Decision-making for High Renewable Electricity Futures in the United States

M. Bazilian, T. Mai, S. Baldwin, D. Arent, M. Miller, J. Logan

National Renewable Energy Laboratory, CO, USA
U.S. Department of Energy, Washington, DC, USA
Columbia University, NY, USA

ABSTRACT

Our research suggests that in 2050, 80% of total U.S. electricity demand could be supplied by renewable electricity technologies that are commercially available today at a cost similar to or lower than published estimates for other clean energy scenarios. In order to achieve this goal, the U.S. power system will need to evolve toward increased efficiency and system flexibility—in part enabled by grid expansion and new operating procedures. Adjustments in business models, market rules, and regulatory regimes may also be needed to handle these high levels of renewables with their different financial and operating characteristics. This short Report Review highlights aspects of policy, regulation, finance, markets and operations that can help enable high penetration renewable electricity generation futures. It uses analytical results from the NREL Renewable Electricity Futures (REF) Study [1] as a basis for discussion. As technical issues have been shown not to be key impediments for this pathway at the hourly level for the bulk system, we focus on other aspects of public and private decision-making. We conclude by describing how the REF might inform future research and development by the scientific community.

1. Introduction

As deployment of renewable sources of electricity (RE) gain traction, technical, economic, social, and environmental questions arise as to their role and integration in power systems and the wider energy sector. Multiple international studies have explored the possibility of achieving high levels of RE penetration, primarily from the perspective of greenhouse gas (GHG) mitigation. The NREL Renewable Electricity Futures Study (REF) [1] presents a systematic analysis of a broad range of potential renewable electricity futures for the contiguous United States based on the most detailed consideration to date of geographic, temporal, and electric system operational aspects. It finds that renewable energy resources, accessed with today’s commercially available renewable generation technologies, could supply 80% of total U.S. electricity generation in 2050 while balancing supply and demand at the hourly level. Fig. 1 presents the resultant estimated generation capacity in 2050 by technology, for a suite of exploratory scenarios with renewable penetration levels ranging from 20% (Baseline) to 90%.

Fig. 2 shows nationwide dispatch by generator type during the annual peak coincident load in 2050. The operational simulations did not project any hours of unserved load during the peak load hour, lowest coincident load hour, or any other hour of the year [1].

2. Beyond technology: how to get there?

Multiple technology pathways exist to achieve a high renewable electricity future. Several countries now have penetration levels of variable generation (wind and solar) in excess of 15% of their overall power generation mix; and many jurisdictions (e.g., Spain, Portugal, Ireland, Germany, Denmark, and the U.S. state of Colorado) have experienced instantaneous penetration levels of over 50% variable generation. With...
these higher penetration levels of variable RE, jurisdictions have begun modifying practices that evolved in an era of large, dispatchable, central-station conventional power plants. These jurisdictions demonstrate that: (i) higher penetration levels of variable RE have implications for grid operations, wholesale and retail power markets, and infrastructure needs, and (ii) constraints that limit transmission infrastructure, grid flexibility, or the use of particular types of resources can be compensated for through the use of other technologies, policies, markets and operational approaches. International experience suggests that a new generation of power sector policies are critical to ensure an effective, efficient high generation of power sector policies are national experience suggests that a new markets and operational approaches. Inter-

variable RE have implications for grid oper-

Fig. 1. Scenarios of installed capacity in 2050 [1]. 

3.1. Policy and regulation

Policy and regulatory implications of such a transformation of the power sector are significant, and will be important in procuring new RE generation, extending and improving electricity grids, and promoting greater energy efficiency and responsive demand, among others.

Policies to secure new RE generation should be responsive to changing market conditions and market pricing in order to encourage continued growth in RE capacity at reasonable cost. A key research question includes how to most efficiently incentivize sustained additions of the most appropriate and cost effective capacity for the particular service requirements. Options used or considered range from existing policies such as production and investment tax credits to alternatives such as real estate investment trusts (REITs), feed-in tariffs (FiTs), master limited partnerships (MLPs), securitization [7], renewable portfolio standards (RPSs), carbon policies including Clean Energy Standards [8], cap and trade, economy-wide carbon intensity targets, and/or carbon taxes [9].

Grid extension will likely be a key enabler in a high RE future in the U.S. Streamlining siting and permitting [10] both for generation as well as transmission and distribution (T&D) would address some key market barriers [5].

Finally, policies and emerging technologies to promote more efficient and responsive demand will accelerate the energy transformation, both by reducing the scale of the requisite capacity additions, but also by reducing the scale of reserve generation capacity needed to balance variable RE. Regu-

2.2. Markets and operations

Both electricity market design and power system operations will impact the power system transformation in power plant economics, power system flexibility, and generation adequacy, among others. Market and operational issues are broad, ranging from physics and fundamental power engineering, to portfolio approaches to hedge risk, to new ways of improving resource mapping and forecasting.

