



Technology, Policy and Finance for Clean and Renewable Energies

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NREL at a Glance

1,800

Employees,

plus more than

400

early-career researchers
and visiting scientists



World-class

facilities, renowned
technology experts

nearly
750

Partnerships

with industry,
academia, and
government



Campus

operates as a
living laboratory

\$872M
annually

**National
economic
impact**

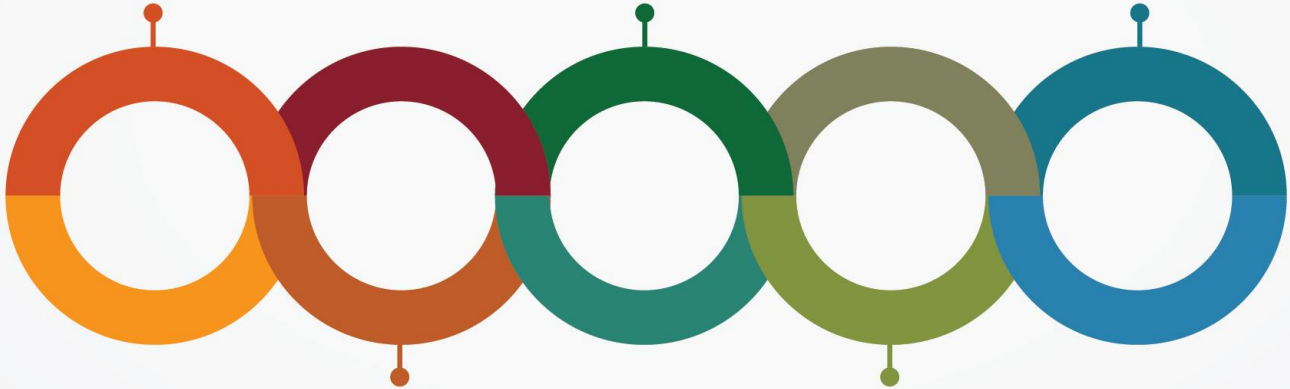
NREL advances the science and engineering of **energy efficiency**, **sustainable transportation**, and **renewable power technologies** and provides the knowledge to **integrate and optimize energy systems**..

