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Article

A Smarter Grid for Renewable Energy: Different States of Action

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Abstract: Smart grid has strong potential to advance and encourage renewable energy deployment, but given the multiple motivations for smart grid, renewables are not always central in smart grid policy discussions. The term “smart grid” represents a set of technologies, including advanced meters, sensors and energy storage that are crucial for the integration of more renewable and low carbon electricity into the electric power grid. However, developing and building a smart grid is jurisdictionally complex, path dependent and context specific; states and regions are approaching grid modernization in different ways. This paper reports on a comparative analysis of smart grid development in seven U.S. states. We use state-level policy documents to learn what motivates smart grid development and how smart grid is framed in relation to renewable energy. In some states, renewable technologies are presented as an integral part of the smart grid policy discussion, while in others they are largely absent.

Keywords: electricity; smart grid; grid modernization; transition; renewable energy

1. Introduction

While renewable energy technologies like wind and solar have huge potential to reduce both greenhouse gas emissions and other negative environmental impacts from electricity generation, integrating these technologies into the electric power grid poses ongoing technological and institutional challenges. In the U.S., large-scale development of renewable power requires modernization of the electric power grid: both the high voltage transmission needed to transport and integrate electricity generated from large, and variable renewable energy projects and the low-voltage distribution network needed to integrate small-scale, decentralized renewable energy [1–4]. The term "smart grid" represents these advances and includes a broad array of individual technologies including advanced meters, sensors, energy storage, and others that are crucial for the integration of more renewable and low carbon electricity into the electric power grid [1,2,5–7]. Smart grid also encompasses the development of new standards, management practices, and systems to increase reliability, ensure affordability and manage temporal and spatial variability of renewable electricity generation [8–10].

Smart grid has the potential to deliver multiple societal benefits including a more reliable and secure energy sector, a more powerful economy, a cleaner environment, and an empowered citizenry engaged in energy system management. In different contexts and among different key actors, the potential benefits (and risks) of smart grid are prioritized differently. Although the critical links between a "smarter" grid and renewable energy are among the most prominent justifications for smart grid, the multiple promises of smart grid result in a complicated policy discourse that extends beyond connections between smart grid and renewables. Developing a smarter grid involves the evolution of intertwined technical and social systems linking public and private stakeholders at federal, regional, and state levels. Grid modernization is also path dependent—meaning that decisions made today can create long-term lock in—and jurisdictionally complex, with countries, regions, and states approaching smart grid development differently [11–18].

Building a smarter grid is both costly and valuable: the Electric Power Research Institute estimates that smart grid investments in the U.S. will cost $338–467 billion over the next 20 years, and provide $1.3–2 trillion in benefits [19]. The American Recovery and Reinvestment Act of 2009 included $4.5 billion in federal government support for smart grid, and helped to leverage $5 billion in private investment. While federal support is helpful, in the heterogeneous patchwork of policies, regulations and power systems, U.S. state governments emerge as crucial stakeholders for both smart grid and renewable energy development [20–26]. State legislatures pass policies to promote alternative energy; state public utility commissions are tasked with evaluating the benefits and costs of new smart grid investments and approving utility projects; and state energy offices often support demonstration projects or evaluate policy and regulatory compliance. Together, these state actors have developed complex and sometimes contradictory views of the tradeoffs associated with smart grid and the relative synergies with renewable energy development. How state policy documents reflect the opportunities presented by smart grid and its intersection with renewable energy technologies remains an important, but understudied area of inquiry.

In this paper, we present a systematic, comparative analysis of the policy discourse and social context of smart grid development and the role of renewable energy across seven diverse states. We analyze and compare a sample of state-level policy documents on smart grid from state legislatures, public utility commissions, and energy office web sites from the states of California (CA), Illinois (IL), Massachusetts (MA), Minnesota (MN), New York (NY), Texas (TX), and Vermont (VT). The goal is to compare the policy discourse surrounding smart grid and its connections with renewable energy development. In particular we explore stated motivations for smart grid development and how smart grid discourse is framed and its relation to renewable energy technologies. Following this introduction, we provide background on the socio-technical context for renewable energy and smart grid development in each of the seven states. We then describe our research methods, followed by a presentation of results. We conclude with a discussion of state-level variations in motivations and framing, focusing on how the diverse smart grid discourses contribute to our understanding of the state-level challenges of linking smart grid with renewable energy development. While this paper focuses on the United States, differences in smart grid development have also been noted in European and Asian countries [11,13–15].

