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Socio-Political Evaluation of Energy Deployment (SPEED): An integrated research framework analyzing energy technology deployment

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Abstract

Stabilizing atmospheric concentrations of greenhouse gases to reduce the risks of climate change requires a major transition in society's energy infrastructure; yet despite a growing sense of urgency, deployment of alternative emerging energy technologies has been slow and uncertain. This paper proposes a systematic, interdisciplinary framework for the integrated analysis of regulatory, legal, political, economic, and social factors that influence energy technology deployment decisions at the state level to enhance awareness of the interconnections and enable improved energy policy and planning and accelerated change in society's energy infrastructure. This framework, Socio-Political Evaluation of Energy Deployment, (SPEED), integrates analysis of laws, regulations, institutions and policy actors as well as varying regional perceptions and levels of awareness about the risks and benefits of emerging energy technologies to facilitate improved understanding of the complex interconnected components of state energy systems. While this framework has been developed with U.S. states as a model, the SPEED framework is generalizable to other countries with different sub-national structures. We present three research methods that could be applied within the SPEED framework that could be particularly helpful in

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understanding the integrated socio-political influences on energy technology deployment: (1) policy review and analysis, (2) media analysis, and (3) focus groups and structured interviews with key stakeholders. By integrating the fields of technology diffusion, environmental policy, comparative analysis of states, and risk perception, future empirical research conducted within this SPEED framework will improve understanding of the interconnected socio-political influences on energy technology deployment to enable energy modelers, policy-makers, energy professionals, state planners and other stakeholders to develop and implement more effective strategies to accelerate the deployment of emerging energy technologies.

Keywords: Deployment; Energy technology; Technology diffusion; Technology innovation; Climate change mitigation

1. Introduction

The need for a transition in society's energy infrastructure is increasingly acknowledged due to growing environmental, economic, and geo-political concerns associated with the current energy system [1–5]. The urgency associated with this transition has intensified with increased societal awareness and understanding of the impacts and threats of anthropogenic climate change resulting primarily from energy derived emissions of carbon dioxide (CO_2), the dominant greenhouse gas contributing to climate change [6–10], and the emergence of critical geo-political concerns surrounding energy security [11,12].

A shift away from our current high-carbon energy system towards a carbon managed energy infrastructure that emits little or no carbon is essential for stabilizing atmospheric concentrations of CO_2 to mitigate climate change [4,9,13]. Given the long atmospheric residence-time of CO_2 (~100 years) coupled with the long lifetime (~50 years) of energy technology infrastructure, the impact of today's energy-related policy and energy technology investment decisions will impact emissions rates for decades to come [9].

To achieve stabilization of atmospheric CO_2 concentrations, a massive global deployment of alternative emerging energy technologies is required. Emerging energy technologies are deployed into sub-national state energy systems that are embedded into larger national and global energy systems; these energy systems are comprised of both technical and socio-political (non-technical) dimensions. While the energy systems of some sub-national states may facilitate deployment of emerging energy technologies, components of the energy system in other states may hinder deployment.

Despite this scale and the growing urgency associated with the societal need for an energy technology transition, diffusion of emerging energy technologies has been slow and uncertain [14–16], and many obstacles to the wide-spread deployment of emerging energy technologies are apparent, but not yet well understood nor well characterized. In the U.S., states play a crucial role in the deployment of energy technologies, because decisions driving siting, finance, and public acceptance all occur largely at the state level. Given the importance of U.S. greenhouse gas emissions (roughly 20% of the global total [17]) and the lack of a comprehensive federal climate policy in the U.S, understanding the mechanisms and patterns of energy technology deployment within and among U.S. states is a critical component for predicting and planning for energy-related greenhouse gas emissions reductions.

Research exploring the challenges of energy technology diffusion and deployment has generally focused on economic and technical aspects at the national level [18–22]. Yet, energy technology diffusion models and research that rely primarily on technical and cost attributes with a focus on national level energy policy and regulation miss crucial state-level socio-political influences. Often overlooked in current research is the complex state-level socio-political context within which new technologies must be integrated and deployed. This socio-political context includes diverse institutions and actors, regulations and laws, as well as business and economic factors, and is influenced by varying perceptions and levels of awareness about the risks, benefits and costs of emerging technologies.

State-level socio-political factors may facilitate or thwart successful technology diffusion. For example, existing regulations and institutions may not be designed to deal with new, emerging technologies, and negative public perception can create resistance to technology deployment. Alternatively, supportive institutions and positive public perception can facilitate technology siting and deployment. Despite recognition of the critical role these socio-political influences play in technology diffusion [23–25], insufficient attention has been paid to these factors. Further, such factors are complex, interconnected, and have not been characterized with an integrated approach. In the geographically and demographically diverse United States, state-level differences in factors influencing diffusion of emerging energy technologies have received some attention [26,27], but given that it is at the state level where new energy technologies will be sited, permitted and built, insufficient understanding of state-specific factors is likely to delay the transition of U.S. energy infrastructure.

Many different emerging energy technologies have potential to contribute towards the needed energy transition. Conservation, efficiency, renewable electricity derived from wind, solar, and geothermal sources, alternative fuels for transportation including ethanol, biodiesel, and hydrogen [9,28,29], other new not-yet-developed technologies [13], and the recently developed and increasingly important carbon capture and storage (CCS) are all likely to play a role in this transformation. Different challenges and opportunities for deployment and diffusion are associated with each technology, and these influences may vary significantly across and within different states.

Recognizing the important interplay of these complex socio-political factors in influencing technological deployment at the state level, we propose a novel interdisciplinary framework to improve understanding and modeling of energy technology deployment to facilitate improved energy technology policy and planning. The Socio-Political Evaluation of Energy Deployment (SPEED) framework integrates the examination of state-level laws, regulations, institutions and policy actors with the exploration of varying perceptions and levels of awareness about the risks and benefits of emerging energy technologies. By integrating elements from the fields of technology diffusion, regulatory analysis, risk perception, transition management, and policy diffusion, future empirical research conducted within this integrated framework will allow for a more nuanced and systematic understanding of the role of state-level socio-political factors in energy technology deployment decision-making. This SPEED framework will enable energy modelers, policy-makers, energy professionals, state planners and other stakeholders to better evaluate, develop, and implement effective strategies for deploying emerging energy technologies.