MEGA TRENDS

Population Growth

Food & Water

Mobility



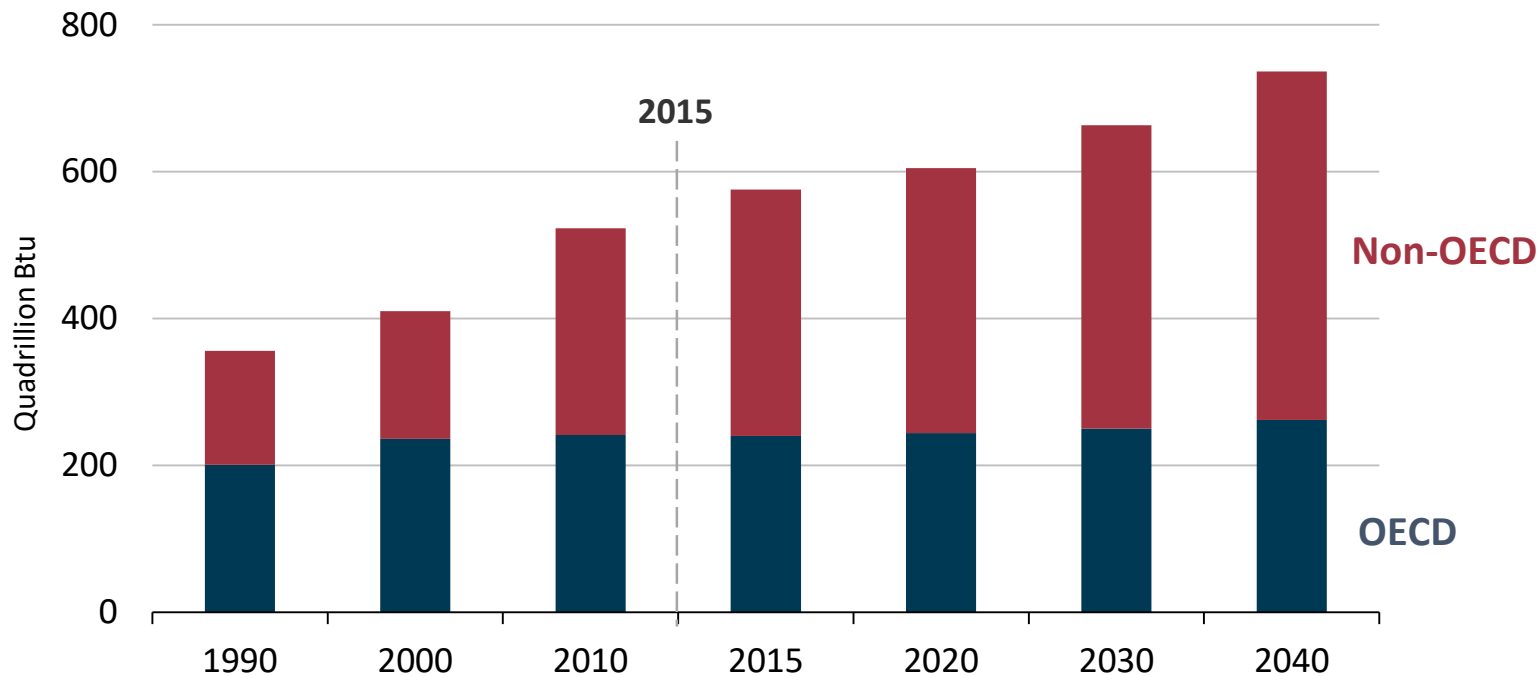
Urbanization

Electrification

Global Trends in Digitization, Decentralization, Decarbonization

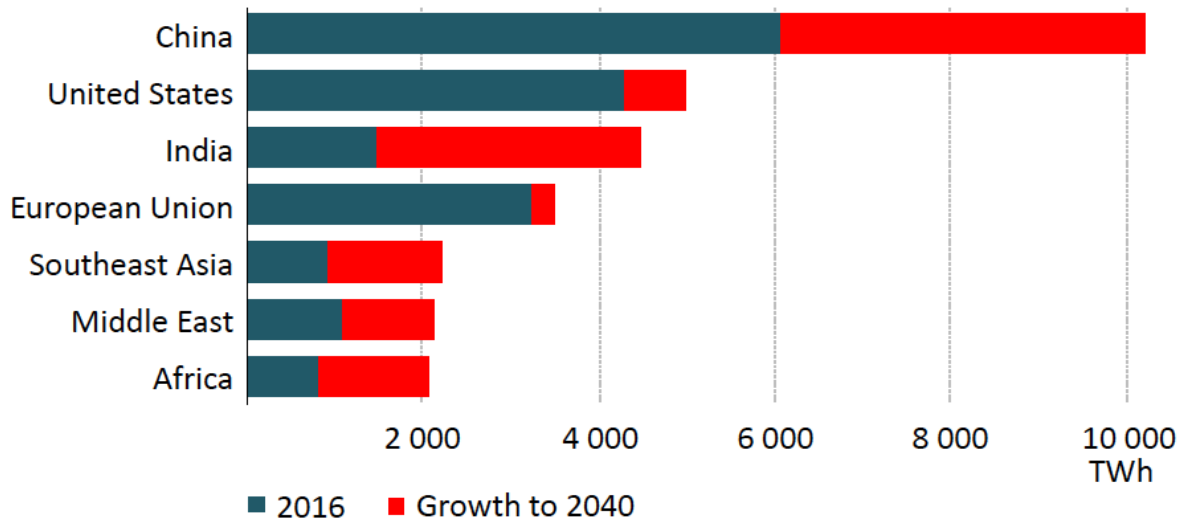
World Energy Consumption Rises 28% between 2015 and 2040

World Energy Consumption

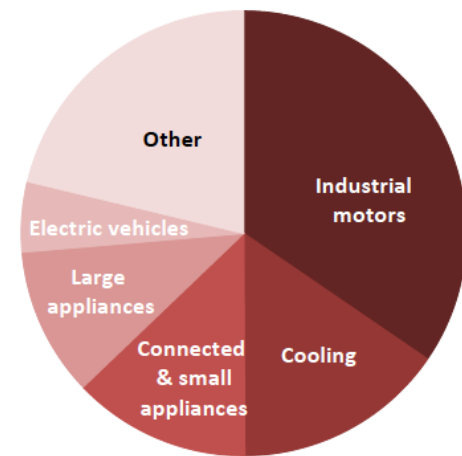


Electrification Will Dominate Energy Growth

Electricity generation by selected region



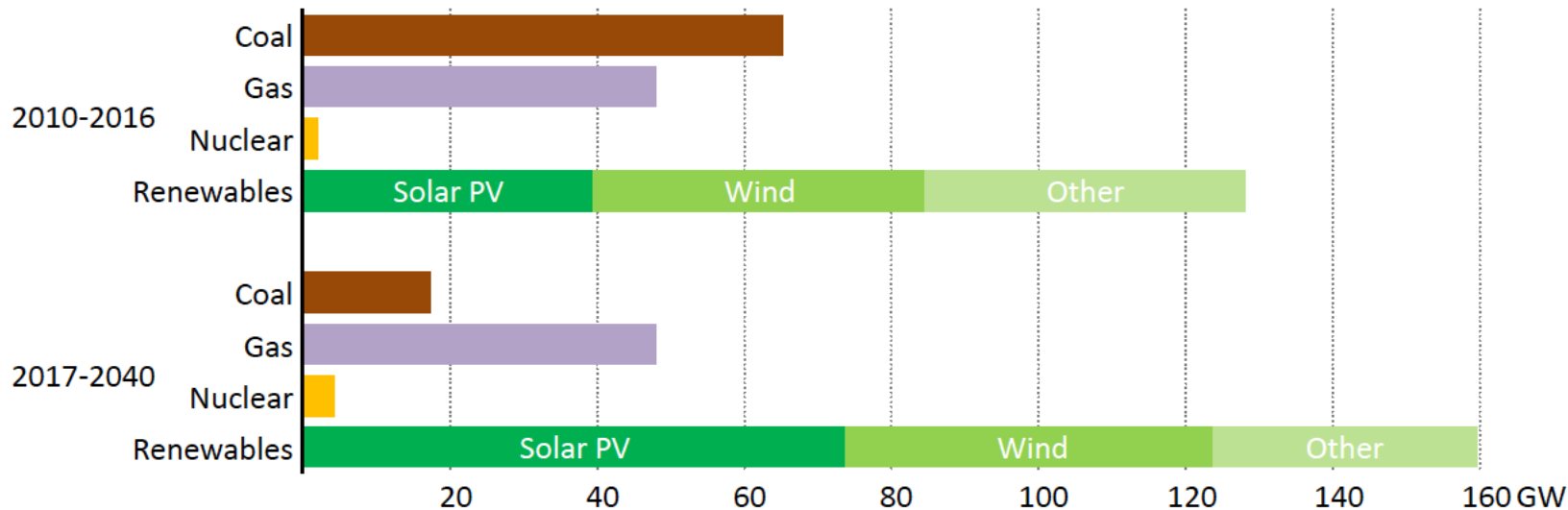
Sources of global electricity demand growth



