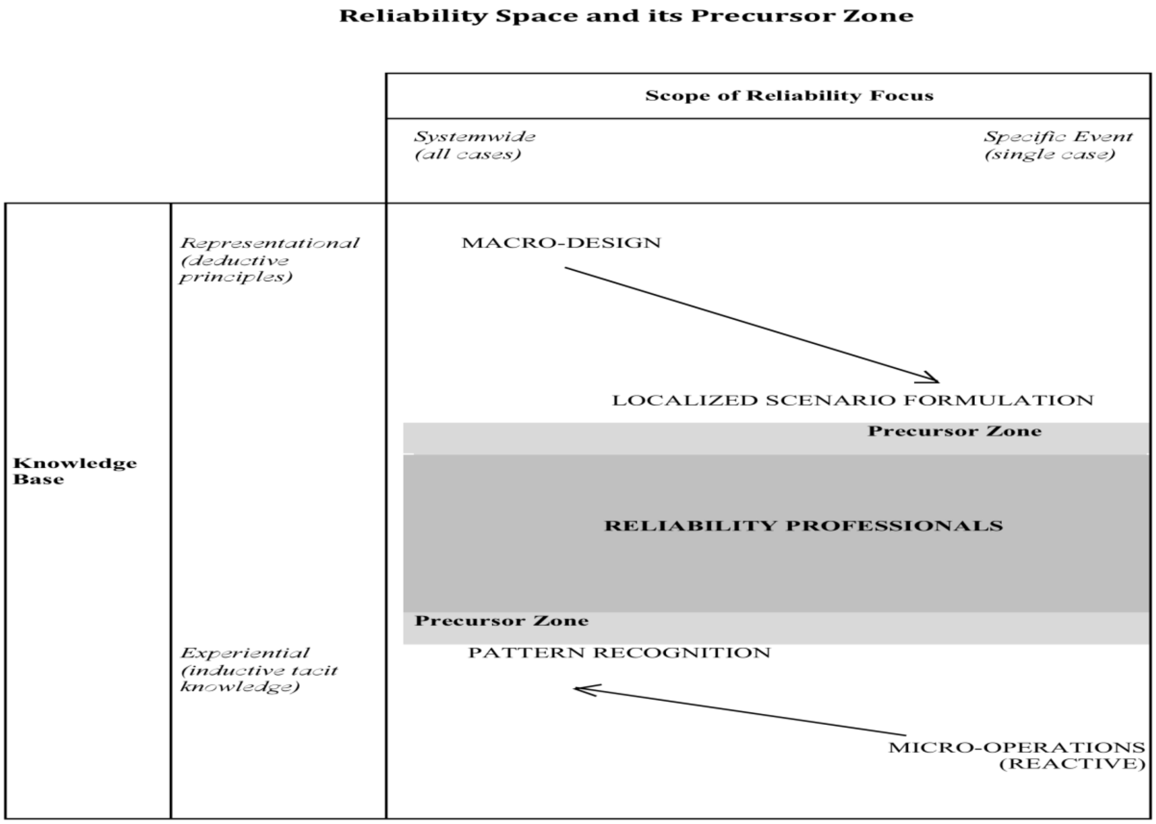
The judgment of operators and managers may not be written out and taught as formal principles. Where decisions and action in a nuclear power plant must be undertaken within procedural frameworks established by formal prior analysis, in CAISO there is an important role for improvisional actions taken as a consequence of real-time, on the spot analysis.

In observing operations in CAISO it quickly became apparent that given its far less settled conditions of operation a special cognitive challenge emerged for operators. Think of the mental approach or what we call the “cognitive space” in which operators have to function to manage their technical systems reliably. A sketch of that cognitive space is presented below:

The reliability space can be described in two dimensions: the type of knowledge they must use to operate and the scope of the attention they must pay to make good decisions and understand what’s happening in their technical systems.

The knowledge can run from formal deductive principles in science and engineering to experience-based tacit knowledge. The scope of attention can encompass the entire grid and its connections or be narrowly focused on a single portion of the system where a problem or event has taken place, say a portion of transmission line that has failed or a generator that’s gone offline.

Figure 2: A Cognitive Model of Operators in Networked Reliability Settings



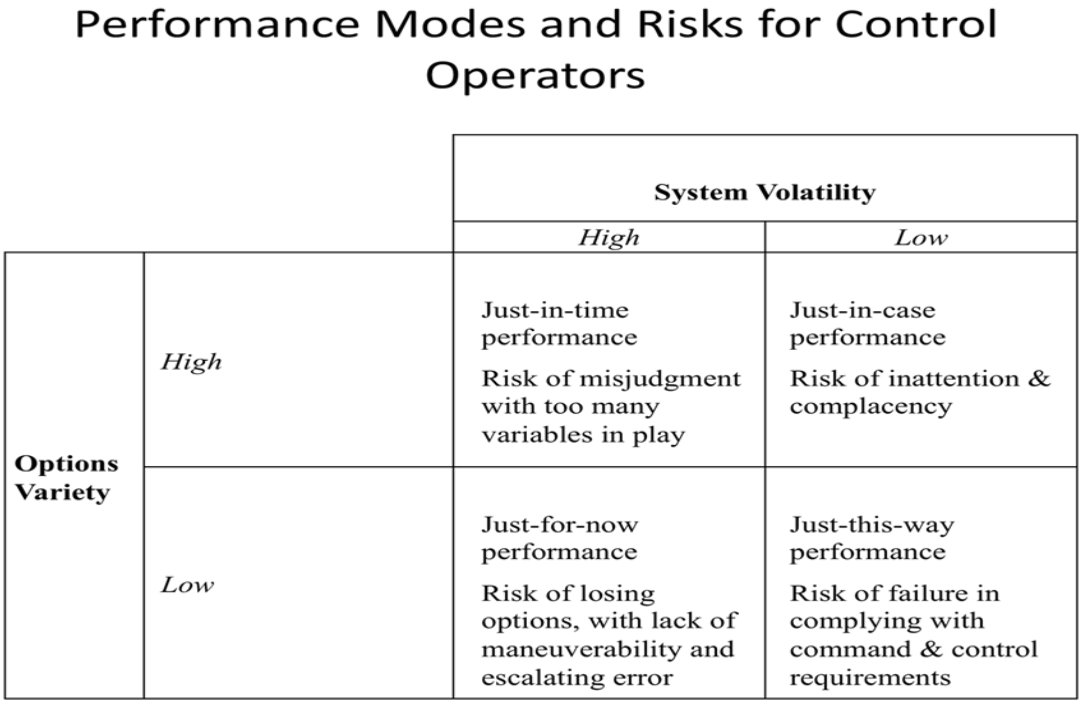
At the extremes of either of these cognitive dimensions reliability is threatened. Attempting to understand and manage an entire complex and highly variable system like an electrical grid holistically only through its formal design logic is fraught with peril because there will be conditions not anticipated or covered in a formal design. Trying to manage by focusing only on a single point of failure and applying only experiential understanding could lead to myopic and reactive “fire-fighting” by operators who fail to consider the wider implication of actions they take. This cognitive extreme risks losing sight of the forest for the trees; the former risks seeing only the forest and missing individual trees. It’s also risky to attempt to impose only a system-level understanding onto a single case or to generalize to the entire system a lesson learned from a single case.