2. Socio-Technical Context for Smart Grid and Renewable Energy

We conducted a comparative analysis of seven states that were selected to highlight the diversity of contexts for smart grid development in the United States (Figure 1, Table 1). Three of the seven are populous states with single-state electricity markets (CA, NY, and TX), and the other four participate in Regional Transmission Organizations which coordinate transmission system planning and wholesale electricity markets across multiple states. Minnesota and Illinois are a part of the Midwest Independent System Operator (MISO) and Massachusetts and Vermont belong to the New England Independent System Operator (ISO-NE). Two of the states remain traditionally regulated where the utility owns the generation, transmission and distribution infrastructure and is regulated by the state Public Utilities Commission (MN and VT) and the rest have undergone some form of electricity market restructuring where different companies own different parts of the system and the level of state regulation varies. Some of the states (CA, TX) have supported heavy utility investment in smart grid and smart meters, others have plans to do so (IL, VT, NY), while the remaining states have supported more limited initial investments (MA, MN). All of the states have renewable portfolio standards (RPS) or goals and have invested to some degree in renewable energy technologies [27,28]. All of the states in our sample have interconnection policies and other financial incentives to promote renewables and connect them to the electric grid, though the degree and type of support varies. Additional information about state energy use, smart grid and renewable energy policies and legislation is provided in Supplementary Information, Appendix 1 Tables A1 and A2 [29].

Table 1 highlights key demographic and electricity system characteristics for each state, and Table 2 reviews relevant policies in each state. Total electricity generation varies from 204 TWh in California to less than 7 TWh in Vermont, with the largest percentage of renewable generation coming from the same two states, where roughly 30% of the in-state electricity production in both CA and VT is generated from renewable sources. The current price of electricity varies considerably among the seven states with a minimum of 8.4 cents/kw·h in MN to 16.4 cents/kw·h in NY.

Overall, California has the most smart grid investment and the highest percentage of electricity generated by renewables. Texas has also invested heavily in smart grid, and has the largest amount of installed wind in the U.S. Minnesota has invested the least in smart grid, with most smart meters owned by rural electric co-operatives, though installed wind levels are high. Variation in the number of installed smart meters or AMIs is large, and only CA, TX, and VT, are on a path toward more than 50% of households having advanced meters by 2015 [30].

Figure 1. Location of the seven states in comparative analysis. California (CA), Illinois (IL), Massachusetts (MA), Minnesota (MN), New York (NY) and Vermont (VT) all have different levels of smart grid deployment and renewables penetration.

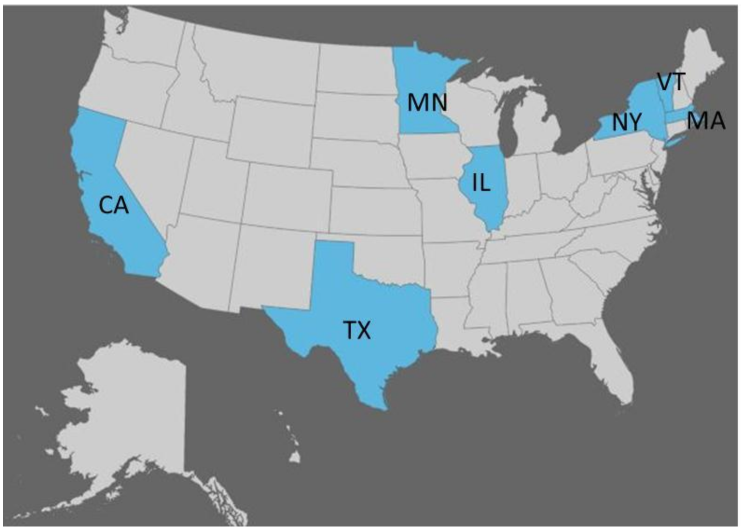


Table 1. (**a**) Demographic and electricity system profile of each state. (**b**) Renewable Generation and Percent Electricity from Renewables does not include nuclear generation but does include large-hydropower. Sources: U.S. Energy Information Administration 2013 [31], Sherwood 2012 [28], NREL 2012 [27].

State	Population (Million)	Total Electricity Generation (TWh)	Total Electricity Consumption (TWh)	Total Renewable Generation (TWh)	Renewable Generation (%)	Average Electricity Price (¢/Kwh)	Installed Wind (GW)	Installed Solar (MW_{DC})
CA	37.2	204	260	60	29	13	5.5	1,564
IL	12.8	201	145	5	2	9.1	3.6	16
MA	6.5	43	57	3	7	14.3	0.1	75
MN	5.3	54	68	8	15	8.4	3	5
NY	19.4	137	144	31	23	16.4	1.6	124
TX	25.2	412	360	29	7	9.3	12.2	86
VT	0.6	7	6	2	30	13.2	0.2	12
US Ave.	12	80	74	8.6	14	9.8	0.79	79

Table 2. (**a**) Policies and technologies for renewable energy and smart grid development in the seven states. (**b**) Texas is the only location that does not have statewide net metering; rather this is managed on a community-by-community level. (**c**) Additional information on smart grid project expenditures is provided in Appendix Table A1.