India adds the equivalent of today's European Union to its electricity generation by 2040, while China adds the equivalent of today's United States

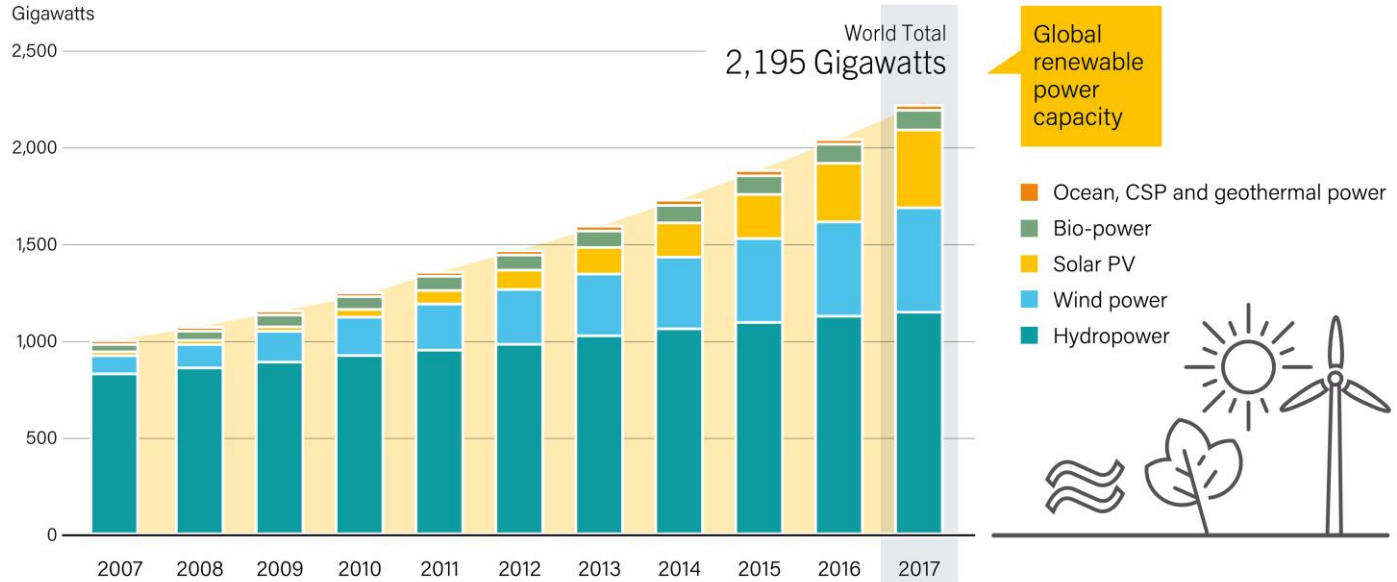
Renewables Dominate Power Capacity Growth

Global average annual net capacity additions by type



Global Renewable Power Capacity

Global Renewable Power Capacity, 2007-2017



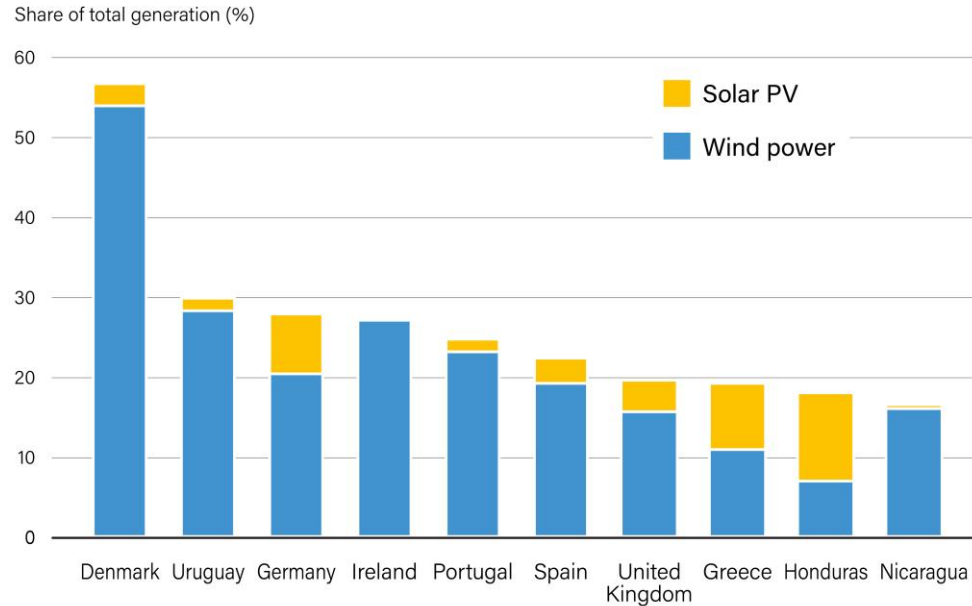
REN21 RENEWABLES 2018 GLOBAL STATUS REPORT