In addition to proposing this interdisciplinary framework, this paper highlights the need for empirical research and comparative case studies examining deployment of specific emerging technologies in and across different states to enable characterization of the complex interactions among the many socio-political variables that have potential to influence energy technology deployment at the state level. Such future research could provide diverse and valuable insights about potential state-level barriers and opportunities for various emerging energy technologies with potential to contribute to climate mitigation and enhanced energy security.

We first provide theoretical justification for the SPEED framework, by reviewing literature on transition management, technology diffusion, state-difference, and risk perception. This is then followed by a discussion of potentially critical state-level socio-political factors with influence over energy technology deployment, and a presentation of several methodologies that can be applied within the framework. A final section demonstrates the SPEED framework by considering its application for two specific emerging energy technologies, wind power and carbon capture and storage (CCS).

2. Theoretical justification for the SPEED framework

The SPEED framework seeks to weave together several different interdisciplinary threads to better assess factors influencing state energy policy formation and energy technology deployment. SPEED builds upon insights from both traditional forms of technology assessment that focus on understanding social impacts of articulated technology [30], and attempts to incorporate key components of constructive technology assessment—specifically insights into technology forcing and niche-management [31–33]. However, SPEED is more narrowly targeted on the energy sector and focuses on how such frameworks highlight state-level decisions affecting actual energy technology framing and deployment.

From the emerging field of sustainability science, transition management provides a useful structure to guide exploration of institutional transformations related to deploying emerging energy technologies. Building from a transition management frame, technology diffusion research examining factors that influence how new technologies spread and are adopted, provides valuable interdisciplinary perspectives. Drawing from the literature on state difference, which emerges from political science, provides clues on how different policies are both formed and how they spread from state to state. And the field of risk perception provides an additional frame for evaluating and incorporating the technological risk perceptions among key actors involved in energy policy formation and energy decision-making. Together, these fields provide a strong theoretical underpinning and practical methodology for exploring and informing energy policy debates and formation, as well as technology deployment within different state contexts. A conceptualization of interlinkages among these theoretical frames is demonstrated in Fig. 1.

2.1. Transition management

In responding to the need to transition toward sustainability, the emerging literature of transition management provides a useful structure for examining the large-scale transformation of governance regimes in response to complex, long-lasting and multi-level societal problems. This methodology balances and integrates the importance of long-term goals and the crucial nature of short-term demands [34–37], highlights interactions among multiple management levels ranging from international, national, sub-national, regional, and local [36], and identifies and incorporates the notion that new technologies develop within niches [34]. Grounded in complex adaptive system theory, transition management focuses on the complexity of transition and recognizes the interactions, interdependencies, and feedbacks between different actors, technologies, infrastructures, institutions, and governance systems [36].

This framework specifies three different levels of exploration of transition within an evolutionary frame: strategic, tactical, and organizational, each of which involves different policies and actors [37]. The strategic level focuses on higher level activities of leaders (government, business, non-profit) who engage in strategic visioning and discussions, laying out long-term aspirational goals and objectives and establishing the structure and context for the issue. The tactical level concentrates on agenda and coalition building, and negotiations involving existing institutions and structures and transforming them to carry out the larger strategic goals. Finally, the operational level concentrates on project building and

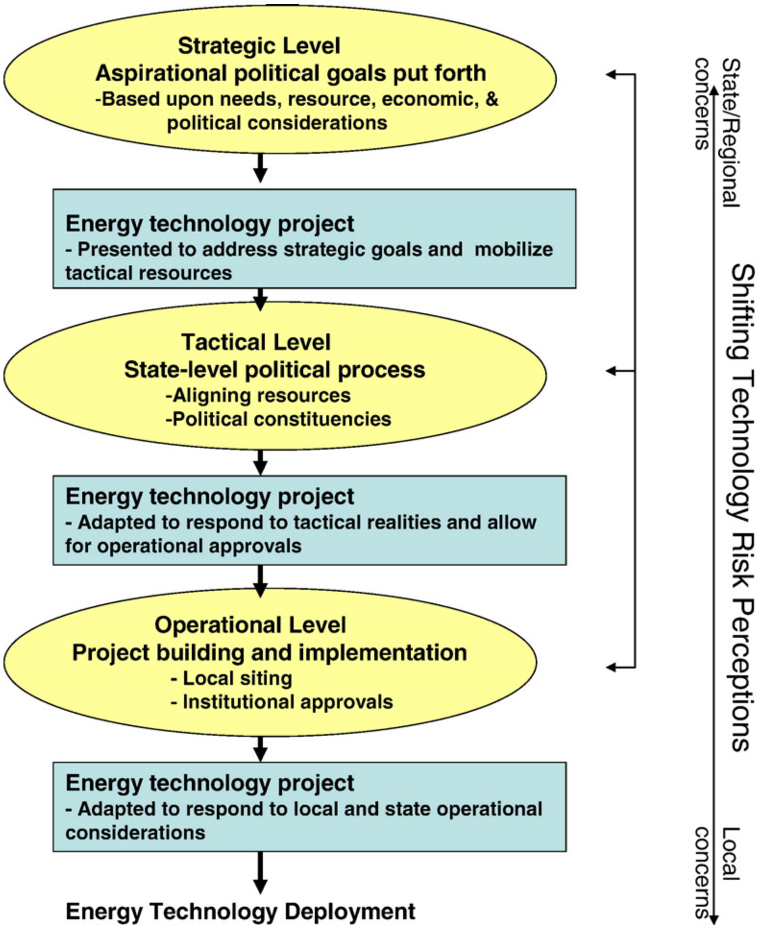

Fig. 1. Conceptual and operational model demonstrating SPEED framework interlinkages among theories of transition management (ovals), risk perception (on right side), state-level policy analysis (throughout), and technology diffusion (rectangles). The cycle is iterative, messy, and dynamic and decisions at any point may have influence on the process throughout the cycle. Key actors at each stage attempt to manage risks (economic, technical, environmental, etc.) to their benefit.

implementation, focusing upon variation and flexibility [37]. These different levels interact, reinforce, and iterate throughout the processes of innovation. Research that integrates analysis at each of these three levels provides insights that cannot be captured by a focus on just one of these levels.