State	Net Metering Size Limits (kW) [1]	Renewable Portfolio Standards	Total Smart Grid Budget in Million $	Number of Smart Grid Projects [3]	Number of AMI Installed in 2011 and (Estimated % of user coverage in 2015) [4]	Electricity Market Status
CA	1,000–5,000	33% by 2020	1,198	14	10,610,811 (Over 50 %)	Suspended
IL	40	25% by 2025	721	7	181,667 (Under 50%)	Restructured
MA	60–10,000	15% by 2020	296	16	46,241 (Under 50%)	Restructured
MN	40	25% by 2025 [2]	65	7	172,810 (Under 50%)	Traditional
NY	10–2,000	29% by 2015	444	8	18,785 (Under 50%)	Restructured
TX	Voluntary by utility	10,000 MW by 2025	1,079	19	5,658,595 (Over 50%)	Restructured
VT	20–2,200	20% by 2017	326	5	123 (Over 50%)	Traditional

[1] State policies may only apply to certain types of utility (Investor Owned Utilities, Municipal Utilities and Rural Electric Co-operatives). Additionally, different customer classes (industrial, commercial or residential) often have different capacity limits to qualify for net metering. For example, a residential PV system in New York is limited to 25kW, for other customer classes, it can be 2 MW. [2] Xcel Energy is required to have 31.5% of renewable generation by 2020; all other IOUs: 26.5% by 2025; other utilities: 25% by 2025. [3] This number represents projects listed in 4 national databases: sgiclearinghouse.org, smartgrid.gov, energy.gov, and edisonfoundation.net. [4] The number of AMI in 2011 was calculated from EIA Form 861, Table 8.

3. Methods

We conducted thematic analysis of documents posted on state government websites to compare state-level discourses on smart grid. We used qualitative textual analysis because we sought to discover more than the face value meaning of the documents; rather we used them to identify each state's motivations for developing smart grid and the socio-technical frames they used to connect smart grid with renewable resources [32,33]. We analyzed the texts thematically to provide analytical structure, while maintaining textual richness. Beyond identifying and counting word use, themes offer conceptual focus, and provide a guide for identifying discursive patterns that, when appropriately combined, clarify the logic of a world view [32]. We derived thematic categories from the socio-political evaluation of energy deployment (SPEED) framework [34], which offers a systematic analytical method for assessing the socio-political context of energy system evolution. Our research team previously developed and applied the SPEED framework to structure analysis of socio-technical factors that influence decisions on the deployment of other emerging energy technologies (wind power and carbon capture and storage), particularly as related to perceived risks and benefits [20,35,36].

For additional information on specific focal areas for thematic qualitative analysis refer to Appendix 3 Table A3.

Our search for smart grid documents posted on state government web sites took place between 1 October 2012 and 1 June 2013 and included the sites of (1) state legislatures; (2) state public utility commissions; and (3) state energy offices. For each of the seven states smart grid related documents were identified by clicking on these three state websites and then using the search engines embedded within each site to search for the terms "smart grid" and "smart meter". Our goal was to replicate the experience of a web user interested in smart grid, while simultaneously developing a data collection protocol to enhance process consistency and replicability across web sites. To assemble the sample of documents for analysis, we then used the site embedded search engine to order the returned documents by "relevance." Finally, we selected a sample of the 20 most relevant documents from each state (this included the first 20 articles that focused on smart grid and electricity system change). We conducted thematic analysis on the resulting 140 documents, which included 479 pages of text and 451 PowerPoint slides. We chose to include "smart meter" as a search term because smart meters are a prominent part of smart grid development in many states and our preliminary analysis suggested "smart meter" often shows up in smart grid-relevant documents without specifically mentioning the term "smart grid". The publication dates of these documents ranged from 2000–2013. The files hosted on state websites include many different types of documents including material produced by entities other than the state government. The documents include reports, legislation, presentations, Federal Energy Regulatory Commission (FERC) filings, state filings for regulatory compliance, business practice manuals, white papers, market reports, informational public utility documents, newspaper articles, public comments and press releases relating to smart grid policy and development. A full list of the documents analyzed is presented in Appendix 2.

We imported these documents into NVIVO 10.0™ and coded them to assess the motivation for smart grid development and how smart grid is framed. We also searched for mentions of renewable technologies. We used and adapted a codebook from a previous study to guide coding of framing of smart grid in our sample [20]. After multiple coding practice rounds, coders achieved acceptable intercoder reliability (Kappa = 0.8–0.88). Two researchers independently coded each document and then consulted with each other to reconcile any differences in interpretations of coding results [20,37].