RENEWABLES 2018
GLOBAL STATUS REPORT

REN21 Renewable Energy
Policy Network
for the 21st Century

High Shares of Variable Renewable Power on the Grid

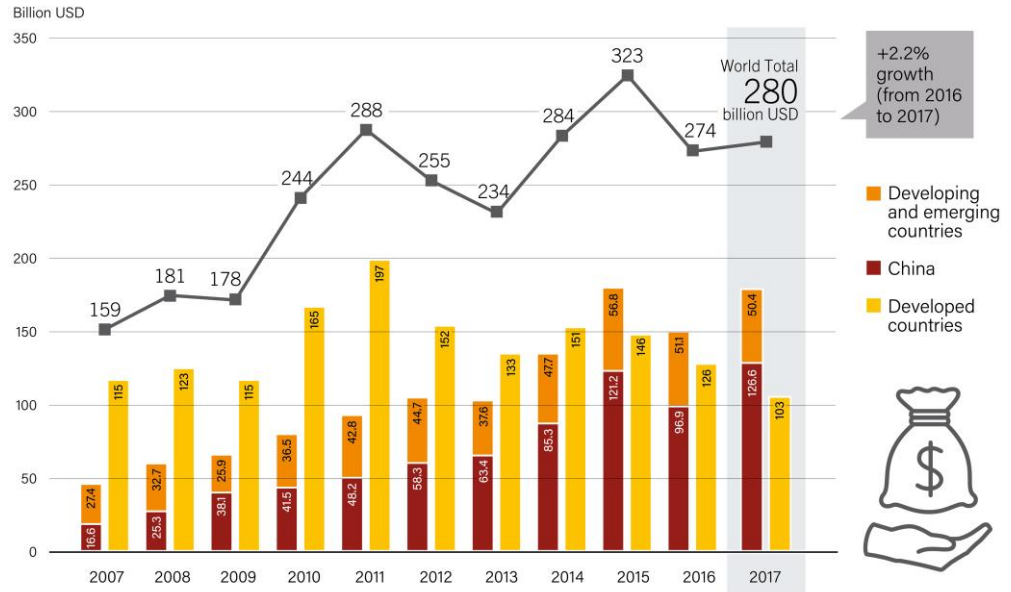
Share of Electricity Generation from Variable Renewable Energy, Top 10 Countries, 2017



Global Investment in Renewable Energy

- Global **new investment** in renewable power and fuels in 2017: **USD 279.8 billion (+2.2%)** (USD 319.8 billion incl. large hydropower)
- Investment in new renewable power capacity roughly **three times** that in new fossil fuel capacity
- **Renewable energy: 68%** of the total amount committed to new power-generating capacity in 2017
- **USD 310 billion (est.)** committed to constructing new renewable power plants, compared to:
 - Fossil fuel-fired generating capacity: USD 103 billion
 - Nuclear power capacity: USD 42 billion

Global New Investment in Renewable Power and Fuels in Developed, Emerging and Developing Countries, 2007-2017