Skillful and experienced operators, whom we came to call reliability professionals, avoid these extremes by operating in the middle of both the knowledge and attention dimensions. They mix both formal and experiential learning in their understanding of how their systems work. They also see a middle range of their system not trying to focus on everything at once and not getting lost in the particulars of one narrow piece.

This position supports the cognitive skills they use in operating and managing their systems. One skill is that of pattern recognition. They are very good at detecting a larger pattern in events that are happening at local points and at foreseeing how a local action might have wider implications. They also are good at formulating and remembering scenarios for action. Their construction and use of scenarios resembles closely the “recognition-primed” decision-making process used by experts in aviation and fire-fighting as described by psychologist Gary Klein (Klein, 1999; 2011). Note also that for these reliability professionals, conditions of high system volatility as well as new technologies, or organizational practices that degrade their pattern recognition or their scenario formulating capability can place them in a precursor zone with respect to reliability.

Finally, we were able to discern that operators at CAISO added to their “process variance” by having multiple performance modes in which to operate, modes which allow the, to more closely match the shifting managerial requirements of different grid conditions they could encounter. These differing performance modes are described below:

Figure 3



Performance Modes and Risks for Control Operators

		System Volatility	
		High	*Low*
Options Variety	*High*	Just-in-time performance Risk of misjudgment with too many variables in play	Just-in-case performance Risk of inattention & complacency
	Low	Just-for-now performance Risk of losing options, with lack of maneuverability and escalating error	Just-this-way performance Risk of failure in complying with command & control requirements

When grid conditions are stable and options plentiful operators work in their nominal performance mode. We call it "just-in-case" performance because operators often engage in thinking ahead exercises (some call it the "what if?" game) about possible contingencies and what options they would employ to cope with them. These exercises are done by operators to ward off the risk of complacency associated with this lowest tempo mode of operation.

When grid conditions become less stable but options still remain for operators (e.g. there is still plenty of reserve generation or alternate transmission paths available) operators respond by shifting into an alternate performance mode which we termed "just-in-time". Here their focus is on real-time and they may need swiftly to shift to alternate options. Sometimes in this mode they are improvising options rather than simply reviewing an inventory of previous action scenarios. The risk in this mode is that of operator misjudgment under pressure for real-time responses to many variables in play.

If instability continues and operators run out of options they then face the least desirable and least reliable performance mode, "just-for now". This term stems from informal phone calls made by CAISO dispatchers to generator operators during the 2001California energy crisis begging them to keep their generators running "just-for-now" until load dropped and they could again recover reserve safety margins for grid operation. As one dispatcher observed ruefully during this mode, "I'm all tapped out." The risk here is that if operators cannot exit this mode quickly even a small failure can ramify widely and trip the grid into escalating instability and failure.

Finally, CAISO operators had a last performance mode available to them to stabilize the grid. This mode, "just this way" is a formal, law-based command and control configuration to override voluntary discretion by grid participants. Initiated by a formal "declaration of emergency" by CAISO this mode allowed operators to invoke mandatory requirements for generators to provide power (even suspending air quality restrictions on their operation), and order distribution utilities to shut down interruptible load and/or implement rolling blackouts among their customers. This mode of last resort, while it could stabilize the grid, put operators at the mercy of compliance among a wide set of grid participants, with a risk of major grid failure if this compliance did not occur as expected.

These performance modes enlarged the set of managerial resources available to operators. With the high range of input variance the grid can present to operators, multiple performance modes allow them a variety of response modes to cope with this variance.[11]

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[11] In cybernetics, there is a parallel "law of requisite variety" which asserts the existence of a necessary level of complexity to control complexity (Ashby, 1957; Weick, 1995).

APPENDIX B - Schulman

Research Questions for Transmission Planning Reliability

1. What strategies for reliable planning are currently being used by transmission planners in the Western interconnection? How do these vary by sub-regions?

2. Is there agreement on criteria for a “successful” transmission planning process among planners and stakeholders in the Western sub-regions? Are there potential case studies of planning success?

3. What constitute error signals in the transmission planning process? How are they detected and by whom? What is the lag between the signals and planning activities and events?

4. How does transmission planning connect to operator perspectives on reliable grid management? What are the variations in these connections across Western sub-regions?

5. What is the skill base for a successful transmission planner? What cognitive capacities are required? Do these vary across planning problems or time horizons?

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WIND ENERGY CLUSTERS: RULES FOR EMERGENCE

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Introduction

Economic clusters are concentrations of interconnected companies and institutions around which complementary and supporting organizations and institutions such as training, finance, transport, marketing, and research and development group (Bresnahan, 2004; Kukalis, 2010; Lorenzen & Maskell, 2004; Markusen, 1996; Porter, 1998, 1998a, 2000, 2000a; Pouder & St. John, 1996; Powell et. al., 2002; Saxenian, 1994). The U.S. has many examples –San Jose and electronics, New York City and financial services, Hollywood and the movies, Detroit and autos, New Jersey and pharmaceuticals, Boise and farm machinery, and Minnesota and medical devices. Can renewable energy clusters be created that will stimulate the economy, create jobs, and increase economic output (Green Jobs Initiative and the International Institute for Labour Studies, 2012; Barret & Hoerner, 2002; Bowser & Gomberg, 2007; Hoerner & Barret, 2004; Prindle, et. al., 2007; Renner, et. al., 2008)?

With its thriving biomass industry, Brazil already is a success story. China has made rapid advances. Different forms of renewable energy and regions in the world have different capacities for economic growth and job creation. Germany and Spain have been European leaders. In the U.S. the greatest wind potential runs down the center of the country starting in Minnesota near the Canadian border and ending in Texas. This paper examines the European examples. Then, it turns to the U.S. and compares wind energy development in Minnesota and Texas in order to provide guidance as to what are some of the organizational pre-conditions for creating flourishing wind clusters.

I argue that for a flourishing wind energy cluster to be in place there must be (i) boundary rules as to who is in the cluster and who is not, (ii) rules for allocating the costs and benefits of cluster activities, (iii) rules for resolving conflict, and (iv) rules for changing the rules when they need to be changed. These pre-conditions were in place in Texas and not in Minnesota and therefore the pace of wind energy development in Texas exceeded the pace of wind energy development in Minnesota.