While the transition management framework recognizes the importance of bottom-up developments strategically used as part of a larger policy goal, it also has identified increased use of policy instruments that incorporate systemic complexity in the management of innovation processes [38]. This growing awareness of the interwoven sub-systems involved in innovation and technology diffusion calls for more synthetic examination of actor roles and institutions at the state level, as it recognizes actors both as responding to change and as agents shaping change [39].

Several recent studies have enhanced the transition management literature by suggesting different approaches to induce learning for a societal shift in sustainable energy technologies, including visioning and scenario building [40], promoting a national dialogue [41], and small scale, bounded experimentation with new and emerging technologies [42–44]. Empirical analysis of state-level influences on technology diffusion arising from variation in policy environments and in perceptions of risks and benefits of specific technologies contributes a valuable new dimension to the transition management literature.

2.2. Technology diffusion

The literature on technology diffusion spans legal, policy, economic, sociology, and managerial science fields [23,45], and the importance of socio-political factors influencing diffusion is well documented [24,25]. As a technology is deployed into a larger socio-political context, actors, networks and institutions respond, and as more units of a technology are installed, the technology system evolves. Jacobsson and Johnson [24] discuss the evolution of technology systems where specific technologies emerge within a system of actors, networks and institutions. This framework, by accounting for price/performance measures, inducement and blocking mechanisms, and forces beyond the market, facilitates the comparability of very different technologies with different characteristics. The proposed framework adapts this structure and integrates it into a broader characterization of the interconnected roles of actors, networks and institutions at the state level in technology diffusion and deployment.

While the existing literature has not focused on the importance of states within the context of diffusion, Wejnert's [23] framework discusses the need to incorporate diffusion variables into 1) characteristics of innovations, exploring public and private tradeoffs as well as costs and benefits, 2) characteristics of the innovators, incorporating societal entities, familiarity with innovation, status, personal and socio-economic characteristics and the position of the innovators in social networks, and lastly 3) diffusion of innovation, where the environmental, geographic, societal, and political conditions of a technology are explored. Building on this suggestion, this proposed framework integrates analysis of a diverse array of diffusion variables.

2.3. State difference

Within any country, sub-national states often have very different policies, institutions, and state-level actors that have significant influence on regional decision-making and public perception. In the geographically and demographically diverse United States of America which has fifty different and dynamic states, there is a rich literature on state-level policy differences; the literature on the importance of states as "policy laboratories" and the influence that state actions have on the policy making process encompass economic, political, and group theory frameworks [46–53] with significant work focusing on social policy. There is also a strong literature examining the role of states on environmental policy and regulation [52,54–59] and on energy policy [48,49,53,60]. This literature encompasses both economic and political framings with which to examine the role of regulation, response to organized interests, state capacity to formulate and execute environmental and energy policy [54,61]. Additionally, states have taken independent positions to reduce greenhouse gases, improve fuel economy, and improve air quality [62–64].

While the impacts of state-level policies on deployment of some energy technologies have been explored and catalogued [26,65–70], these studies have not coupled policy analysis with state-specific assessment of actors' perceptions, awareness, and understanding of the risks and benefits of specific energy technologies. An additional critical state-specific variable rarely integrated into peer-reviewed policy studies is the natural resource endowment for a specific energy technology (notable exceptions are the Department of Energy (DoE) studies on renewable technologies [71] and the DoE Carbon Sequestration Regional Partnerships [72]). For example, blowing wind is required for wind power, sufficient solar intensity is required for solar power, and an appropriate underground storage site, usually a deep sedimentary basin, is required for storing captured CO_2. These resources vary significantly within and across different states.

In the United States, state-level differences in factors influencing diffusion of emerging energy technologies have received some attention [26,27], but given that it is at the state level that new energy technologies need to be sited, permitted and built, the level of attention paid to state difference seems insufficient. The proposed framework will enable and encourage systematic analysis of state difference that integrates state-specific policy analysis, state-specific perceptions, awareness, and understanding of risks and benefits, with state-specific natural resource potential for specific emerging energy technologies.

2.4. Risk perceptions of key actors

The perceptions of key actors (including community and business leaders, politicians, entrepreneurs, etc.) of risks and benefits of emerging energy technologies have potential to influence deployment by three primary mechanisms: (1) impacting policy decisions that may provide incentives or barriers to deployment, (2) influencing siting of specific new facilities required for the new technologies, and (3) increasing consumer demand for the new technology. The importance of 'key actors' perceptions and positions in deploying energy technologies can be seen from the analogous literature on public perception in the siting of hazardous facilities [73–75].

A rich literature has compared public perceptions of risk based upon different variables including gender, socio-economic status, and race [76–81], particularly on the risk perception of nuclear energy [82], and several studies have comparatively assessed risk perception across different countries [81,83–87]. A significant gap exists, however, when it comes to comparative analysis of risk perception among different regions or states within a single, but geographically large and diverse country such as the United States. This proposed framework incorporates the perceptions of key actors of the risks and benefits of emerging energy technologies to fill this gap; this framework could also facilitate additional studies of state-level variation of risk perception on other critical issues.