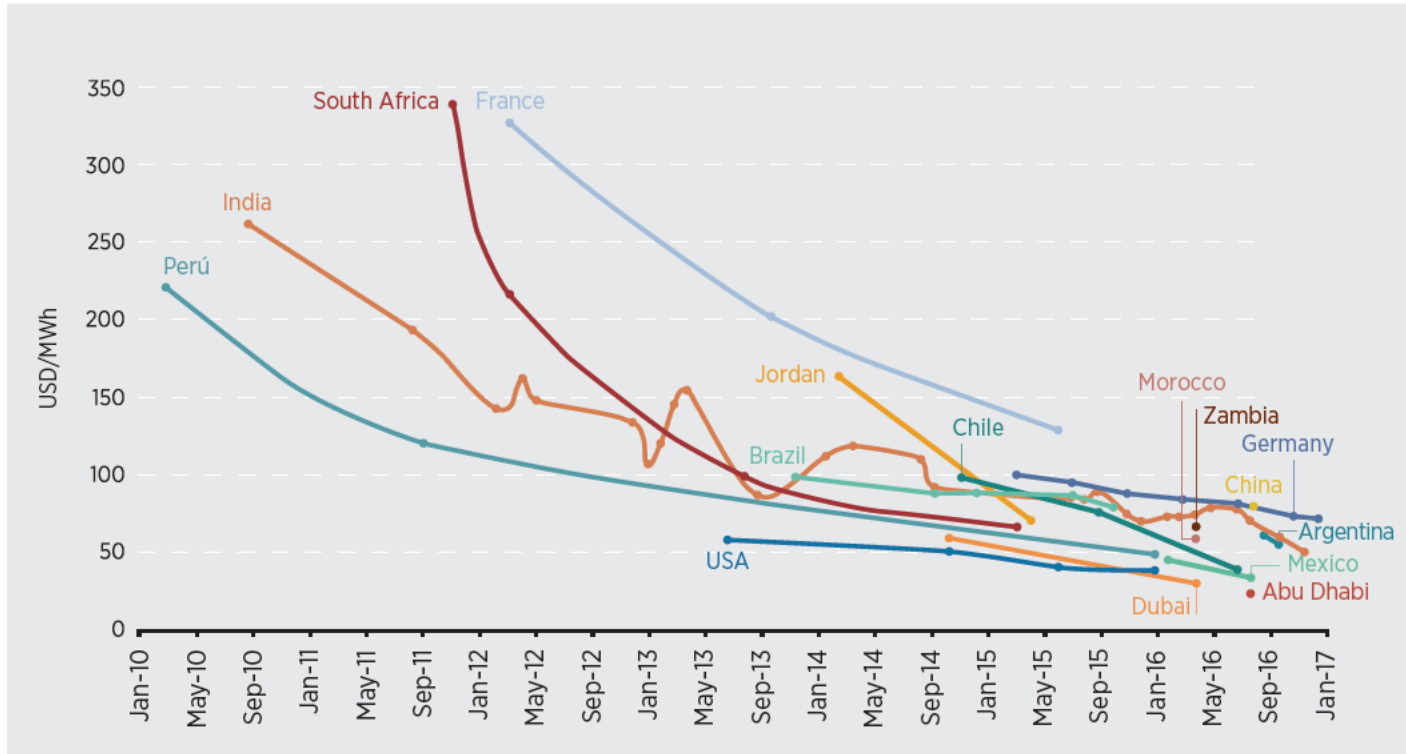


Source: BNEF

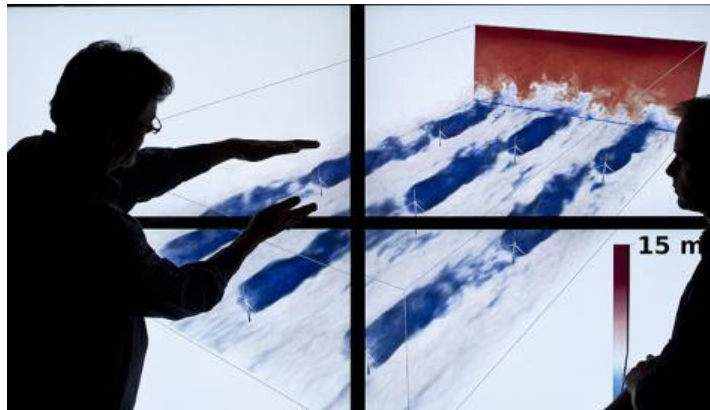
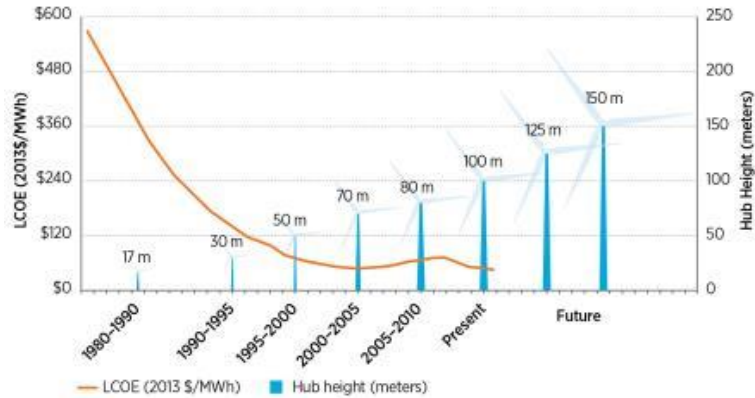
REN21 RENEWABLES 2018 GLOBAL STATUS REPORT



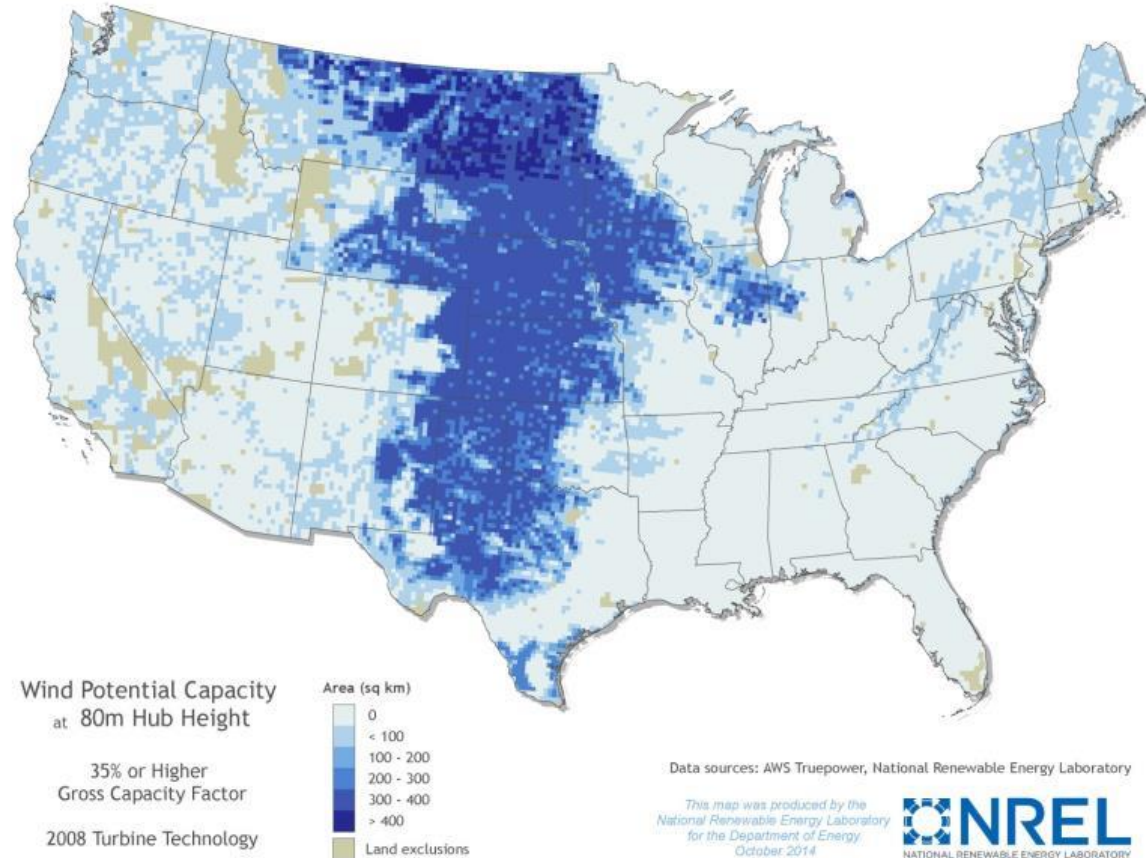
Costs and Performance of PV exemplifies decadal advancements