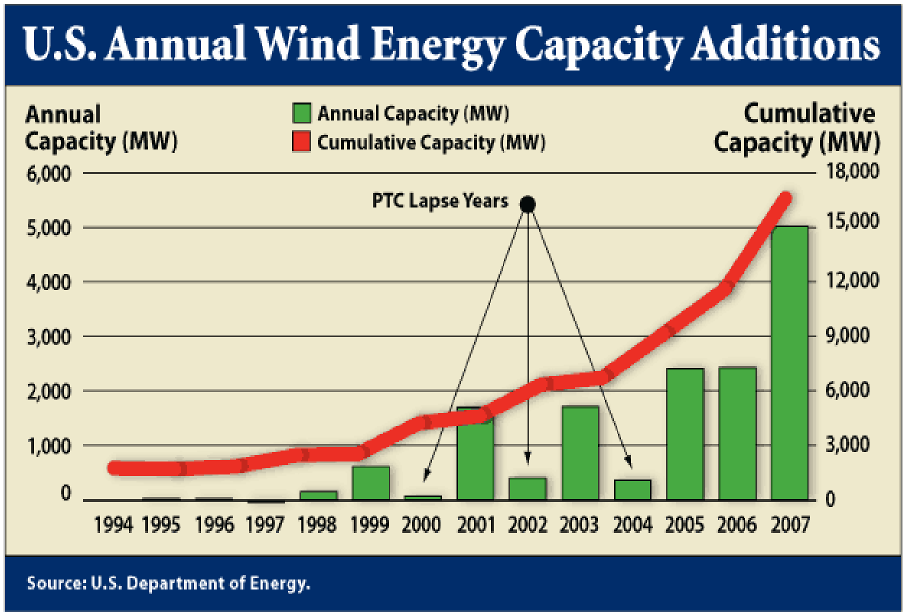
Spain and Germany

Spain and Germany were leaders in wind energy development in Europe. Nearly 16% of the Spain’s electricity is generated by wind, in Germany wind accounts for about 9% of generation,

	Feed-in tariff	Renewable performance standard	Capital subsidies, grants, or rebates	Investment or tax credits	Public investment, loans, or financing	Energy production payments/ tax credits	Sales, energy, excise tax, or VAT reduction
Germany	Yes	Yes	Yes	Yes	Yes	No	Yes
Spain	Yes	Yes	Yes	Yes	Yes	No	Yes
U.S.A.	No	No	Yes	Yes	No	Yes	No

Table 1: Public Policies for Renewable Energy in Germany, Spain, and the U.S.

while the U.S. generated about 2% of its electricity by wind (World Wind Energy Association, 2011). Spain and Germany took the lead not because they had more wind resources. The main difference is in public policies (Bernard, Craig, and Sened, 2011). First, their governments signed the Kyoto climate protocol. They were committed to greenhouse gas reductions. Second, they had a different array of public policies which have proven more favorable to win (see Figure 1). While they had a national renewable performance standard and offered feed-in tariffs, pubic investment loans, and financing, the U.S. federal government gave energy production payments and tax credits. Third was the predictable nature of the policies in Germany and Spain in comparison to the U.S. For instance, the U.S. production tax credit expired three times between 1999 and 2004 and each time it expired renewable energy production fell sharply.[12]



Source: U.S. Department of Energy.

Figure 1: U.S. Annual Wind Energy Capacity Additions

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[12] The production tax credit, which provides a 2.2-cent-a-kilowatt-hour credit for electricity produced by wind and other forms of renewable energy, is set to expire on Dec. 31, 2012. According to the American Wind Energy Association. Letting the credit lapse could lead to the elimination of more than half of the 75.000 wind energy jobs in the U.S. by 2012.

Another important factor is the organization of the transmission system. Spain has but one grid operator Red Eléctrica de España which functions at the national level as the control center for renewable energy projects. Germany has four grid operators who operate under government mandates to prioritize grid expansion for the sake of new renewable energies. In comparison, the U.S. has many different grid operators and limited interconnections between electricity generated in the West, East, and Texas (see Figure 2).