3. The SPEED framework: a structure for future research

3.1. Practical need for an interdisciplinary integrated framework

While many factors contribute to energy technology decision-making, state-specific socio-political factors have potential to be critical to deployment, yet systematic analysis of these often interconnected factors is lacking. The application of an integrated interdisciplinary framework to energy technology diffusion research will enable integrated assessment and evaluation of the multitude of factors with potential to influence patterns of energy technology deployment. By explicitly acknowledging potential for interconnected complexity among a wide array of factors, such a framework will facilitate improved understanding of how energy technology deployment occurs at the state level and will provide insights on how to alter the current process to support and encourage accelerated adoption of alternative emerging energy technologies.

Before presenting the details of the SPEED framework, we first introduce and justify the proposed framework by presenting a list of critical state-level socio-political factors with potential to influence energy technology deployment. While this discussion is not exhaustive, the list demonstrates both the variety and complexity of socio-political influences that should be considered in future integrated research.

Based upon a broad and general review of state-level energy technology decisions, we have developed an initial list of some of these interconnected state-level factors (Table 1). We have distinguished socio-political factors from technical factors; technical factors include resource availability, the state-specific transmission and electricity infrastructure situation, and energy demand growth. Among the many socio-political factors, we have categorized potential influential factors into five groups: institutional, regulatory and legal, political, economic, and social.

Institutional factors include the balance between investor-owned utilities, municipal utilities and rural electric co-operatives, dispatch policy of the regional reliability organizations, available technology transfer mechanisms and institutional experience with particular energy technologies. Whether or not the state is a net energy exporter or importer is another institutional factor that influences political framings surrounding energy.

Regulatory and legal factors influencing deployment of energy technologies include existing and proposed legislation coupled with state-specific case law. For instance, existence of a Renewable Portfolio Standard or state-specific greenhouse gas mitigation target could influence and alter future state energy policy and energy decisions. Siting policies, insurance requirements, property and liability issues will also influence opportunities and hurdles for technology deployment. State politics and the regulatory environment also influences specific actors, proponents or opponents of different energy technologies, as well as relative power relationships among different constituencies. All energy policy will be embedded within competing state priorities for resources and attention; this makes political saliency critical.

State-specific economic factors, such as the cost of electricity, how costs are passed along to the consumer, urban and rural economic development and employment considerations, and other structural factors (tax incentives, ease of market entry, resource ownership) and the state business climate will interact in framing relative benefits and costs of the technology. In addition, economic and financial risk is managed among the actors associated with specific technologies.

Perception of the new technology by both the public and key actors and stakeholder groups will weigh heavily on the perceived fairness of the distribution of risk and benefits. Historical land use, active opposition and how the technology affects the relationships between various social groups will all play a role.

Each of these factors is dependent on the others, and the interaction among the factors is dynamic throughout different stages of policy formation and technology deployment. This list of potential influences on energy technology decisions in Table 1 demonstrates the complexity of state-level energy systems that emerging energy technologies are deployed into. Some states' technological systems may facilitate deployment of emerging energy technologies, while deployment in other states may be hindered by some of these influences. The primary purpose of the proposed SPEED framework is to create an explicit structure and propose some potential research methods that can be applied within that structure to enable improved understanding of the interplay of these factors to facilitate more rapid deployment of emerging energy technologies.

Table 1
State-level factors within the energy system with potential to influence technology deployment—analysis of such factors is incorporated into SPEED framework analysis

	Area	Considerations	Actors and Institutions
Technical	Technical	• Resource availability within state • Associated resource availability (e.g. water, land) • Transmission considerations • Energy demand patterns • Existing electric infrastructure • Demographic profiles (electric demand growth or decline) • Research base	State energy office, geologicsurvey, natural resources department, oil and gas office, public utilities commission, statistical/ demographic office, electric power companies, transmission organizations, research institutions, technical experts
Socio-political	Institutional	• Restructured or regulated electricity market • Balance of investor-owned utilities, municipalities and co-ops generating electricity • Dispatch policy (state level and regional level) • Technology transfer mechanisms • Institutional experience (state institutions, historic industrial activities, industry development plans) • State energy producer or importer	Governor, legislature, state employees, power company employees, non-profits, business community, energy office, transmission organization, muni, co-op and IOU's active in state, energy and environmental non-profits, Chamber of Commerce
	Regulatory and legal	• State-specific energy and environmental regulations (air, water, waste, climate) • Renewable portfolio standard • Siting policies • Other state policies (tax credit, liability limit, financial arrangements) • Insurance requirements • Property ownership regimes • Liability considerations • Transmission issues	Governor, legislature, state environmental office, energy office, county and city commissioners and boards, insurance commission, public utilities commission, courts, lobbyists, industry, environmental, energy, and consumer non-profits
	Political	• Overarching energy policy goals • Natural coalitions to support/oppose technology • Power relationships among political constituents concerned with energy system • Political saliency of environment/energy/climate • Competing political priorities	Governor, legislature, lobbyists, State Democrat and Republican parties, third parties
	Economic	• Cost of electricity, industry cost structure • Whether state is an energy importer or exporter • Rural and urban economic development • Benefits, costs and risk to local residents • Employment considerations • Entrepreneurial climate • Tax incentives and other budget priorities • Ease of market entry • Ownership patterns • Important businesses and industries within state	Public utilities Commissions, Chamber of Commerce, consumer protection groups, Departments of Economic Development, energy intensive industries within state, businesses, farmers, other stakeholder groups
	Social	• Perception of technology/industry by key actors • Public trust and past relations with industry • Perceived fairness of risks and benefits • "Not in my Backyard" (NIMBY)—other opposition • Historical land use • Impact on social groups and relationships	Citizens, official government bodies at state, county and city levels, non-profits and citizen groups, business community, agricultural interests

3.2. Structure and potential research methods to be applied within the SPEED framework

The SPEED framework builds upon the three levels of transition management (discussed in Section 2.1) integrating the strategic level, the tactical level, and the organizational level [37]. The SPEED framework guides research that systematically identifies and explores interconnections among the diverse socio-political factors and key actors that can influence energy technology diffusion at the state level and analyzes these factors and actors within a transition management structure. The key actors to be considered include state regulators, policy-makers, technology developers, entrepreneurs, scientists and engineers, environmental advocacy groups, and others. These actors develop broad policy initiatives, form coalitions to support or oppose technology deployment within the energy sector, and cooperate in drafting and implementing new policies. By pairing policy analysis and political history with research on state-level perceptions of key actors within the energy system this framework will enable identification of complex and often neglected dimensions of technology diffusion.