The coding team identified motivations for advancing smart grid (Table 3) and socio-technical frames used to discuss smart grid development. They also noted how often and in what ways renewable energy technologies were discussed. The coding of motivation for advancing smart grid included the following categories: (1) A "renewables" code includes all mentions of the need for smart grid for large-scale projects like wind farms, large solar installations, *etc.* and other general mentions of the potential for smart grid to enable more renewables integration, (2) a "distributed generation" code includes mentions of the potential for smart grid to enable smaller-scale renewable technologies like rooftop solar, (3) an "adapt and integrate standards" code includes mentions of how smart grid can contribute to meeting standards including the renewable portfolio standards and interconnection standards, and (4) "efficiency and demand response" code includes mentions of any motivations associated with improving system efficiency and changing patterns of electricity demand. This last code represents motivations that are not explicitly linked to renewable energy but were often a prevalent motivation.

Table 3. Examples of thematic-qualitative analysis of Motivation and the Framings used. More detailed analysis of framing is provided in Supplemental Information Appendix 3.

Motivation	Framing Examples
Increase Large-Scale Renewables	Technical: Challenges of transmission and integration of variable renewable resources Economic: Cost of building additional transmission and integrating renewables Political: Contribute to state renewable energy generation policy goals Environmental: Reduce emissions, affect local land use Cultural: Develop renewable energy resources for self-reliance or energy security Health and Safety: Health effects associated with changing the electric system
Distributed Generation (DG)	Technical: Considerations with DG and low-voltage distribution network with two way flow Economic: Consumers are able to earn money through net metering Political: Contribute to meeting other state policies like RPS Environmental: Shift location of emissions Cultural: Self-sufficiency, local sourcing, production of "loca-volts" Health and Safety: Changing location of emissions, safety to power line workers
Adopt and integrate mandates and standards	Technical: Lack of smart grid equipment standards affect technology compatibility Economic: Costs of adopting smart grid standards and ensuring interoperability Political: Political costs of approving smart grid or renewable energy projects in the face of public opposition Environmental: Standards could potentially help to harness environmental benefits of smart grid Cultural: Culture of creating and adopting standards through long and slow processes Health and Safety: Cybersecurity concerns can only be addressed by consistent security standards
Other: Increase Energy Efficiency (EE) And Demand Side Management and Demand Response (DSM/DR)	Technical: Challenges in verifying energy efficiency savings or technical challenges for implementing demand response Economic: Reduce cost of new transmission, save consumers money on electricity costs, consumers save money by reducing or shifting electricity use Political: Meet political goals associated with energy efficiency, meet state or corporate demand response polices Environmental: Reduce electrical use, reduces associated emissions and environmental harm, lower emissions through conservation, reduced use of dirty peaking plants Cultural: Culture of traditional utility industry towards risk stifling innovation, increase customer awareness of energy consumption and engage customers Health and Safety: Reduced electricity use could help to improve air quality, affect exposure to air pollution