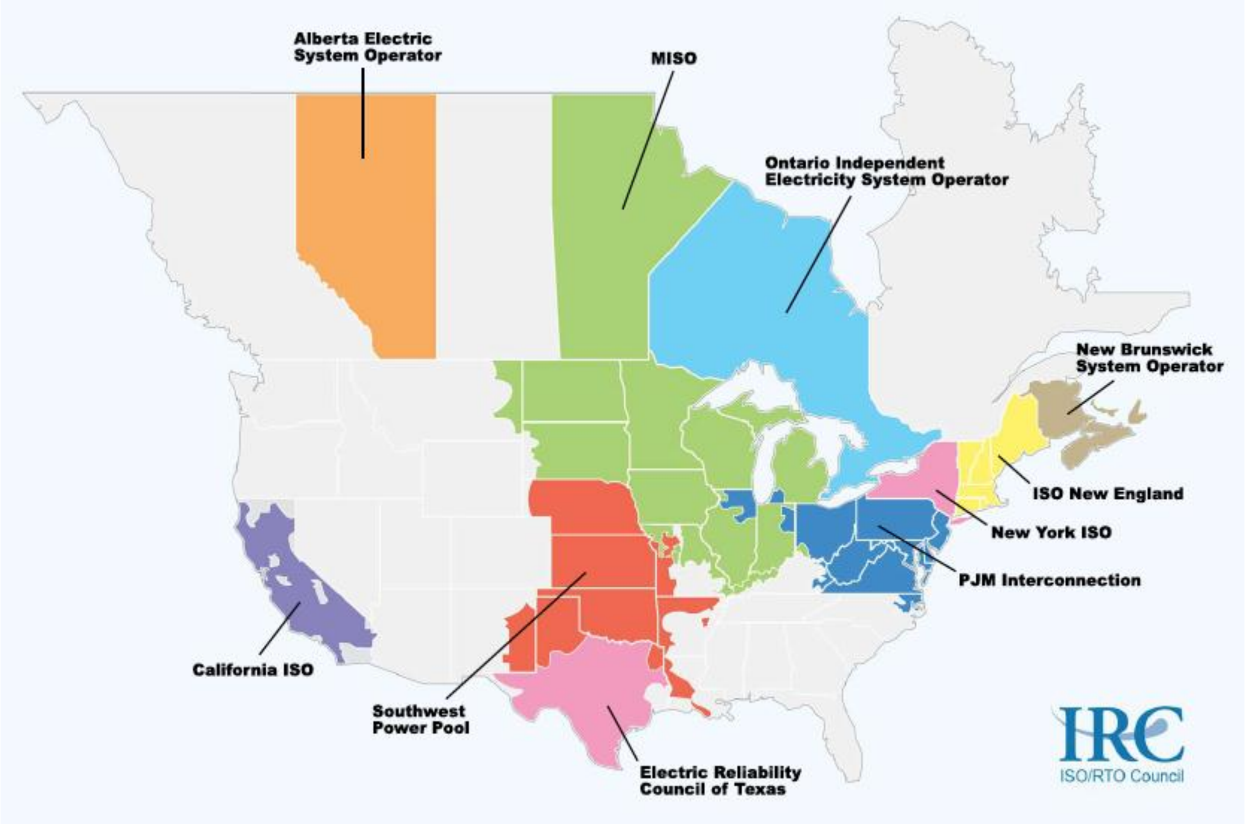

Figure 2: North American Electric Power Zones

By 2006 Germany, Spain, and Denmark had doubled the number of their wind energy jobs in five years. They created upwards of 120,000 new jobs in wind energy (Combs, 2007; Renner, Sweeney, and Kubit, 2008; European Programme of the Executive Agency for Competitiveness and Innovation, 2009). Spain's Navarra region provides an example of wind based revitalization ((Green Jobs Initiative and the International Institute for Labour Studies, 2012). The region has a population of 620,000. The share of wind in electricity generation went from zero in 1994, to 46% in 2009. Business and unions agreed to policies that would promote renewable energy as a way to overcome poor economic conditions in the region in the 1980s. Skill shortages were alleviated and an active research program started. Unemployment fell from above 12% in 1993 to below 5% in 2007. Renewable energy companies are given credit for the creation of 6,000 jobs.

The U.S.

In the U.S., the National Renewable Energy Lab (NREL) estimated that wind farms had more than twice the economic impact of equivalent coal or gas fired electric plants (Land, & Tegen, 2009). Wind turbines, rotors, blades, structural towers, hubs, generators, and assorted controls had to be designed, manufactured, assembled, maintained, and inspected. Supply chain industries (cement, steel, metal casting, machining, and cast iron) produced bearings, nuts, bolts, blades, gears, rotator blades, braking systems, and yaw controls for turbines. Installation brought still more employment as design teams, project management companies, and construction firms used tensioning and other high grade construction equipment to install the towers and attach the blades. It was estimated that more than 400 workers were needed to install 100 wind turbines and towers (Boswer and Gomberg, 2007). Then, there was the advanced research and development which had to take place if new wind energy technologies and storage were to come into being. The indirect effects -- substantial rural economic development and local tax income -- rippled through an economy. If the U.S. generated 20% of its electricity from wind by 2030, as many as 180,000 new jobs might be created (Lantz and Tegen, 2009).

While the U.S., unlike Spain and Germany, did not have a national renewable energy performance standard (RPS), many U.S. states (29) and the District of Columbia did. Some of the states were very aggressive – New York called for 29% of its electric production to be renewable by 2015, California 33% by 2020, Hawaii 40% by 2030, and states like Minnesota, Oregon, and Ohio 25% renewable by 2025. The job creation and GDP growth potential of renewable energy in these states was considered to be high. The U.S. also could reduce its production of greenhouses gases.

Texas and Minnesota

Two of the states with the highest potential were Texas and Minnesota. They accounted for more than a third of the job creation that wind could bring. Texas rapidly surged forward, while Minnesota lagged. In 1998, Texas had but 41 megawatts of wind energy capacity, while Minnesota had 135. By 2007 Texas had 4,356 MW of capacity, and Minnesota had 1,299. With total installed capacity of 10,223MW in 2010, Texas produced more wind than any U.S. state. This growth in wind generation revitalized poor West Texas counties. For example, Nolan County, which had prospered until the Depression, had been in continued economic decline (New Amsterdam Wind Source, LLC. 2008). Devastated by the weakening of the cotton and petroleum industries, it suffered from a steady fall-off in population. Twenty percent of the population was living in poverty until 2004 when the wind energy industry took-off. Stimulated by high-capacity transmission lines and favorable rules for citing turbines, 1 in 14 jobs in county (1,124 jobs) were directly related to wind. In addition, there were an estimated 1,500 construction jobs created. Building permit values grew 192% in 2007 over 2001 values, sales tax revenues grew 40% percent in 2007 over 2002 values, and the total property tax base expanded from $.5 bill in 1999 to $2.4 billion 2008.

Why did Texas achieve these benefits, while Minnesota lagged behind? Texas' RPS, passed first in 1999 and amended in 2005, called on the electric utilities in the state to increase renewable energy capacity to 10,000 MW by 2025 (Tex. Stat. §25.173) or roughly 5 percent of the state's total electricity demand. The state achieved this level of renewable generation in early 2010, 15 years ahead of schedule (Bernard, Craig, and Sened, 2011). In 2007, Minnesota enacted similar legislation, a statewide RPS (Minn. Stat. §216B.1691) that mandated that Xcel Energy, the largest utility, generate 30 percent of its electricity from renewables by 2020 and that all other utilities generate 25 percent of their electricity from renewables by 2025. The Minnesota goals were more far-reaching than those of Texas and at the time represented the most stringent policy in the nation. However, Minnesota progress in achieving these goals was far slower (see Table 2).

Table 2: Added and cumulative wind power capacity and national rank of Minnesota and Texas 2007 to 2009

Year	Added Capacity (MW)		Cumulative Capacity (MW)		National Ranking (Cumulative Capacity)	
	MN	TX	MN	TX	MN	TX
2007	405	1618	1299	4356	3	1
2008	455	2671	1754	7118	4	1
2009	56	2292	1809	9410	5	1

American Wind Energy Association 2010

Ostrom's work on the management of common pool resources can be used understand what took place. Texas adhered more closely to her rules for cluster emergence than Minnesota (see Table 3).[13] In Texas, boundaries were clearer, better means were in place for allocating the costs and benefits, conflict was avoided, and better mechanisms existed for adjusting the rules as needed.