Specific objectives of future empirical research conducted within the SPEED framework include: (1) identify the dominant socio-political influences on energy technology decisions at the state-level; (2) learn from state-specific diffusion history of different energy technologies at different stages in their deployment history; (3) compare and contrast the relative importance and the interactions of socio-political factors across different states; (4) characterize the complex interactions among the many socio-political variables that have potential to influence energy technology deployment; (5) contribute to transition management theory by integrating relevant concepts drawn from literature in technology diffusion, state-difference, and risk perception; and (6) contribute to the policy discourse related to energy technology deployment and how policy can facilitate a societal response to climate change by communicating insights on the interlinkages among these influences to stakeholders.

The SPEED framework acknowledges that existing technological systems and perceptions of emerging energy technologies are mutually entailed and have a temporal dimension. Perceptions influence deployment decisions, and when a new technology is deployed, the system changes, which again influences perceptions. Both the technological system and the perceptions within are dynamic; this dynamic complexity is represented in Fig. 1.

A variety of interdisciplinary research methods could be applied within the SPEED framework to study and compare different emerging energy technologies in different states; we suggest three research approaches that could be particularly helpful in improving understanding of the integrated socio-political influences identified in Table 1: (1) policy review and analysis, (2) media analysis, and (3) focus groups and structured interviews with key stakeholders. Applying these research approaches in concert will enable the evaluation of how strategic, tactical and operational levels interact to facilitate and/or inhibit the deployment of different emerging energy technologies in different states. All three methods, when applied to specific emerging energy technologies (wind, solar, biofuels, carbon capture and storage, and others) in specific states, can provide empirical data that will contribute to the comparative analysis of energy technology deployment and highlight opportunities and challenges within specific contexts.

Integrating the three levels of transition management and the three potential research methods described below, Table 2 provides a suggested structure on how these methodologies can be integrated to address the different levels of transition management.

Table 2
Integration of three levels of transition management and three potential research methods within the SPEED framework

Transition management level	Potential research methods
Strategic—visioning, long-term goals and objectives, context for issue	• *Policy review and analysis*—examination of policy objectives presented by Governor, State Legislature • Media Analysis—representation and coverage of policy goals in the media, examining public perception and underlying rationale for policy goals
Study component: opinions of actors within states, broad policy goals articulated by actors	• *Focus groups*—examination of key stakeholder perceptions of overarching policy goals. Focus groups of key stakeholders in the private, non-profit, and government sector framing of strategic goals.
Tactical—agenda and coalition building, negotiations, transforming institutions to carry out larger goals	• *Policy review and analysis*—analysis of institutional mandates through study of legislation passed, development of legislation explored through archival research and structured interviews with policy-makers • *Media Analysis*—local media coverage of energy technology legislation, groups involved in energy policy
Study component: institutions and coalitions involved in planning and deploying new energy technologies	• *Focus groups*—understanding perceptions of policy formation, coalitions, and legislative process and proposed actions for implementing policy goals
Operational—project building and implementation	• *Policy review and analysis*—semi-structured interviews with energy office managers, non-profits and industry personnel, small developers, entrepreneurs, farmers, analysis of limits of existing institutional action, examination of resources, experience and results in implementing policy, documentation of changes enacted within existing organizations to deploy emerging energy technologies, overview of new procedures, rules, and structures. • *Media analysis*—local media coverage of energy technology implementation and deployment
Study component: how organizations and institutions implement policies, how organizations have changed and adapted to implement policies and actualize policy goals, methods of evaluation of policy goals	• *Focus groups*—perception of how institutions have changed in relation to implementing new policies and deploying emerging energy technologies

3.2.1. Policy review and analysis

State-level policy review and analysis can involve three components: legal, regulatory, and institutional. Analysis of existing and proposed legislation that may enable or hinder the diffusion of specific energy technologies can be compiled. To examine the strategic level, identification of broad policy goal statements that preceded legislation can be accomplished by reviewing executive orders, press releases, and stated goals of key leaders in the state (governor, legislators). To examine the tactical level, semi-structured interviews and literature review (legal and public policy) can analyze legislation formulation. Interviewing experts can create a systematic 'behind-the-scene' view of legislation formulation, examining actions and influence of coalitions, interest groups, and key individuals that contributed to technology and policy framing and passage of the legislation (where applicable). Finally, operational level changes can be examined through structured interviews with state and local officials charged with implementing the stated policy goals and legislation, the affected business community, non-profit sector, and public stakeholders. Each element mentioned above is embedded within a quantitative and qualitative analysis of the state energy system. Information on natural resource endowments, existing energy infrastructure (plant type, build, amount of coal, gas, oil, or renewable energy used), cost of electricity throughout the state, demand growth projections, appointment and composition of public utility commissions and other factors underlie comparative policy review and analysis within the SPEED framework.

The reconstruction and analysis of energy policy history in different states provides understanding of the position/rationale of the different actors and a nuanced perspective of the legislative process, focusing on conception, development, and implementation. Expert interviews and review of policy material could allow identification of themes that influenced strategy, tactical, and operational aspects of technology deployment within very different energy systems in different states. Policy review and analysis integrates document review with field research to better evaluate the state policy context within which emerging energy technologies are deployed.

3.2.2. Media analysis

In addition to state-level policy review and analysis, media analysis provides tools to quantitatively assess variations in regional perception and levels of awareness about climate change and energy challenges, as well as more specific perceptions of risks and benefits of individual emerging energy technologies. Research indicates that the news media plays an important role in developing the public's perceptions of science and technology because media link technical assessments of experts to the psychological assessments of laypersons [88–91]. Gregory [89] argued that the media influences communication between technical experts, policy-makers, and the public by "interpreting scientific findings for the public, providing key information, selective summaries and overall assessments of the quality and relevance". Because of this interpretive function, media analysis can integrate and link policy review and analysis with the focus groups and stakeholder perception analysis.

