

Firm Power Generation

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Editors:

Richard Perez and Jan Remund

The Technical Report is available for download from the IEA-PVPS website www.iea-pvps.org.

Executive Summary

This report builds on the foundational *Firm Power Report* published in January 2023, presenting a consolidated overview of expert insights and technical progress in firm power generation—the capability of energy systems to reliably meet electricity demand 24/7, year-round.

Key Concepts and Strategies

Firm Power from Variable Renewable Energy (VRE): Wind and solar, despite their variability, can be engineered into firm power sources through strategic system design. The most cost-effective strategies include:

- **Optimal VRE Blending:** Combining wind and solar to better align with demand profiles.
- **Physical Storage:** Utilizing batteries, pumped hydro, or other technologies to store surplus energy for later use.
- **Overbuilding with Curtailment (i.e., Implicit Storage):** Installing excess VRE capacity and selectively curtailing output to reduce reliance on physical storage.
- **System Flexibility:** Adjusting demand or supplementing VREs with dispatchable generation (e.g., gas turbines operating on 100% renewable fuels).

Additional strategies include:

- **Geographic Dispersion:** Spreading VRE resources to mitigate weather and seasonal variability—balanced against transmission infrastructure needs and local resilience.
- **Hydrogen Integration:** Using curtailed energy for hydrogen production, which can be reinjected into the grid via, e.g., fuel cells.
- **VRE-Coincident Loads:** Developing new loads that match VRE output to consume otherwise curtailed energy.

Key Takeaways

This updated report incorporates over 25 expert contributions and reinforces the 2023 findings:

- Analyses of hourly supply–demand balancing across diverse regions find that fully renewable VRE systems can economically provide year-round electricity..
- VRE Overbuilding and curtailment are essential key drivers, showing that firm power can be supplied at low cost, even without seasonal storage or large cross-continental grid expansion

Task 16 Task Managers: Jan Remund jan.remund@meteotest.ch and Manajit Sengupta manajit.sengupta@nrel.gov

- Limited dispatchable thermal generation using e-fuels can lower overall system costs.
- Market reforms are crucial to unlocking the least-cost firm power configurations.

Expert Contributions

The report categorizes contributions into two main areas:

1. **Comprehensive Solutions:** Modeling fully renewable, economically optimized power systems at national, regional, and local scales. Case studies from China, Australia, Italy, Switzerland, Canada, and the EU demonstrate the reliability and viability of firm VRE-based grids.
2. **Transition Strategies & VRE Fundamentals:** Analyzing VRE variability and exploring interim solutions that leverage current market structures—such as enhancing forecast accuracy or introducing innovative market mechanisms compatible with existing regulations.

Conclusion

Firm renewable power is not only technically achievable but also economically competitive. Realizing this vision requires advanced modeling, strategic system design, and—most importantly—market reforms to support new configurations. These findings affirm the 2023 report and offer a clear roadmap for transitioning to resilient, fully renewable energy systems.

Optimal firm power configurations — particularly the amount of VRE overbuilding — depend on local resources, strategic assumptions, and system capabilities—such as access to low-cost supply-side flexibility or sector coupling. The studies presented span a range of scenarios, from '*tabula rasa*' models with VRE-only generation and new e-fuel flexibility, to configurations integrated into regional systems with existing flexible renewable generation or mature sector coupling options.