Clear Boundaries

The first difference between Texas and Minnesota is boundary clarity. The U.S. Federal Energy Regulatory Commission (FERC) has established regional transmission organizations (RTOs) to manage the power grid by moving electricity and coordinating, controlling, and monitoring its

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[13] For references to the institutional analysis and design framework of Ostrom, see Ostrom (1986, 1990, 1998, 1999, 2000, 2005, 2008, 2009, 2010); Ostrom and Walker (1991); Ostrom et al. (1992, 1994, 2002), and Poteete and Ostrom (2008).

transmission. Most RTOs are multistate in nature (refer back to Figure 2) and manage the transmission assets of a series of utilities that each face differing policy frameworks, including RPS. The exception to this case is the RTO in Texas, the Electric Reliability Council (ERCOT), which covers approximately 75 percent of the state, including the major urban centers and the southernmost portion of the windy panhandle. Due to ERCOT's intrastate nature, it is only subject to state authority and legislation and so avoids a host of federal regulations and is not muddled with the policies established in other states (Fleisher 2008). The regional transmission operator in Minnesota, in contrast, the Midwest Independent Transmission Operator (MISO) is not only responsible for managing the transmission grid in Minnesota but it must manage and coordinate the grid of 12 other Midwest states and the province of Manitoba. It must coordinate the interests of all these states and the Canadian province before it makes decisions. Due to the vast geographical space that it represents its membership, each with equal representation in the decision making process and diverging policy directions, includes over 30 transmission owners, 45 power marketers, 27 independent power producers, 17 municipal or cooperative utilities, 4 large scale consumers, 8 environmental groups, 15 state regulatory groups, and 12 public consumer groups.

Ability to Allocate Costs and Benefits

The unique nature of the rules that prevail in Texas and that do not prevail in Minnesota allow for greater ease in allocating the costs and benefits among active players. The PUC in Texas, unlike that in Minnesota, has considerable power to ensure grid expansion in a timely fashion. In addition to the renewable energy requirement, the 2005 Texas amendment to the RPS granted the PUC the authority to allocate costs and benefits necessary to bring about timely construction of new transmission facilities (Texas Senate 2005: Sec. 1). This situation was very different in Minnesota. Wind power growth in Minnesota like Texas depended on expanding the transmission grid. The highest wind potential in the state was along its western and southwestern borders, far from the state's large cities. New wind projects in these areas therefore required extensive construction of transmission lines for the transport of the electricity. To this end, 11 transmission-owning utilities, including Xcel Energy, formed a joint initiative named CapX2020, which had project proposals pending judgment by the Minnesota Public Utility Commission (PUC). However, because the PUC lacked effective authority in allocating the costs and benefits of new transmission construction, the process of approval was exceedingly slow. Unfortunately, Minnesota's RPS failed to set a mandate for the construction of additional transmission lines, unlike the case of Texas, only requiring utilities to "make a good faith effort" (§216B.1691, Subd. 2). The Minnesota law did not provide an authoritative body with the power to order new transmission construction.

Table 3: Adherence to Rules for Cluster Emergence – Texas and Minnesota

Boundary Rules Who are participants What is property jointly held		**Allocation Rules** Production inputs Who benefits	
• **Texas Conforms** *regional transmission operator in Texas, Electric Reliability Council (ERCOT), covers approximately 75 percent of state, including major urban centers & southernmost portion of windy panhandle*	• **Minnesota Violates** *regional transmission operator, Midwest Independent Transmission Operator (MISO) must manage and coordinate grid of 12 other Midwest states and Manitoba*	• **Texas Conforms** *2005 Texas amendment to RPS grants PUC authority to allocate costs and benefits to bring about timely construction of new transmission facilities*	• **Minnesota Violates** *PUC lacks effective authority to allocate costs & benefits of new transmission construction*
Conflict Management How manage violators Impose sanctions		**Rules for Change** Multi-party “polycentric” Overlapping actors Flexible	
• **Texas Conforms** *Texas bill orders PUC to designate Competitive Renewable Energy Zones ("CREZs") as best areas for wind; once selected CREZs have right to expand transmission, thereby mitigating conflict*	• **Minnesota Violates** *construction of additional transmission spreads discord, with some environmental groups and citizens opposing new transmission lines because of effects on wildlife & private property*	• **Texas Conforms** *ERCOT & PUC jurisdiction overlap, fine-tune policies*	• **Minnesota Violates** *players not stable, FERC & DOE intervention to reduce backlog adds to confusion*

Ability to Resolve Conflict

The Texas rules also anticipated conflict and provided much more effective means for resolving it. Another part of the Texas bill ordered the state PUC to designate Competitive Renewable Energy Zones ("CREZs"), defined as the best areas for wind energy development. Once the Texas PUC selected the CREZs, then the commission automatically had the right to expand the transmission grid to these areas, thereby mitigating conflict that might prevent adequate capacity. In 2008, the Texas PUC selected five areas as CREZs, two in the Panhandle and three in West Texas, and assigned billions of dollars to transmission projects. Once designated by the PUC, conflict about the construction of transmission was curtailed. In Minnesota, after passage of the RPS, the sequence of events was far different. Passage of the RPS initially had a very positive impact. It spurred a nearly five-fold increase in proposed wind projects. If realized, these proposals would have exceeded the ultimate mandated amount of wind power generation by 340 percent. Unfortunately, none of these proposals got off the ground quickly. Hindering this effort was the conflicts that erupted because of stakeholder opposition to grid expansion. While in Texas, the rules anticipated this conflict and provided for a way to resolve it, in Minnesota no one had direct authority to deal with the conflict. The construction of additional transmission lines spread discord among the stakeholders, with environmental groups and citizens opposing new transmission lines because of their fear of the effects on wildlife and private property, while Minnesota's utilities and regulators continued to favor them. In 2007, a diverse coalition consisting of environmental groups, citizens, utilities, and regulators had formed to advocate for the passage of Minnesota's RPS. Although they had collaborated successfully for passage of the RPS, this coalition unraveled during implementation.

Ability to Adjust the Rules

Another difference between Texas and Minnesota was in the respective ability to adjust the rules. In Texas where ERCOT's jurisdiction coincided with that of the Public Utility Commission (PUC) the two organizations had a long history of cooperation. They were better able to collaborate and coordinate their distinct spheres of influence and authority than in Minnesota where the PUC had to work with the multi-state MISO. Over time this collaboration between ERCOT and the Texas PUC resulted in the fine-tuning of Texas's renewable energy policies, which contributed to the steady and rapid expansion of wind power capacity in Texas and the ability of the embryonic wind energy cluster to reach its early potential, as evidenced by the state's rapid growth in wind power capacity. In contrast in Minnesota, where there was an extremely lengthy backlog of projects awaiting MISO's approval (Minnesota Department of Commerce 2010), attempts to adjust the rules failed to occur in a timely fashion that materially affected the situation. The players in Minnesota were not stable and self-contained nor did they have a history of cooperation. On August 25, 2008, the Federal Energy Regulatory Commission intervened and approved a plan submitted by MISO to reform the way the backlog was managed by moving from a “first come, first served” basis to prioritizing projects based on their likelihood of approval and adding a “fast track” option (FERC 2008). However, this change did not make an immediate dent in the long queue. The entrance of this external organization simply added to the confusion. Further outside interference took place when the U.S. Department of Energy released a report, *20% Wind Energy by 2030*, in 2008 that included a plan for transmission grid expansion in Minnesota that did not align with the plan proposed by the parties in Minnesota. Rather than rules being adjusted in a regular and predictable pattern among parties who were used to working with one another as they were in Texas, the rules were adjusted in an erratic and ineffective way in Minnesota.