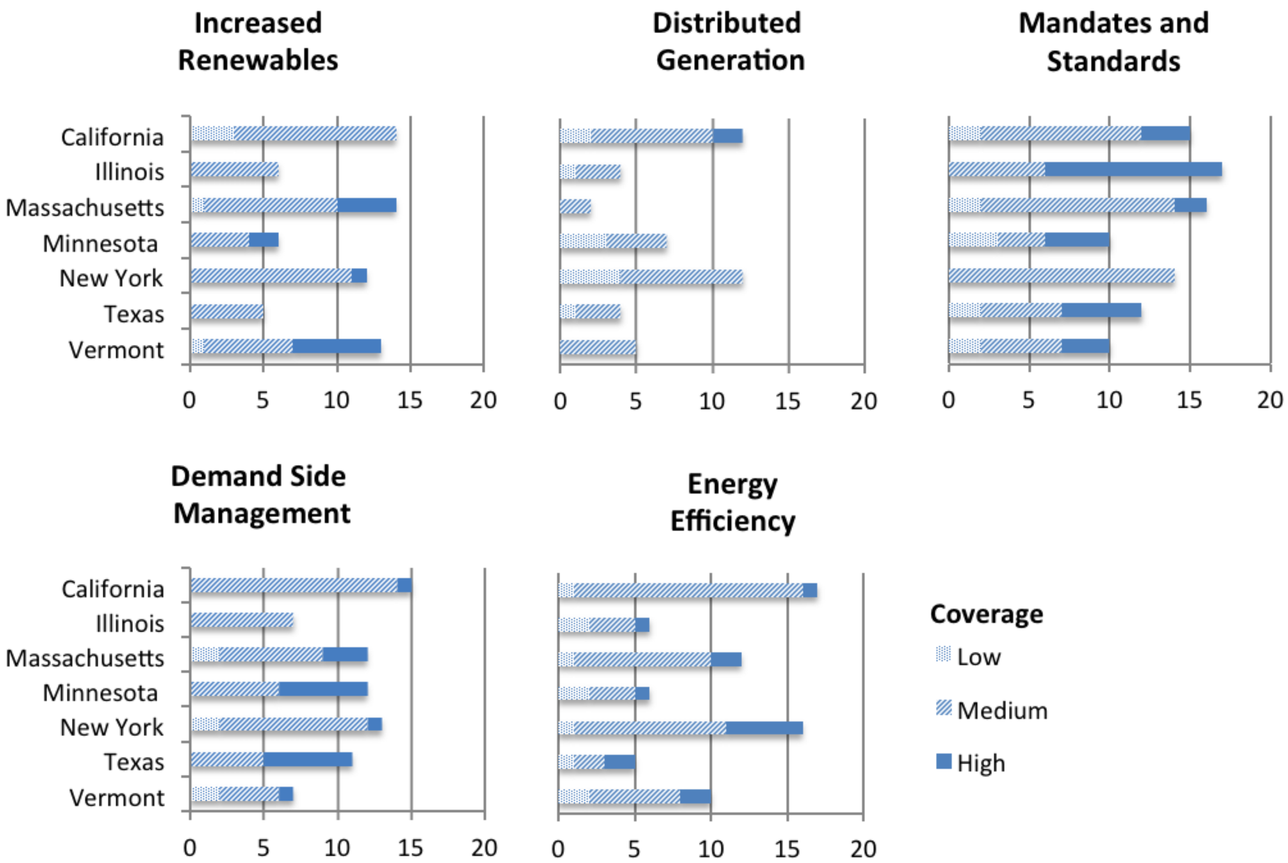
We accounted for variation in type and length of text in the documents analyzed by calculating the percent of the total text that was focused on smart grid concepts. We then clustered the documents in three types: low coverage documents were those that had less than 10% of the text focused on the concept, medium coverage documents were those that had 10–50% of text focused on the concept, and high coverage articles were those with over 50% of the text focused on the concept. For example, in the "Motivations" coding, a document where 60% of the text focused on integrating rooftop solar installations would be coded as "high coverage" for Distributed Generation.

4. Results

4.1. Motivations for Developing a Smart Grid and Renewables

Our analysis revealed that policy documents articulate a broad set of motivations for developing smart grid in all seven states. While advancing renewable energy is a motivation mentioned in all states, TX, IL and MN mention this in conjunction with smart grid less frequently than the other states (Figure 2). The potential for smart grid to enable distributed generation is more prominently featured in the documents from CA, MN and NY than in the other states where it was mentioned less frequently (mentioned in only five or fewer of the 20 documents).

Figure 2. (**a**) Motivations for developing smart grid technologies across states. (**b**) The numbers on the x-axis are the number of documents coded within each smart grid motivation theme, from no mention, low (0.1–10.9% coverage), medium (11–49.9%) and high (above 50%) coverage.



In several instances, smart grid was presented as a tool to accomplish other societal goals and likened to other enabling infrastructure systems, as exemplified in this quote from Vermont (Document codes are the state with document number, all documents listed in Appendix 2):

"*First and foremost, the smart grid is a means to an end. It is a tool that, like all tools, has no inherent value beyond its ability to help us do things that we think are useful. ... In a way, the smart grid is similar to the Internet. The Internet has no value by itself; its value is in all the things it enables us to do that make our lives better and more productive—or, sometimes, less productive.*" VT-05.

While integrating renewable resources was often mentioned as one of the motivations for developing smart grid, it was not the only goal. The potential for smart grid to offer efficiency and demand side management is prominently mentioned in documents from all states.

The motivation for developing smart grid that was mentioned most consistently across all states was linked to adopting mandates and meeting standards. These motivations included the potential to fulfill policies or mandates to modernize the existing electrical grid. Evolving standards, ensuring interoperability of smart grid equipment as well as coordination across different governmental actors were also important. For example, in Illinois state discourse centered on aspects of the Energy Infrastructure Modernization Act [38], and specifically on enacting Public Utility Commission (PUC) policies and developing cost-recovery mechanisms for smart grid. For example, several Illinois documents focused specifically on the Public Utilities Regulatory Policies Act (PURPA) as well as on the development of interoperability standards through cooperation with organizations such as National Institute of Standards and Technology (NIST).