Media analysis could be focused on print articles in the top-ranked state newspaper (determined by circulation), or could also include assessment and analysis on other media sources including radio, television, and internet sources. Major media outlets rarely highlight energy policy development. Rather, they frame stories relevant to energy policy in terms that are deemed more newsworthy, such as national security, environmental quality, and public health. Because framing is so fundamental to media coverage of energy, frame analysis [92] would be particularly useful. In studies of the media, frame analysis shows how aspects of the language and structure of news items emphasize certain aspects (and omit others). Frame analysis can identify relationships between key themes, the degree to which the print media link specific technologies to climate change, what tone they exhibit (positive/negative) toward specific emerging technologies, the valence of positive/negative characterization, and how science and technology (broadly defined) are treated.

Analyzing how the media presents and discusses deployment of emerging energy technologies will enable assessment of the degree to which energy technologies are framed as (1) strategic responses to broad goals such as achieving energy security and mitigating climate change, (2) tactics such as legislation intended to achieve these goals, and (3) operations that focus on details of implementation. The relative salience of strategic, tactical and operational frames will provide valuable information regarding general levels of attention and awareness of these technologies and a temporal component to evaluate how public attention to the deployment of energy technologies has changed over time. Media analysis, including both qualitative and quantitative approaches to assessing the media content, could complement the documentary and interview-based policy analysis, as well as the focus group-based analysis of public perception by providing a broad picture of the lay public's attention and awareness as it relates to the legal and economic framework in different states.

3.2.3. Focus groups and structured interviews with key stakeholders

Stakeholder focus groups and structured interviews allow for understanding of strategic, tactical, and operational factors, to assess state-level variation in perceptions of risks and benefits of emerging energy technologies among various actors. Given that previous research of public perceptions of energy technologies [87,93,94] has demonstrated that general public surveys provide limited information because the public is largely unaware and uninformed about emerging energy technologies, the coordination of focus groups with opinion leaders, decision-makers, and energy-technology-gatekeepers (individuals and representatives of groups with strong influence over energy technology decision-making) could be valuable. The focus groups and structured interviews target state regulators, policy-makers, technology developers, entrepreneurs, scientists and engineers, environmental advocacy groups, relevant businesses, and other key actors.

Focus group research allows for the gathering of information that provides insights to understanding public responses to different sets of technologies and provides insights on the social construction of meaning and motivation related to different sets of technologies. Structured interviews allow for one-on-one assessment of interviewee motives, perceptions and framing of both the energy technology as well as the larger context. While survey responses are useful in providing general public opinion information, focus groups and structured interviews are more likely than surveys to elicit data reflecting how community experiences, emotions, and sensations contribute to motivations related to diffusion and adoption of emerging technologies [95–97].

4. Applying the SPEED framework to considering deployment of wind and carbon capture and storage (CCS)

The value of the SPEED framework can be illustrated more clearly by considering its application to specific emerging energy technologies. This section briefly considers how the SPEED framework and the proposed research methods could be applied to analysis of two very different but important emerging energy technologies: wind power and carbon capture and storage (CCS). In addition this section provides details of a specific recent case in California where the application of the SPEED framework could have identified some critical linkages among influences that could have enabled a different outcome with regard to advancement of CCS technology.

While wind and CCS are very different emerging technologies with different deployment challenges and different potential deployment patterns, they are both critical contributors to the portfolio of technologies needed for an energy system transition for climate change mitigation. Both wind and CCS have enormous potential to change the energy technology landscape and dramatically reduce CO_2 emissions, so application of the SPEED framework to future research on these technologies would be particularly valuable. Integrated research focusing on both of these very different yet important technologies could allow for effective and strategic examination of the interplay of socio-political factors that can influence deployment of these and other emerging energy technologies.

4.1. Application example: deployment of wind power

Wind power has potential to generate substantial amounts of carbon-free energy, and deployment rates of wind power throughout the world have been growing rapidly. In the US, wind power generating capacity increased by 27% in 2006 and is expected to increase an additional 26% in 2007 [98]. Despite this rapid growth, wind power deployment has had a complex and varied history in different states [99]. Wind power's distributed infrastructure can be deployed on or offshore. Wind turbine technology has been developing and improving over centuries and is economically viable today, though siting and ecological concerns associated with birds (and fish in off-shore applications) have been delaying deployment in many locations. Despite recent advances in wind deployment, for wind technology to become large-scale (large-scale wind is generally considered comprising at least 20% of generation) integration challenges with the current energy system, including intermittency of power, energy storage limitations, and transmission capability, need to be overcome [100], as do social challenges of local public opposition limiting siting of wind turbines in some locations [101–106]. Supporters of wind power include entrepreneurs, farmers, and environmentalists, as well as coalitions between them [107]. Wind power has a long history and is rapidly increasing, yet scaling up to large-scale wind deployment still faces considerable challenges.

While several studies have explored public perception of wind energy independently [105,108–110], research integrating state-specific assessments of perceptions of the technology among different key actors with other state-specific variables has not been done. Analysis of the history of wind deployment within the SPEED framework would provide valuable insights about critical factors influencing advancement and scaling-up of wind power.

Preliminary analysis of factors influencing wind deployment in two geographically and politically different states, Massachusetts and Minnesota, summarized in Table 3 demonstrates state-specific variation. Discourse and debate surrounding deployment of wind technology, and deployment patterns in these two states are very different. In Massachusetts, the proposed Cape Wind off-shore wind project, which would be the nation's first off-shore wind farm with a capacity of 468 MW, has been stalled by strong opposition by some influential actors based primarily on aesthetic concerns [101]. In addition, despite a multi-million dollar state-sponsored Massachusetts community wind initiative, only a handful of on-shore wind turbines have been deployed in Massachusetts [111]. In Minnesota, in contrast, community owned wind power has wide support as a rural economic development tool, and the state currently has 895 MW of wind power from over 65 different projects [112]. Additionally, utilities in Minnesota are required to build renewable energy. For example, Excel Energy, the largest investor-owned utility in Minnesota is required to procure 30% of its electricity from renewable energy by 2020 and recently announced their 1000th Megawatt of wind energy [113]. This preliminary comparison of wind deployment in two states begins to illustrate how the application of the SPEED framework to research involving systematic characterizations and analyses of the interplay of factors that contribute to state-level differences could enhance understanding of energy technology deployment.

