Integrating Variable Renewable Energy in Electric Power Markets: Best Practices from International Experience

Research Highlights

Many countries—reflecting very different geographies, markets, and power systems—are successfully managing high levels of variable renewable energy (RE) on the grid. Australia (South Australia), Denmark, Germany, Ireland, Spain, and the United States (Colorado and Texas), for example, have effectively integrated variable RE utilizing diverse approaches.

Analysis of the results from these case studies reveals a wide range of mechanisms that can be used to accommodate high penetrations of variable RE (e.g., from new market designs to centralized planning). Nevertheless, the myriad approaches collectively suggest that governments can best enable variable RE grid integration by implementing best practices in five areas of intervention:

A. Lead Public Engagement, Particularly for New Transmission

Installing transmission that may be required to accommodate new RE can be challenging; stakeholders may express concerns over land use changes, environmental damage, decreased property values, or health concerns. A foundational component of siting new transmission is public engagement—a two-way exchange of information.

Action to Improve Public Support: lead public engagement to communicate to the public why new transmission is essential.

Examples: public stakeholder exchange in Texas and Germany; burying of high-voltage grid in Denmark.

B. Coordinate and Integrate Planning

Planning comprises an inherently complex set of activities that are undertaken by multiple groups and jurisdictions for a given power system. Variable RE can be accommodated by integrating the planning of generation, transmission, and system performance; ensuring institutions and markets are designed to enable access to physical capacity; and building from local and regional planning to better integrate and coordinate information across jurisdictions.

Actions to Improve Planning: share best practices and guidelines for adapting advanced planning capabilities; support capacity of institutions to increase integration, complexity, and coordination of—and stakeholder participation in—planning; and provide vision for how to move from analyses and recommendations to actions.

Examples: market-based guided development in Australia; centralized planning in Texas.

C. Develop Rules for Market Evolution that Enable System Flexibility

Higher penetrations of variable RE require increased flexibility from the power system. Markets that encourage flexible storage and demand response can support the integration of variable RE through load shifting, balancing, and frequency and regulation.

Actions to Support Flexibility: lead the development and innovation of market designs; encourage market operators to adopt rules to improve system efficiency; and play a leading role in negotiating a framework for integration that optimizes flexibility across regions.

Examples: market design that encourages system flexibility through expanded power markets, fast market design, combined heat and power, and negative prices in Denmark; National Electricity Market operation in Australia; encouragement of storage in Germany; demand response participation in Texas.

D. Expand Access to Diverse Resources and Geographic Footprint of Operations

Integration studies have consistently found that expanding access to diverse resources aids the

integration of high penetrations of variable RE. This can be achieved in two ways: enlarging effective balancing areas, and diversifying the location and types of RE generation. Regional market pricing, RE zones, and hybrid market solutions that allow reserve sharing are some of the approaches to encourage diversity.

Actions to Expand Diversity: support the study and evaluation of options to diversify resources and enlarge balancing areas, and convene stakeholder discussions to overcome institutional challenges in merging or increasing cooperation among balancing areas.

Examples: expanding regional integration in Ireland; proposed Energy Imbalance Market in the Western U.S.

E. Improve System Operations

Integrating advanced forecasting techniques into fast market operations, the control room, and other standard operating practices can help predict the amount of RE available to the system. Grid codes—rules that govern how power plants connect to and support the grid—help ensure that variable RE is compatible with, and can help contribute to the stability of, the power grid. A necessary first step is to evaluate existing rules to determine whether new approaches to planning, design, and operation are needed for high penetrations of variable RE.

Actions to Improve System Operations: support development of national or regional forecasting systems and work with regulatory commissions to evaluate model grid codes, recommend changes, and implement recommendations.

Examples: market use of advanced forecasting in Australia; system operator use of multiple and advanced forecasting in Denmark; creation of the innovative Control Centre for Renewable Energies in Spain.

Figure 1 illustrates, within each of these areas, when actions typically need to be implemented as a country transitions from low to high RE penetration.

	Public Outreach	Planning	Market Rules	Expanded Access	System Operations
At LOW RE Penetrations	Involve public stakeholders in planning	Evaluate system flexibility, penetration scenarios, transmission needs, and future flexibility needs	Evaluate market design and implications for higher penetrations of RE	Assess renewable energy resources and options for encouraging geographic diversity	Build capacity of grid operator staff; review regulatory changes needed to require advanced forecasting
At MEDIUM RE Penetrations	Communicate to public why new transmission is essential	Regulatory and legislative changes needed to accommodate revised scenario planning, such as laws to support renewable energy zones (REZs)	Ensure that market design and pricing environment aligns with technical needs, such as accessing flexibility, minimizing uncertainty, and managing risk	Make necessary regulatory, market, or institutional changes	Implement grid codes to accommodate high penetrations of variable RE
At HIGH RE Penetrations		Monitor and review effectiveness of actions; revise	Ensure broad systems solutions are sought, including smart grid/demand response, storage, and complementary flexible generators		

Figure 1. Key activities in transitioning from low to high RE penetration.

Any country's ability to successfully integrate variable RE depends on a wide array of factors: technical requirements, resource options, planning processes, market rules, policies and regulations, and institutional and human capacity. The more diverse and robust the experience base from which a country can draw, the more likely that it will be able to implement an appropriate, optimized, and system-wide approach. Going forward, successful RE integration will thus depend upon the ability to maintain a broad ecosystem perspective, to organize and make available the wealth of experiences, and to ensure that there is always a clear path from analysis to enactment.

For additional information, see Cochran, J.; Bird, L.; Heeter, J.; Arent, D. J. (2012). Integrating Variable Renewable Energy in Electric Power Markets: Best Practices from International Experience. NREL/TP-6A00-53732. Golden, CO: National Renewable Energy Laboratory.

The 21st Century Power Partnership is a multilateral effort of the Clean Energy Ministerial and serves as a platform for public-private collaboration to advance integrated policy, regulatory, financial, and technical solutions for the large-scale deployment of renewable energy in combination with deep energy efficiency and smart grid solutions.

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