The potential of smart grid to contribute to meeting the state's RPS was also mentioned regularly as a motivation. For example, in New York, one document highlights smart grid drivers in relation to renewables:

"*Lower costs in achieving state energy plan goals for renewable energy portfolio—the 15% by 2015 goal. ...and... The Smart Grid's ability to reduce/eliminate transmission congestion and to use storage to match renewable energy delivery to demand, are critical to realizing these benefits.*" NY-19

This quote demonstrates how smart grid can help California achieve its state renewable goals:

"*Moving to a Smart Grid will help deploy clean, renewable energy sources like wind and solar around the state.*" CA-10

In all states, policy documents mentioned the potential of smart grid to enable demand side management as a motivation. Documents from CA, MA and NY attributed energy efficiency as a motivation to develop smart grid, but this motivation was not as prevalent in the other states. Policy documents discussed demand side management and energy efficiency to engage consumers and change electricity use. Many documents suggested that consumers could save money on electricity bills if they were given more information. Additional information on dynamic electricity prices would allow consumers to better align their energy consumption with the cost of generation. Demand side management is also sometimes linked to renewable energy where shifting electricity use could help to accommodate variable generation from renewable resources, as highlighted in this quote from Massachusetts:

"*The Vineyard Energy Project involves the deployment of customer systems to enable real-time load measurement and management while helping customers optimize their electricity usage. The main* *objective is to assess the effectiveness and customer acceptance of the technologies and determine the extent to which they can help accommodate greater penetration of wind energy.*" MA-01

Motivations like distributed generation and increasing large-scale renewable generation were not, however, mentioned with the same frequency in all states. For example, more than twice as many policy documents from CA, MA, NY and VT mentioned increasing renewables as a motivation for smart grid compared to documents from IL or TX. While TX and IL generate a smaller overall percentage of their total electricity from renewable resources, both have large amounts of installed wind (12 and 3.6 GW respectively) and Texas also has over 86 MW of grid-connected solar photovoltaic (PV) [27,28]. This suggests distinct differences in how smart grid and renewable policy discussions are occurring in these states.

4.2. Framing of Smart Grid

In addition to motivations, we also examined how these state policy documents frame smart grid development, *i.e.*, the extent to which smart grid was discussed within six different socio-technical frames: technology, politics, economics, the environment, health and safety, and culture (Figure 3). Economic framing was most frequently used to discuss smart grid in these documents, followed by political framing, and then technical framing. Cultural, environmental, and health and safety framing were less frequently used to describe smart grid advancement.

Economic and political framing for smart grid development were often coupled, reflecting the role of the public sector in financing smart grid development. The importance of federal ARRA support for states is demonstrated in this example from California:

"*As to Smart Grid, the nation just got Willie Wonka's golden ticket to help fund it, with the $4.5 billion available for Smart Grid initiatives in the American Recovery and Reinvestment Act, delivered compliments of your clean green energy President, Barack Obama.*" CA-04

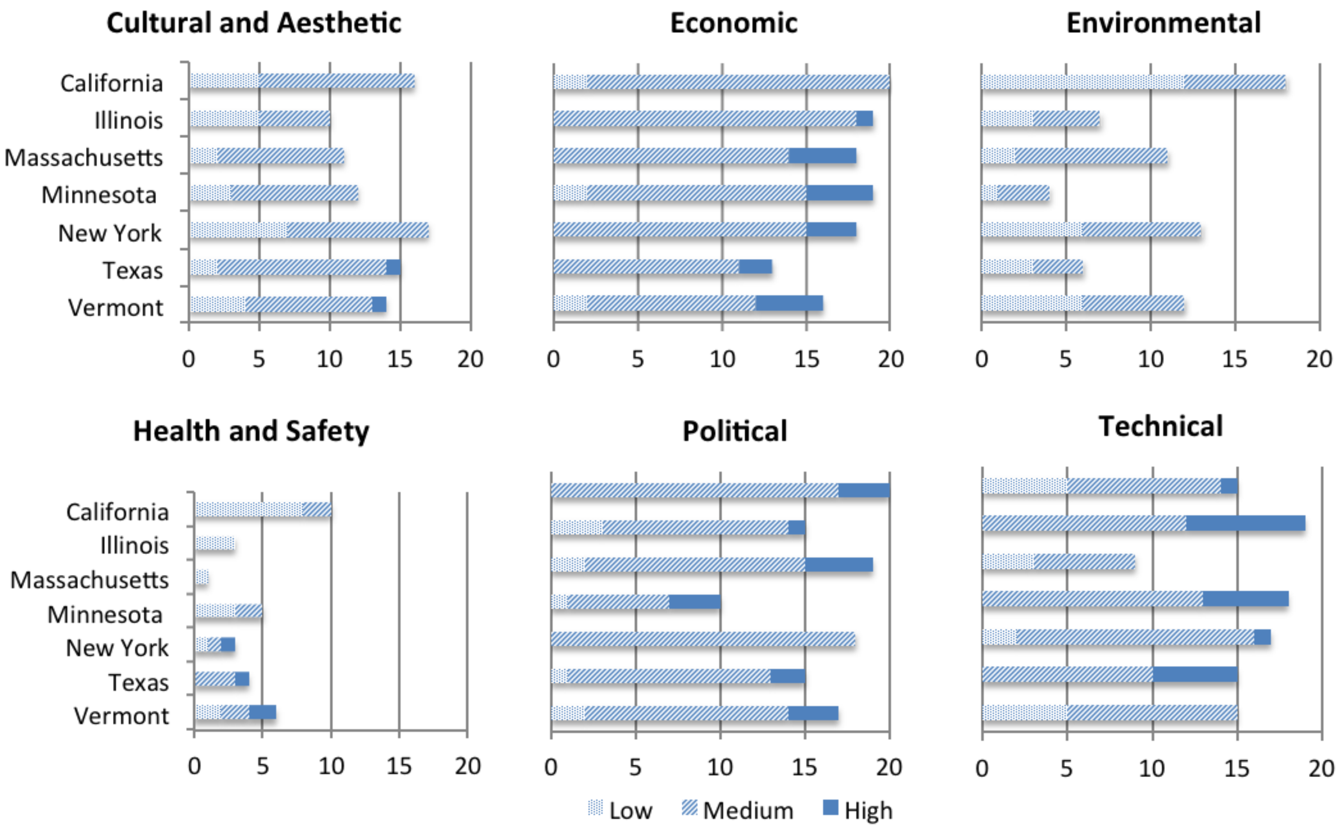
In addition to federal support, integrated economic and political framing was also mentioned in reference to state-level support for smart grid:

"*The foundation laid with initial stimulus funding is taking root in several states across the nation. For example, Illinois is on the way to becoming a leader in smart grid technology with the passing of Illinois Smart Grid Legislation authorizing a $3.2 billion statewide smart grid build-out.*" MA-19

Many of the documents also used economic and political framing when focused on the challenges of paying for a smart grid, linking the needs for political support and cost allocation to fund smart grid development.

"*The Texas Legislature recognized the benefits that can accrue from smarts meters, expressly supporting the deployment of smart meters in Texas, and directed the PUCT to develop a non-bypassable surcharge to recover costs associated with the deployment of smart meters.*" TX-18

Figure 3. (**a**) Framing of smart grid development in policy documents from the seven states. (**b**) The numbers on the x-axis are the number of documents coded within each smart grid motivation theme, from no mention, low (0.1–10.9% coverage), medium (11–49.9%) and high (above 50%) coverage.



4.3. Smart Grid Framing and Renewables

For the smart grid discourse that focused on linkages with renewable energy, the most prominent frames were economic and technical, reflecting financial and operational integration challenges. Some of this discourse also focused on the high-voltage transmission grid, highlighting the importance of multiple stakeholders.

"*For wholesale renewables, grid planning could be more proactive in identifying the locations where the generation of energy has higher value to stakeholders. ... Instead of reacting to the locational decisions of wholesale renewables developers, policy makers could ensure that the market is encouraged to go to the places where the generation has the most value.*" CA-15

Different types of renewable energy, including solar distributed generation (DG) or large-scale wind, are represented as having multiple economic benefits for market, grid, and job creation value. This is demonstrated in a Minnesota quote describing the value of distributed solar PV:

"*Why Solar DG? .... individual PV systems can lower electricity bills for all consumers…....*

prevent ….air pollution…….reduce harmful particulate emissions from fossil-fuel generation, …… [PV] creates more jobs per MW than any other energy source ……. it can make the electricity grid more reliable and secure." MN-07

The passage also highlights the integration of multiple frames—technical, economic, health and safety, and environmental—to describe the benefits of renewable solar distributed generation.

Renewables are embedded in the smart grid discourse in some states, and distinct differences are apparent among the seven states. The overall discourse focuses on goals, siting, integration, and the role of renewables in the future energy system. The quote below highlights the complex interplay between economic, political, and cultural (including aesthetic) frames for wind energy development in Vermont:

"*Vermont's scenic landscape is recognized around the world and is highly valued by its citizens. At the same time wind energy is becoming an increasingly valuable natural resource for Vermont. Wind Turbines that get a Certificate of Public Good from the Public Service Board can be "net-metered" when linked to the statewide power grid.*" VT-20

In California, the technical and economic frames are used to highlight the value of a smarter grid with renewables providing electric system benefits.

"*If the state's wind turbines are spinning at full speed, a customer on dynamic pricing could see low prices, letting them know that it's a good time to run their equipment.*" CA-04.

