Policies and Programs to Integrate High Penetrations of Variable Renewable Energy

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Goals of Project

- Highlight the diverse approaches for enabling high renewable energy penetration
- Synthesize lessons on effective policies and programs
- Present avenues for action to energy ministers and other stakeholders

Photo from Invenergy LLC, NREL/PIX 16037
Approach

- Case studies
  - Australia
  - Denmark
  - Germany
  - Ireland
  - Spain
  - United States: Colorado & Texas
- Comparative analysis
- Extensive stakeholder consultations
Sponsors and Expert Team

- Supported by the Clean Energy Ministerial

- Experts from diverse institutions:

Photo by Dennis Schroeder, NREL/PIX 19887
## RE has achieved varying degrees of penetration

<table>
<thead>
<tr>
<th>Country</th>
<th>% Renewable Generation (2010)</th>
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</thead>
<tbody>
<tr>
<td>Australia</td>
<td>8%</td>
</tr>
<tr>
<td>China</td>
<td>19%</td>
</tr>
<tr>
<td>Denmark</td>
<td>34%</td>
</tr>
<tr>
<td>Germany</td>
<td>18%</td>
</tr>
<tr>
<td>India</td>
<td>15%</td>
</tr>
<tr>
<td>Ireland</td>
<td>13%</td>
</tr>
<tr>
<td>Mexico</td>
<td>18%</td>
</tr>
<tr>
<td>Spain</td>
<td>34%</td>
</tr>
<tr>
<td>Thailand</td>
<td>8%</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>7%</td>
</tr>
<tr>
<td>United States</td>
<td>11%</td>
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</tbody>
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Highest penetration on annual basis

Challenges: An Overview

• Grids and markets were traditionally not designed to accommodate significant amounts of variable generation

• Variable renewable generation may be
  — located far away from load centers, and require new transmission
  — more distributed and located closer to population centers, and thus more ‘visible’ to the public
Specific Implementation Challenges

• Legal, market, and institutional barriers—Increasing power system flexibility needed to integrate variable RE (e.g., through larger balancing areas, new market rules) may require significant ecosystem-wide changes

• Coordination—Due to the involvement of multiple agencies and jurisdictions, developing and implementing a shared vision could be challenging

• Public support—The public may not understand or support actions necessary to integrate renewables

• Customizing solutions—There is no one-size-fits-all solution to integrating variable renewables; countries need to determine the most appropriate combination of approaches
Addressing The Challenge

• What approaches from the public and private sectors have most effectively enabled the integration of variable renewables?

• How should countries tailor these approaches for a given market, geographic, and institutional context?

• How can human and institutional capacity be strengthened to meet this challenge?
Actions to Accommodate High RE

A. Lead public engagement, particularly for new transmission
B. Coordinate and integrate planning
C. Develop rules for market evolution that enable system flexibility
D. Expand access to diverse resources and geographic footprint of operations
E. Improve system operations
## Actions Reflect Market Status

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<tbody>
<tr>
<td>Involve public stakeholders in planning</td>
<td>Evaluate system flexibility, penetration scenarios, transmission needs, and future flexibility needs</td>
<td>Evaluate market design and implications for higher penetrations of RE</td>
<td>Assess renewable energy resources and options for encouraging geographic diversity</td>
<td>Build capacity of grid operator staff; review regulatory changes needed to require advanced forecasting</td>
</tr>
<tr>
<td>Communicate to public why new transmission is essential</td>
<td>Regulatory and legislative changes needed to accommodate revised scenario planning, such as laws to support renewable energy zones (REZs)</td>
<td>Ensure that market design and pricing environment aligns with technical needs, such as accessing flexibility, minimizing uncertainty, and managing risk</td>
<td>Make necessary regulatory, market, or institutional changes</td>
<td>Implement grid codes to accommodate high penetrations of variable RE</td>
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<td>Monitor and review effectiveness of actions; revise</td>
<td>Ensure broad systems solutions are sought, including smart grid/demand response, storage, and complementary flexible generators</td>
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</tbody>
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Source: NREL
A. Lead Public Engagement, New Transmission

Examples

**Texas**: New transmission lines were key to integration; line construction, often resisted, was successful due to extensive and varied opportunities for public feedback.