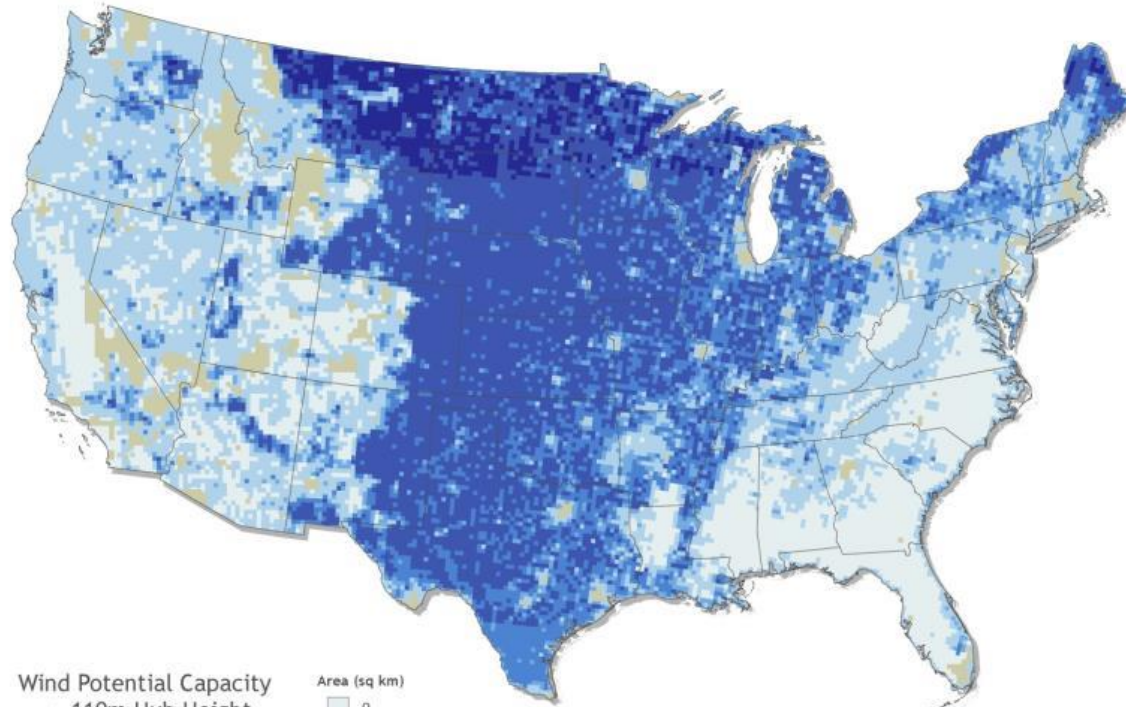
Potential of Wind: More Generation as Turbines Grow



Wind Energy Potential Capacity at 80m Hub Height 2008 Turbine Technology



Wind Energy Potential Capacity at 110m Hub Height 2014 Turbine Technology

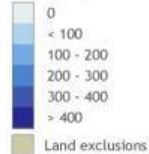


Wind Potential Capacity
at 110m Hub Height

35% or Higher
Gross Capacity Factor

2014 Turbine Technology

Area (sq km)