While most smart grid documents hosted on state websites present renewables and smart grid in a very positive light and highlight the future benefits and technological potentials, developing smart grid and renewable energy remain a controversial proposition for some citizens. State websites host public comments on various smart grid policy initiatives and the potential role of renewables in the energy mix. Writes an Illinois ratepayer about ComEd's policies:

"*I am opposed to the massive subsidization of wind energy through hidden fees on my electric bill to pay for transmission lines to support this economically unfeasible, unreliable, NON-BASELOAD form of energy. The Transmission Delivery Fees on my power bill amount to a hidden tax. ... Stop the madness.*" IL-14

5. Discussion and Conclusions

Within the U.S., state-level documents regarding smart grid provide an important lens to understand how the discussion of renewable sources for electricity is being framed. While economic and technical frames dominate this discussion, the political frame also plays an important role. In many of the states (CA, NY, and MA), renewable energy technologies (both large-scale and small distributed generation) are presented as an integral part of the smart grid policy discussion, while in others (TX and IL) they remain largely absent. Smart grid has strong potential to encourage renewable energy deployment; but given the multiple motivations for smart grid advancement, renewables are not always central to smart grid policy discussions. Additionally, smart grid discourse is often focused on the electric sector and ignores larger energy issues [39].

Links between smart grid and renewable energy reveal complex and varied contexts across state policy documents. In all states, developing a smart grid is often framed as a means to achieve other policy and electricity system goals. Smart grid is most often viewed as a set of technologies which could aid in improving electric system reliability, enhancing resilience in the face of disruptions, and promoting efficiency and demand side management. Our analysis suggests that if renewables are to play an important role in smart grid development, linking them to the economic, technical and political frames dominant within state discourse will be important. The frequency and contextual framing of these linkages varies by state.

The economic, technical, and political frames dominate smart grid discourse, with the most common intersection being economic and political framing. This framing highlights the magnitude of investment required to promote both smart grid and renewables. Building a smart grid is going to be expensive, and public financing plays a major role in smart grid development. The jurisdictional complexities associated with cost allocation results in a politically charged set of challenges.

In CA, NY, and MA, the environmental frame also played an important role, while it is less prevalent in other states. For states like CA, NY, and MA, smart grid is often presented as a key technology for meeting renewable policy goals and helping to integrate variable resources into the electric system and maximize their value. In these states, smart grid and the renewable energy policy objectives are presented as complimentary and synergistic. Here, smart grid and renewables are often presented within an environmental frame linking climate change to policy action. In these states, smart grid policies including demand-side management and adopting RPS or technology integration standards are often presented as motivations, which would also help support renewable energy development. This is different from states like TX or IL, where the renewable energy connection is largely absent from the smart grid policy documents and climate discourse in state-energy policy is more limited. MN and VT were more mixed, with more mentions in MN of distributed generation and of renewables in VT, but less of a link to the environmental frame than CA, NY and MA.

Interestingly, the discursive connections between smart grid and renewables do not appear to be directly related to the renewables deployed in state. TX and IL, the two states with the least mention of renewables in their smart grid policy discourse, have extensive renewables profiles, and in TX's case, large investments in smart grid technologies. TX hosts the largest amount of wind capacity in the nation (12 GW of installed wind) and is ranked 8th for grid-connected PV. TX has already met its renewable targets under its renewable goal and the environmental frame remains a weak frame to support policy innovation [21,22]. Renewable generation represents 2% of Illinois's electricity generation, but with a large amount of installed wind at 3.6 GW. Despite the large amount of installed wind and ongoing investment in renewables, smart grid policy discourse does not highlight renewables as frequently as other states. This suggests that discussions of renewable energy development and integration are occurring outside of smart grid policy forums in TX and IL. In contrast, in the states of MA, CA, and NY advancing renewables and smart grid are intricately linked in the state policy discourse.

This analysis highlights the divergent smart grid and renewables discourse across the seven states. In some states, renewable energy development is a valid and often-stated motivation for smart grid development and is often linked to other environmental or climate goals. In other states—surprisingly in those with high levels of installed wind—this motivation for smart grid development is notably absent. One explanation for this is that renewables development is more mature in TX, IL and MN, so smart grid may not be perceived as a critical prerequisite. Another explanation is that smart grid discourse in those states has avoided the environmental frame because of potential political benefits of using other frames. Additional research to better understand stakeholder perspectives would help to flesh out the smart grid and renewable energy discourse.

The state-level differences in framing smart grid and renewables development present challenges for both federal and state-level policy makers, and for those attempting to transfer policies from one state to another. In some states, federal and state policies supporting smart grid development may also support goals to develop and integrate renewables technologies. A policy that synergistically supports both smart grid and renewables in one state, however, may be largely irrelevant for renewable energy in another state. While smart grid development is a perquisite for high levels of renewable penetration, other motivations dominate smart grid discourse in many states. The fates of renewable energy and smart grid are linked and the synergies are playing out differently in each state. While this paper focused on the United States, many of the lessons are generalizable in different countries and across different contexts.

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Conflicts of Interest

The authors declare no conflict of interest.

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