Integrating these factors into a more comprehensive model for technology diffusion will allow for more accurate predictions of actual diffusion rates and also help to highlight challenges and opportunities for emerging energy technologies nationwide. Such information is useful for project developers at the state level, and modelers at the national and international level who seek to refine estimates of technology diffusion with real-world insight and information.

4.2. Application example: analysis and preparation for carbon capture and storage deployment

Carbon capture and storage (CCS) is another emerging energy technology at a very different stage in its development than wind. CCS has potential to enable deep reductions in CO_2 emissions from fossil-fuel generated energy by capturing CO_2 at large fossil-fuel based power plants and injecting the captured CO_2 into secure underground geologic formations ensuring the CO_2 will remain out of the

Table 3
Preliminary comparative assessment of factors influencing wind deployment in Massachusetts and Minnesota applying the SPEED framework

	Area	Massachusetts	Minnesota
Technical	Technical	Large off-shore wind resources off Cape Cod On-shore wind resources throughout the state No fossil-fuel reserves, but substantial renewable resources	Good wind resources in Southwestern Minnesota Various projects deploying turbines in rural Minnesota
Socio-political	Institutional	Jurisdiction over development of Cape Wind has been controversial Multi-million dollar state-sponsored Community Wind Collaborative	Municipal and rural electric co-operative utilities provide 30% of all electric sales Xcel energy sells 50% of all electricity and runs the only nuclear plants in the state
	Regulatory and legal	Renewable Portfolio Standard took effect in 2002 encourages wind deployment by providing guaranteed growing demand	Requirement for Xcel energy to buy wind energy in exchange for storing nuclear waste at reactor site
	Political	High level political lobbying (even at U.S. senate level) against project Powerful individuals and groups aligned against project Environmental coalitions split	Special state tax incentive to promote community owned wind projects Governor and state legislators goals to reduce greenhouse gases and promote rural development Coalition of farmer and environmental organizations
	Economic	Promoting renewable energy is framed as a long-term economic development strategy	State is net energy importer Some community ownership of turbines has emerged
	Social	Wind turbines seen as aesthetic eyesore on seashore Public opposition to on-shore wind turbines also strong	Wind turbines framed as vehicle to promote rural development and use less coal Rural areas used to have wind turbines before electrification

atmosphere [114–116]. The cost of adding CCS to a new coal power plant is estimated to be roughly 20% more than that of building a new plant without CCS [114], yet the importance of the potential of this technology in our future energy infrastructure is evidenced by new recent public discussion about the technology by state and national leaders as well as new proposed legislation relevant to the technology in several states [117–120]. Research, development and demonstration of CCS technology have been funded by both public and private parties over the past decade, as desire to drastically reduce CO_2 emissions while allowing continued use of cheap and abundant fossil-fuels such as coal has increased [16,121].

While the individual technological components of CCS are proven and supported by extensive experience in other applications within the oil and gas industry and the power sector, the configuration, the integrated application, and the scale of the components used in CCS are novel. Concerns about the safety in siting CCS facilities, uncertainties about the long-term stability of CO_2 stored underground, and the significant infrastructure costs required for this technology are among the challenges facing the deployment of CCS. In addition, existing regulatory and legal frameworks are not equipped to facilitate CCS diffusion [122], and public perceptions of the risks and benefits could influence acceptance, siting and deployment [123–125]. Supporters of advancing CCS technology include the fossil-fuel industry, the federal government, as well as some environmentalists [121].

CCS is a new configuration of existing technologies that is largely unfamiliar to the public. CCS has not yet been adopted at scale in the United States, but with ongoing projects in Europe and Africa coupled with several planned projects in the U.S., CCS is rapidly advancing toward deployment [16,121]. Given the large potential CCS has for reducing CO_2 emissions for climate change mitigation and given its preliminary status as a set of emerging technologies that have not yet been deployed, future research conducted within the SPEED framework designed to identify and analyze state-specific socio-political factors that could influence future deployment of CCS in different states would be valuable.

An initial comparative assessment of factors likely to influence CCS deployment in two states, Montana and California, is presented in Table 4. Both of these states have proposed legislation to facilitate CCS deployment, but the framing of the state discussion about the technology has been quite different. Montana has large coal resources, has demonstrated interest in advanced technologies including CCS to enable the conversion of coal to liquid fuel, and has plans to increase the export of coal-generated electricity. California's proposed CCS legislation, in contrast, is primarily a response to aggressive state greenhouse gas regulations. Although CCS is an increasingly critical set of technologies for considering future coal utilization in a carbon constrained world, there is currently much uncertainty about whether and how CCS could be deployed due to minimal public awareness and a lack of either federal or state policy to regulate and to advance CCS deployment. Detailed analysis within the SPEED framework of the various socio-political state-level factors likely to influence advancement of CCS in different states would be extremely valuable, therefore, as society increases its efforts to grapple with how to satisfy growing energy demand while reducing CO_2 emissions.

4.3. Recent case demonstrating potential of SPEED analysis: advancement of carbon capture and storage in California

This section details the specifics of a recent case that demonstrates how linkages among several key socio-political key actors influenced a proposed innovative carbon capture and storage project in California. By introducing the specifics of this case we are illustrating how more integrated understanding from analysis within the SPEED framework could have identified some of these linkages and provided crucial insights that may have resulted in different decisions more supportive of advancing emerging carbon capture and storage (CCS) technology.