Conclusion

The emergence of vigorous economic clusters that spur regional and global growth consists of a struggle between a cluster’s attempts to have a strong set of public policies that encourages such development and forces outside of it such as competing technologies and other conditions that may prevent the cluster’s progress. Rules must co-evolve with the existence of these public policies. Whatever public policies there are, these public policies must be supplemented by a set of rules that regulate boundaries, allocate costs and benefits, facilitate conflict resolution, and allow for rule change when necessary. Despite the strong logic behind the need for rules, the Minnesota example suggests that they are hard to create in practice. Clusters may become ensnared in institutional voids and vacuums (Fremeth and Marcus, 2011). Their boundaries are poorly delineated   Allocation rules, rules for resolving conflict, and rules for changing the rules are poorly developed.

Thus, rules are needed for clusters to fully reach their potential. Without rules to bind them, the participants neither have a clear sense of payoffs nor the strategies worth pursuing to obtain these payoffs.

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III. Appendix: Project Design and Workshop Details *Dave Koehler, David Solan, and Lisa Bearg; Boise State University*

EPI received a grant from the National Science Foundation's Innovation and Organizational Sciences (IOS) program. The purpose of the project was to identify investigative frameworks based on organizational and management theories that have great potential to improve the effectiveness of regional electricity transmission planning.

A key element of the project was to develop a workshop which brought together industry professionals and scholars from IOS and other appropriate disciplines to identify and prioritize research needs from both perspectives. The workshop, *Regional Electricity Transmission Planning in the West*, convened in Boise, ID on April 26-27, 2012.

If you have further interest in this project, please contact the Principal Investigator at epi@boisestate.edu.

Project Overview

Effective transmission planning is an essential component for the construction of new lines to upgrade the electric grid in order to realize smart grid benefits, bring more renewable-sourced electricity generation online, and ensure the grid's stability. The purpose of this workshop was to identify the organizational, procedural, and regulatory barriers to more effective regional electricity transmission planning in the West. In the process of identifying these barriers, the workshop facilitated the discovery of future research by

1) recognizing the gaps between industry and academia,
2) prioritizing potential research opportunities, and
3) creating collaborative networks among and/or between academia, government, industry, and other stakeholders.

In order to accomplish this discovery, this workshop brought together IOS scholars and industry practitioners to create a unique dialogue, pairing practical lessons from the electricity transmission planning industry to the organizational and management disciplines. Additionally, this workshop provided a forum for IOS scholars to collaboratively develop and prioritize the research opportunities into specific and relevant agendas, providing a foundation for future research in the field.

A significant factor in the workshop's success was participants' shared commitment to improve electricity transmission planning. However, bringing together participants with a shared commitment was not enough to guarantee success. Therefore, the input, comments, feedback, and approval from the project's Organizing Committee regarding the workshop's design, preparations, and implementation were central to achieving the intended objectives. Their principal areas of responsibility were to determine the overall design of the workshop, including 1) improving the format to ensure meaningful interactions; 2) selection of organizational theories, frameworks, and perspectives best-suited to examining the electricity transmission planning processes and organizations; 3) identification of speakers with appropriate expertise in identified theories; 4) pairing selected speakers with TRMs (planning practitioners from industry, government, and stakeholder groups); and 5) identification of the relevant workshop participants.

Prior to designing the workshop, the Organizing Committee suggested that EPI conduct a brief survey of personnel involved in the WECC's Regional Transmission Expansion Planning (RTEP) process to inform the committee about current organizational design and decision-making processes. A semi-structured conversation with Bradley Nickell (Director, WECC Transmission Planning) was conducted on November 4, 2011. The results of the conversation were provided to Organizing Committee members to increase their understanding of the regional planning process.

Armed with more details regarding organizations and processes, the focus shifted to the design of the workshop sessions. Based upon suggestions from the Organizing Committee, the workshop was organized to facilitate conversation, increasing the likelihood that scholars and practitioners engaged meaningfully.   The key point for meaningful engagement was to structure as much time as possible for scholar-practitioner activities on clearly focused topics or assignments. Each of the first three sessions included two Academic Presentations, a Fishbowl Panel, an Audience Response, and three Breakout Groups. Each of these three sessions took approximately four hours, and the majority of this time was reserved for academic-practitioner interactions on focused topics.

After determining the workshop design, the Organizing Committee turned its attention to the identification of theories and frameworks relevant to the selection of organizational theories, frameworks, and perspectives best-suited to examining the electricity transmission planning processes and organizations. Organizational Studies encompasses a broad spectrum with many possible frameworks for investigation; there is a variety of methods available within this discipline to examine electricity transmission planning, some better suited than others. Examples include Organizational Evolution; New Organizational Forms (Palmer, Benveniste, & Dunford, 2007; Lewin, Long, & Carroll, 1999); Modern Organizational Theory (Shafritz, Ott, &

Jang 2005); Organizational Economics Theory; Organizational Behavior Perspective (Shafritz et al., 2005); Whole Network Design (Marsden, 2005); or Social Network Analysis (Reid & Smith, 2009), among many others.

EPI and the Organizing Committee decided to identify three broad frameworks for investigation, allowing the respective scholars to narrow their own investigations. These three frameworks included 1) organization, 2) organizational environment, and 3) technological implications. Approaching the investigative frameworks in this manner provided increased incentive for the academic recruits, as the scholars had more freedom in their explorations. A series of meetings between EPI and the Organizing Committee produced a short list of candidates for the presenters, each with the appropriate expertise to provide interesting and provocative analyses within one of the identified frameworks. After discussing the project and its objectives, each scholar agreed to develop a workshop presentation and an accompanying discussion paper.

Shortly after obtaining agreement from the academic presenters, the Organizing Committee and EPI collaborated to identify and pair Transmission Resource Mentors (TRMs) – transmission practitioners from industry, stakeholder, or government entities – to each IOS scholar before their paper was drafted. This mechanism was designed to increase scholarly-practitioner interactions while strengthening the relevance and impact of the presentation and accompanying discussion paper. At the same time, the TRM provided a resource for the scholar to better understand how transmission planning research could advance IOS theory.