**California**’s Renewable Energy Transmission Initiative—diverse, credible 30 person steering committee committed to achieving consensus and publicly supporting outcomes.

**Denmark**, to address public concerns about aesthetics, plans to bury its entire high voltage grid by 2030.

**What Worked**: Communicated to the public why new transmission is essential.

B. Coordinate and Integrate Planning

**Examples**

**Australia**: National-scale studies provide information, but complex spot market pricing has guided investment in both generation and transmission. Pricing includes

- Location-specific multiplier on regional price to reflect losses
- Connection costs
- Congestion-based pricing

**Texas**: Centralized planning has guided decisions. Competitive Renewable Energy Zones (CREZ) allow generation and transmission to be developed in coordination. Rate payers, not developers, absorb financial risk.

**What Worked**: Improved capacity of planners to handle added complexity

Source: Australian Energy Market Operator
C. Market Design for System Flexibility

Examples

Denmark:
- Large power pool provides greater flexibility, e.g., Norway’s hydro is critical to accommodating high wind penetrations
- Regulating Power Market operates up to 15 minutes before delivery
- Negative pricing provides economically efficient way to reduce output during excess generation
- Combined heat and power (CHP) required to participate in spot power market

Australia: Subhourly (5 min) dispatch intervals reduce need for ramping and improve forecast accuracy. Nodal and negative pricing encourage market efficient location strategies.

What Worked: Identified potential impacts of variable generation on electricity markets and generator compensation
D. Expand Diversity, Geographic Footprint

What Worked: Evaluated options to overcome institutional challenges in merging or increasing cooperation among balancing areas

Examples

Ireland—has twice sought both to reduce its vulnerability to weather variability and also to strengthen its power system through expanding regional integration

- Single Electricity Market with Northern Ireland: required for all electricity >10 MW sold and bought in Ireland; no bilateral transactions permitted
- 500 MW East-west interconnector to U.K. (under construction)

U.S. West lacks an organized wholesale electric market, but an Energy Imbalance Market has been proposed to allow balancing areas to share reserves, and—through this broader diversity—reduce the system-wide variability of RE

Source: Global Energy Network Institute
E. Improve System Operations

What Worked: Supported use of forecasting best practices; training on best practices for grid operators

Examples

Spain’s Control Centre for Renewable Energies
- Monitors RE installations real-time
- Wind farms >10 MW & PV>2MW provide reactive power support
- 97.5% of wind farms have fault-ride through capability
- New operational procedures proposed to maintain optimal voltage control

Australia: Market operators use forecasting model that integrates forecasts from a variety of sources

Denmark: System operator uses multiple, advanced forecasts in planning, congestion management, dispatch, and to assess need for regulating power
System-wide Approach More Effective

Lead public engagement, particularly for new transmission

- Planning requires continuous engagement of diverse stakeholders to facilitate public support for new transmission

Coordinate and integrate planning

- Reduced reserve requirements can be reflected in integrated plans for new transmission and generation

Improve system operations

- New transmission allows expanded access to diverse resources, through new locations and interconnections
- Expanded access to diverse resources reduces variability and improves system operations through increased forecast accuracy
- Improved forecast accuracy reduces reserve requirements for system flexibility

Develop rules for market evolution that enable system flexibility

- Source: NREL
Key Findings—Leadership Actions to Consider

1. Lead the advancement of the technical, institutional, human capital, and market institutions required to enable renewable energy integration

2. Develop visionary goals and plans at national and regional levels, and empower appropriate leadership to bring the visions to fruition

3. Lead the public engagement to communicate goals and needed actions to attain them

4. Engage in international coordination to share best practices and strengthen technical, human and institutional capabilities to achieve higher levels of renewable energy penetration
Thank you

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