In 1996, BP proposed a gasification project at their Carson refinery which would allow them to gasify petroleum coke for energy, capture the produced carbon dioxide and sequester it in an enhanced oil recovery project. From BP's perspective, the project made strategic and tactical sense as it would produce hydrogen and store the CO_2—two of Governor Schwarzenegger's pet initiatives—the BP refinery needed a new energy source and the pet coke was produced at the refinery, but currently trucked to Long Beach, CA, where it was shipped to China [126,127]. Additionally, BP's greenhouse gas reduction target to maintain levels of greenhouse gases below 2001 levels made CCS a logical fit [128]. However, the history of air quality management and environmental justice community involvement with the South Coast Air Quality Management District's RECLAIM program [129] created a political environment that has made

Table 4
Preliminary comparative assessment of factors likely to influence deployment of CCS in Montana and California applying the SPEED framework

	Area	Montana	California
Technical	Technical	Large coal reserves Heavy dependence on coal technology Proposed coal-to-liquids and CCS projects Potential reservoirs for enhanced oil recovery and sequestration	Little coal use in state Potential use of CO_2 for enhanced oil recovery Potential reservoirs for CCS Proposed BP project to gasify petroleum coke at an LA refinery and use CO_2 for enhanced oil recovery
Socio-political	Institutional	Restructured electric market Smaller state institutions with capacity for oil and gas operations	Restructured electric market Large state institutions with high innovation levels and environmentally pro-active
	Regulatory and Legal	Proposed bills in legislature to promote enhanced oil recovery, provide tax benefits and resolve some CCS property rights issues	California Global Warming Solutions Act sets target to reduce GHG Assembly Bill 1925 to study geologic sequestration Assembly Bill 705 to develop regulations for CCS withdrawn
	Political	High level political support for project approvals Natural resource lobby groups aligned for development of technology	Governor support for technology Environmental Justice coalitions responded unfavorably
	Economic	State net energy exporter Current difficulties evident with Restructured environment	State is net energy importer with high cost of electricity
	Social	CCS viewed as way to develop coal resources under carbon constraints	CCS viewed as important technology for reducing GHG Some degree of NIMBYism

siting of large, stationary sources of emissions politically contentious.[3] While the facility secured necessary air quality permits, the Environmental Justice community organized a campaign against the facility, going so far as to block proposed legislation to regulate carbon sequestration at the state level in Sacramento, as they felt they would stand a better chance of defeating the project under existing regulations [130]. As such, an initiative to develop regulations for CCS were stalled in committee and never passed.

This case highlights how key actors involved in proposing an innovative carbon capture and storage project in California did not effectively incorporate the historical community context into their planning,

[3] The South Coast Air Quality Management District writes "October 1993, Rule 2008 — Mobile Source Credits allowed mobile source emission reductions generated by Rule 1610 and future 1600 series rules to be used as RTCs. The objective as stated in the RECLAIM October 1993 Staff Report is to "provide the opportunity for RECLAIM facilities to pursue the most cost-effective approach to reduce facility emissions — through stationary source emission controls or possibly by reducing mobile source emissions through old-vehicle scrapping". From Appendix Comments on the draft and responses comment letter 1, Communities for a Better Environment. February 23, 2001, available at www.aqmd.gov.

and linkages among several key socio-political factors, including risk perceptions and the state-level policy process, prevented the passage of legislation that would have allowed the development of regulations for CCS and would have supported deployment of an innovative energy technology project. In this recent case, analysis within the SPEED framework could have identified some of these linkages and prepared key stakeholders to incorporate consideration of these linkages in their actions by fostering discussion about past energy development activities in the area, by identifying key interveners within the energy and environmental debates, and possibly altering the decision to site a complex industrial facility in a politically charged local environment.

Integrated analysis of influences within the SPEED framework could have provided crucial insights before the policy process and the technology deployment plans were halted due to embedded political and community interests. Such integrated knowledge could have allowed key parties (the project developer, the Assembly Member proposing the enabling legislation, and the local environmental justice community who opposed the legislation and the project) to understand each others' motivations and concerns and potentially enable a different outcome that might have facilitated advancement of this new emerging energy technology.

5. Conclusions

The SPEED framework provides a combined qualitative and quantitative analytic model that formalizes and guides integrated and interdisciplinary research on a complex array of socio-political factors influencing energy technology deployment. The results of research conducted within the SPEED framework will have both theoretical and practical value.

Theoretically, the SPEED framework fosters integrated analysis of two sets of variables that influence deployment of technology: (1) the actors involved in deployment, and (2) the socio-political context in which the deployment process must occur—such integration and co-analysis of these variables has been recently recognized as a need in the technology diffusion literature [23]. Research conducted within the SPEED framework will also enhance the transition management literature by providing empirical evidence to support new theory about state-level socio-political influences on a shift to more sustainable technologies. By integrating analysis and perspectives from the technology diffusion literature, the state-difference literature, and the literature on public perception of risk, new research will contribute to a richer theoretical framework in each discipline, while also adding a more nuanced component to the transition management literature.

Practically, systematic and comparative empirical research conducted within the SPEED framework will provide diverse and valuable insights useful to both public and private actors related to potential state-level barriers and opportunities for various emerging energy technologies with potential to contribute to climate mitigation and enhanced energy security. Enhanced understanding of and awareness of these interconnected socio-political factors at the state level will inform improved energy technology planning and more effective energy policy to support and accelerate the needed transition in energy technology infrastructure. Research conducted within the SPEED framework will also provide information enabling both modelers and stakeholders to better understand the role of the states in technology diffusion. Also, comparative characterization of regional variation in perceptions of emerging technologies provides insights on design of education and outreach efforts related to energy.

Finally, to effectively contribute to the policy discourse surrounding energy technology deployment and to the acceleration of changes in society's energy system for climate change mitigation, broad dissemination of research results on the interlinkages among different influences is critical. This can be achieved through sustained communication among researchers and the energy technology stakeholders that are subjects of research and analysis conducted within the SPEED framework.

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