Finally, EPI and the Organizing Committee collaborated to identify the most relevant workshop participants. Based on these discussions, invitations were sent to practitioners in the planning and operations segments of organizations in the electric transmission industry, such as WECC, CAISO, Bonneville Power Administration (BPA), New England Independent System Operator (NEISO), Northern Tier Transmission Group (NTTG), Pacificorp, Xcel Energy, Duke Energy, Portland General Electric, and ColumbiaGrid. Invitations were also sent to appropriate personnel in electricity regulatory organizations, such as Idaho’s Public Utilities Commission (IPUC) and the Federal Energy Regulatory Commission (FERC). Other stakeholders were also invited, such as personnel from Northwest Energy Coalition (NWEC), Western Grid Group (WGG), Natural Resources Defense Council (NRDC), and Western Interstate Energy Board (WIEB). Finally, invitations were sent to suitable researchers from disciplines outside of the usual IOS scholars.

Summary of the Workshop

The workshop began with an introduction from PI David Solan and an Opening Address from Organizing Committee Chair Andrew Van de Ven, introducing the participants and presenting the context, objectives, and other specifics of the workshop. EPI Assistant Director discussed procedures and expectations.

After the Opening Address, the workshop's first three Sessions began. Sessions 1 & 2 filled the remainder of Day One, while Session 3 filled the first half of Day Two. Each of these sessions were about four hours in length, and included a number of engaging activities. Each activity provided opportunities to add to the workshop's summary of themes while identifying priorities for future research. The first activity of these sessions began with two different *Scholar Presentations*, as described in the previous section.

Following the scholar presentation was a Fishbowl activity, which brought 5-6 participants, each representing different organizations or disciplines, to the middle of the room while everyone else sat in an outer circle – hence the Fishbowl (Eller, 2004). The Fishbowl participants responded to the preceding presentations, providing their takeaways and describing how their organization could be affected positively or negatively. The Fishbowl format induced a conversation among the other Fishbowl participants, which included storytelling and case applications. After each Fishbowl participant had an opportunity to speak, the facilitator took questions from the audience for any of the Fishbowl participants.

After the Fishbowl participants returned to the audience, the workshop facilitator posed two questions to all participants. First, from the themes developed during the presentations and the fishbowl, what are the two most useful ideas that you believe could improve the transmission planning process? Second, which theme currently represents the biggest gap in our knowledge? All of the workshop participants used clickers to respond to the questions, and the frequency count or percentages were then displayed to the entire group. The three breakout sessions were then charged with deliberating some of the higher frequency tabulated responses. After brainstorming their assignments, the three groups reported the results of their discussions, adding to the workshop's summary of themes.

This same format was followed for the next two sessions, providing a rich summary of themes deliberated by the group. After the third session ended on Day Two of the workshop, the audience response mechanism was utilized to prioritize the aggregated list of themes. This process provided important insights into the current gaps in knowledge and the usefulness of applied Organizational Studies research in the energy field. A networking and collaboration gathering provided additional time for the participants to discuss these opportunities and facilitate further conversations regarding potential methods of engagement.

The closing session was limited to scholars to discuss how the emerging field of regional transmission planning may provide important data and information to further IOS. In addition, the attendees for the final session discussed potential research proposals for possible future submission to NSF programs. In short, the final sessions served to 1) identify future research questions, 2) prioritize the identified research opportunities, and 3) encourage the formation of industry/academic research teams and projects for proposal submissions to NSF programs. The workshop ended with closing remarks from Organizing Committee Chair Andrew Van de Ven, summarizing the importance of cross-disciplinary collaboration for these important issues facing the electricity sector.

Summary of Workshop Themes

The summary of themes was the product of discussions by all of the workshop participants. The views presented here are not indicative of any single contributors' personal or organizational views, but rather discussion points from the group in aggregate. These themes are presented in a manner consistent with the Organizing Committee's approach to recruit speakers from the following frameworks: Organization, Organizational Environment, and Technological Implications. There was no clear delineation in the group discussion between these three overarching themes, as topics frequently overlapped among the frameworks. However, this summary attempts to explain the thematic discussions within each division. Each section below provides a summary of the major topics, followed by some important questions that were raised by the group.

Organization

Participants discussed the organizational structures, processes, and culture as potential barriers to improvements in transmission planning. The need for increased collaboration between academia and industry was introduced as a pathway to meet economic, environmental, and social objectives in preparing for the future. Improvements in frequency and accessibility of intra- and inter-agency communications were cited as significant barriers to improvements in transmission planning. Examples include organizational segregation of 1) planning and operations, and 2) generation and transmission planning. The integration of innovation into the process-rich planning methods could assist to expand scope and stakeholder base. Increased engagement, including more education and outreach efforts, could also potentially improve the collaborative planning process. The role of leadership was deliberated as a considerable organizational impediment, as political savvy is a necessary (yet insufficient) requirement to move through the pluralistic democratic process. Similarly, the role of criteria selection used for predictive models provided a backdrop into the many layers involved for decision-making within high-reliability organizations. Key themes and questions for discussion identified by the group were

- How can organizational culture inform us about boundary issues?
- How can regional-level value propositions be expressed to single-issue stakeholder groups?
- How does organizational culture impede innovation?
- What comparisons can be made between organization in a vertically integrated system versus those in a deregulated system?

Organizational Environment

The exchange of ideas among participants included many external factors, or the organizational environment. This conversation began with often cited transmission concerns, such as appropriate methodologies for cost allocation and the linkages of benefits to beneficiaries. On this matter, the group established a baseline in that better definitions were needed for “costs,” “beneficiaries,” “benefits,” “risks,” and “needs.” The dialogue turned to FERC Order 1000, and the potential effects on inter-agency relationships/communication, cost allocation, reliability compliance, and independent power production. The conversation segued easily to federalism and the fragmented authority within the electricity transmission sector (interstate conflicts, lack of regional governance, local siting authority, and the clear institutional separation between planning, siting, and operating). From this thread, suggestions were made for comparisons to the planning and siting of natural gas pipelines and cell phone towers. Boundary objects, impacts, and organizations were discussed at length as opportunities to improve communications, create shared understandings, and improve the decision-making process.

Within the federalism framework, participants deliberated the patchwork of state policies and its effects, as self-interest often impedes regional coordination. The group pointed to a misalignment of objectives at the local, state, regional, and federal levels for transmission development. The roles of Renewable Portfolio Standards (RPS) and state-defined Qualifying Facilities (QFs) under the Public Utility Regulatory Policies Act of 1978 (PURPA) were cited as potentially conflicting objectives. The group identified these inconsistencies in development objectives as the integration of renewables, cost, reliability, policy, and timeframe. Some participants suggested a transition from market-driven to resource-driven transmission development, as the transmission needs identified in regional plans were not usually considered in RPS policies or tax incentive designs. Not only is planned generation a factor in planning new transmission, but where the lines are planned affects which generating technologies will be built. Key themes and questions for discussion identified by the group were

- Is there a better method for cost allocation? How can we better link benefits to beneficiaries? What is the most effective model, and how can models include different incentives?
- What impact will FERC Order 1000 have on other federal agencies?
- How is reliability compliance creating institutional barriers?
- How is “Authority” distributed, to whom, and for what? Is this a question for planning or siting? Are they different?