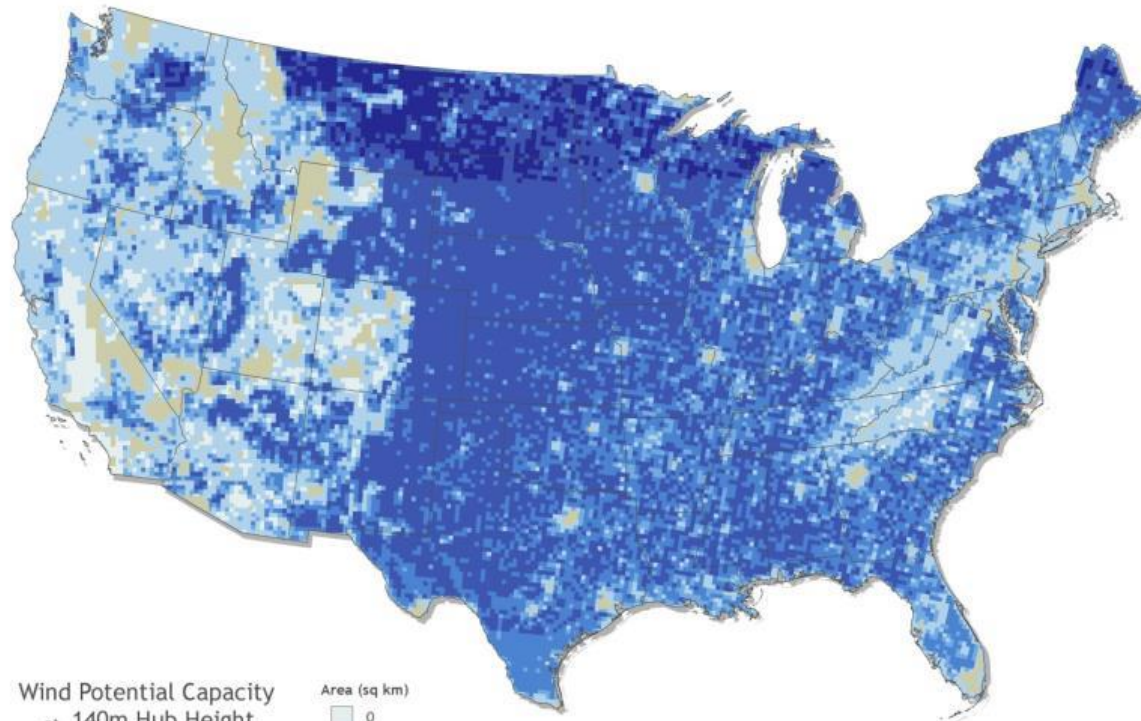


Data sources: AWS Truepower, National Renewable Energy Laboratory

This map was produced by the
National Renewable Energy Laboratory
for the Department of Energy,
October 2014



Wind Energy Potential Capacity at 140m Hub Height 'Near Future' Turbine Technology (150W/m²)

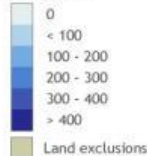


Wind Potential Capacity
at 140m Hub Height

35% GCF

Future Technology

Area (sq km)

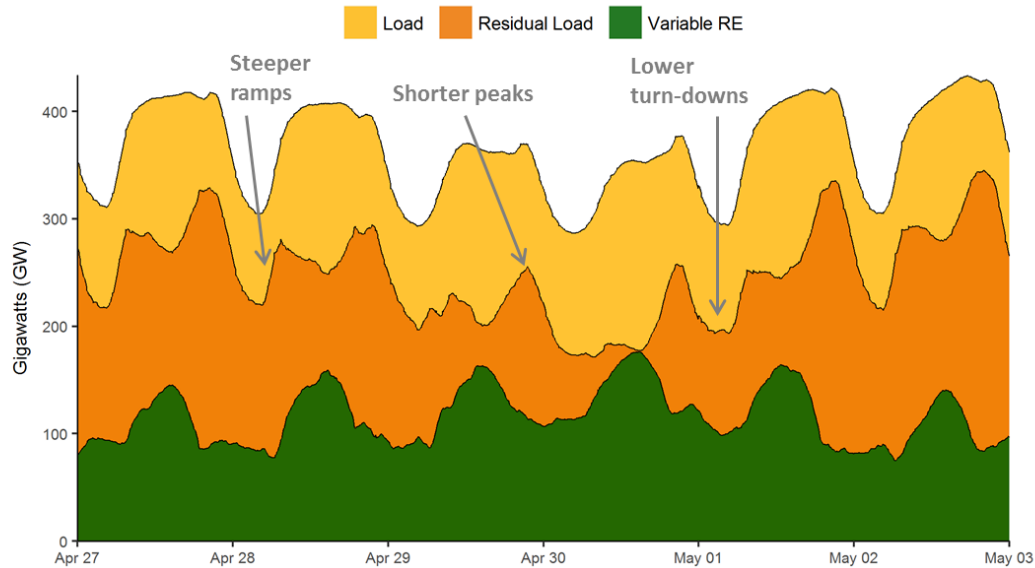


Data sources: AWS Truepower, National Renewable Energy Laboratory

*This map was produced by the
National Renewable Energy Laboratory
for the Department of Energy,
September 2014.*