As an example, rules governing curtail-
ment, energy imbalances, gate closures, ramping and scheduling could have a sub-
stantial impact on both RE and conventional generation project economics and revenue streams [11]. As penetrations of RE grow, regulators will need to examine these rules carefully to balance the competing concerns of consumers, industry, and other stake-
holders, while ensuring a viable value proposition for key power system businesses.

Improving system flexibility through technology choice (e.g., fast ramp combined cycle gas plants), operations, and market function will also be a critical factor for integrating high penetrations of variable RE technologies [11]. Market design elements such as fast gate closure, widespread loca-
tional pricing, and demand-side bidding, are already in place in most energy markets in the US, and provide the foundation to incentivize flexible capability, but may be insufficient to ensure financial return for all actors.

Finally, RE futures are likely to adversely impact the project economics of many conventional thermal generators, which raises questions about appropriate mechanisms to ensure capacity adequacy under high-RE fu-
tures. Fortunately, various ISOs in the US [12]
and abroad (including Alberta, Australia, the European Commission, and the UK [13]) are experimenting with solutions to the capacity adequacy question. Candidate solutions range from strategic reserve requirements to capacity payments to more market-based approaches such as capacity markets [14]. Across the spectrum of regulatory paradigms, significant changes are already underway. Some vertically-integrated systems are considering greater moves toward market-based mechanisms to support greater RE growth (i.e., Japan), while some highly deregulated systems are considering modifications to liberalized market structures to better coordinate planning for low-carbon systems (i.e., the UK). Thus, it would be inaccurate to presume that the pathway to achieving low-carbon power systems is determined by regulatory frameworks. Rather, they are dynamically evolving together [15]. Fundamentally, utility business models will similarly need to evolve.

2.3. Research and development

The REF [1] notes, “...advancements in renewable technologies, reflected by cost and performance improvement assumptions, had the greatest impact on reducing the incremental cost of high renewable generation scenarios.” Advancing our understanding and capabilities for system level integration, forecasting and operations, as well as “traditional” research and development (R&D) focus areas of improving technologies, will be important elements of realizing a high RE future. R&D in other emerging areas of energy include tight coupling with IT systems, cyber security, and links to other sectors such as transport, fuels and chemical sectors, and improved life-cycle emissions analysis [16]. R&D is also required on better models for system planning and improved operations. Likewise links to fundamental R&D such as atmospheric science will be required to help improve forecasting and resource modeling. Other possible areas for R&D include:

- Detailed technical analyses of power system reliability and resiliency.
- Comprehensive cost-benefit analyses to better understand the economic and environmental implications of high renewable electricity futures relative to the water sector [17].
- Improved understanding of the institutional and societal challenges associated with the integration of levels of renewable electricity [18].
- Deeper understanding of supply and demand-side flexibility, including thermal generators and flexible and controllable loads, in conjunction with sophisticated understanding of customer expectations and adaptability.

3. Conclusions

The Renewable Electricity Futures Study [1] demonstrates the resource adequacy of a largely renewable energy-based power system to meet 80% of all loads at the hourly level in the contiguous United States in the coming three to four decades. Creating an enabling environment that is effective, efficient, and adaptive, to achieve such a sustainable energy future for the United States will likely require collaboration between policymakers and scientists.

Much of the required innovation spans numerous domains. Such cross-cutting innovation is not always aligned with current institutional structures. New ways of looking at multi-disciplinary research under headings such as energy systems integration may be one useful way to meet the needs of this changing landscape — both in terms of conducting research and training new researchers.

One item we did not highlight is the need for a national discourse on the interactions between the new abundance of natural gas — primarily from shale — and RE systems. How these two areas are considered will have major impacts for both in the power sector [19]. Ultimately, systems approaches will be the key to providing the best information for decision-making.

Acknowledgments

We are grateful to the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy for sponsoring this work. We also thank DOE’s Office of Electricity Delivery and Energy Reliability for its input and guidance on specific aspects of the analysis, as well as valuable comments and helpful suggestions to improve the content of the report. NREL’s contributions to this report were funded by the DOE Office of Energy Efficiency and Renewable Energy under contract number DE-AC36-08GO28308. The opinions represented in this article are the authors’ own and do not reflect the view of the U.S. Department of Energy or the U.S. Government. Any and all errors are the responsibility of the authors.

References

[18] E. Martinot, C. Dienst, L. Weiliang, C. Qimin, M. Bazilian, D. Arent, Natural gas scenarios in the coming three to four decades. Creating an enabling environment that is effective, efficient, and adaptive, to achieve such a sustainable energy future for the United States will likely require collaboration between policymakers and scientists.

Please cite this article in press as: M. Bazilian, et al., Decision-making for High Renewable Electricity Futures in the United States, Energy Strategy Reviews (2013), http://dx.doi.org/10.1016/j.esr.2013.11.001