- How might we create reasonable public policies? In what ways can transmission planning meet future needs?
- What are the policy drivers for transmission expansion, what are the intended outcomes (economic, accessibility, social aspects, and job creation)?
- Should policies be so reactive? Are we better at responding than preparing?
- Is there a need for a central authority for planning and siting?
- Is the problem with implementation due mainly to social and economic barriers?

Technological Implications

Several discussion points surrounded the intersection of technology and policy, as the fast pace of innovation and technology is misaligned with the planning process. Additionally, the requirement for reliability may impede the entrance of new technologies. Technologies can also be related to beneficiary concepts for transmission, so their energy distribution improvements must be quantifiable in order to be realized, as there is a bias toward transmission expansion over integration of new technologies. Similarly, there is an increased focus on balancing and operating the system. As such, discussions ensued about increasing the amount of input from system operators into the planning and policy processes. Further, the idea was introduced that resource availability and policy modifications are cyclical, so technology integration depends upon very specific circumstances, such as rules and location. The role of crisis events was also considered, as proximity to catastrophe could potentially be linked to the creation of new rules and the exercise of authority. Finally, the discussion included potential comparisons to other complex systems to gain further insights, such as transportation planning (similarities in system-wide process and regulatory system), the drug approval process by the Food and Drug Administration (similarities in cost, time and regulatory process), or the development of the internet (similarities in organizational complexities, resilience and reliability). Key themes and questions for discussion identified by the group were

- What are the gaps between the current transmission system and desirable technologies?
- Which technologies are available? What is far off but still being considered?
- Are there different levels of reliability that are necessary for various segments, such as industry or residential?
- How does reliability relate to the quality of power, and to what extent can the power quality mitigate system issues or provide flexibility to the grid?
- If distributed generation was more advanced or economical, how would this affect the current transmission issues?

- What are we planning for? Who are we planning for? How does modeling differ from reality?
- How can technologies improve the monitoring and needs of delivery, and how does this assist in predicting future transmission issues?
- What level of catastrophe will need to occur in order to stir major change for the system? Are we already in the catastrophe but at a slow pace?

Workshop Conclusion: For Further Research

The session on potential future research identified a number of areas for academic and practitioner collaboration. Subjects that received the most attention included renewables integration and innovation, stakeholder engagement and boundary organizations, maintaining high reliability of the grid while redefining what it means to have an effective planning process and outcomes, and better understanding how policy choices affect decisions and risk in the planning system.

Organizing Committee Chair Andrew Van de Ven's closing comments summarized potential pathways for academia to assist industry in improving the transmission sector. Van de Ven pointed to the need for cross-collaboration and engaged scholarship. Many of the problems identified exceed competence from any single discipline or sector, so collaboration between and among academia, practitioners, and policy-makers is required. Van de Ven also suggested a need for comparative studies of complex systems, nested layering of planning and implementation decisions across stakeholders and time, and institutional logistics such as organizational design, leadership, interdependence, and strategies.

More transparency is needed in understanding the motivations and their desirable transmission outcomes. Factors for expansion of the grid such as reliability and resilience (critical infrastructure that supports a healthy economy and national security), integration of renewables, profitability, job creation, meeting policy objectives, or the integration of new technologies oftentimes compete for inclusion in a region's long-range plan. Alignment between intent in the plan and the outcomes are critical elements in the long-range planning process and outputs.

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Workshop Agenda

Thursday, April 26

7:30-8:00am	Registration / Breakfast / Coffee
8:00-8:20am	Opening Remarks; Andrew Van de Ven, David Solan, & Dave Koehler
Session 1:	
8:20-8:55am	Presentation 1: **Elizabeth Wilson,** *University of Minnesota* *Organizational Environment: Public Policies*
8:55-9:30am	Presentation 2: **Daniel Kirschen,** University of Washington *Technologies and Transmission Planning*
9:30-9:40am	Break
9:40-10:30am	Fishbowl Panel: Elizabeth Wilson, Daniel Kirschen, Dalia Patino Echeverri, David Solan, Desiree Pacheco, Mason Emnett, Marsha Smith, Bob Anderson
10:30-10:35	Break
10:35-10:45am	Audience Response
10:45-12:00pm	Breakout Sessions (Colors)
12:00-1:10pm	Lunch
Session 2:	
1:10-1:45pm	Presentation 3: **Tim Hargrave,** University of Washington Bothell *The Role of Boundary Organizations in Institutional Innovation*
1:45-2:20pm	Presentation 4: **Benyamin Lichtenstein:** University of Massachusetts Boston *Complexity Science Insights into Organizational Ecologies and their Dynamics: The Case of Electrical Transmission Planning*
2:20-2:30pm	Break
2:30-3:30pm	Fishbowl Panel: Tim Hargrave, Benyamin Lichtenstein, Natalie Nelson-Marsh, Paulina Jaramillo, Bill Nicholson, Brian Silverstein, John Cupparo, Fred Heutte
3:30-3:35	Break
3:35-3:45pm	Audience Response
3:45-4:45pm	Breakout Groups (Letters)
4:45-5:00pm	Reconvene for Summary of Themes

Friday, April 27

7:30-8:10	Breakfast/Coffee

Session 3:

8:10-8:45am	Presentation 5: **Paul Schulman,** Mills College *What in High Reliability Organizations (HRO) Research Might be Useful in Transmission Planning?*
8:45-9:20am	Presentation 6: **Alfred Marcus,** University of Minnesota *Rules for Emergence: Insights into the Organization of Economic Clusters*
9:20-9:30am	Break
9:30-10:30am	Fishbowl Panel: Paul Schulman, Alfred Marcus, Yao Yin, Alex Klass, Jeff York, Chris Mensah-Bonsu, Will Hazelip, Rich Bayless
10:30-10:35am	Break
10:35-10:45am	Audience Response
10:45-11:45am	Breakout Sessions (Numbers)
11:45-12:45 pm	Lunch
12:45-1:00 pm	Prioritize Summaries of Themes
1:00-1:45 pm	Networking & Collaboration
1:45-3:00 pm	Regional Transmission Planning as an Emerging Field & Potential Research Proposals (IOS Scholars)
3:00 pm	Closing Remarks Andrew Van de Ven, David Solan

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