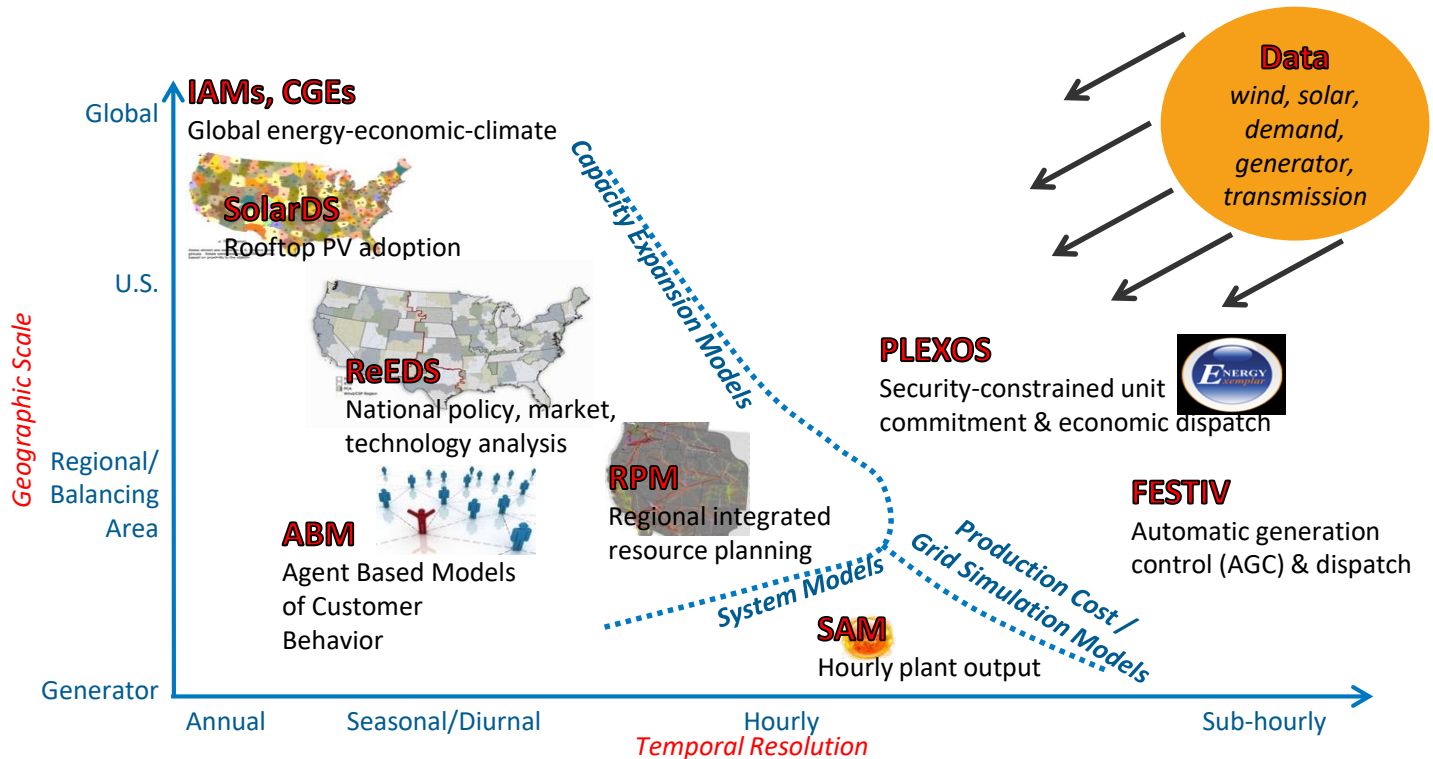


Wind and Solar Add Variability to Supply Side

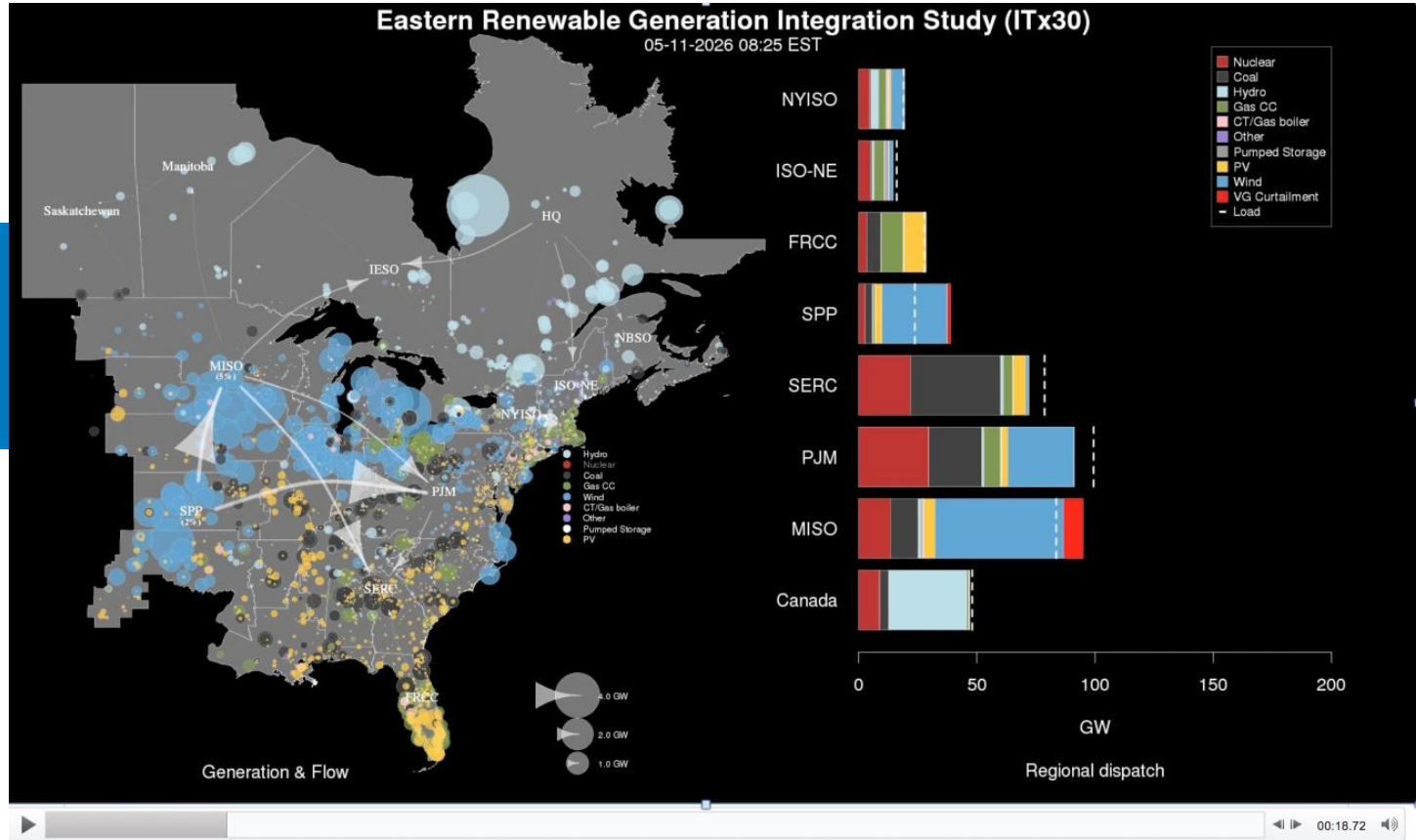


Wind and solar add variability and uncertainty to the generation supply, increasing the need for grid flexibility.

Electricity Modeling at Multiple Scales



Gaining insights from Advanced Visualization



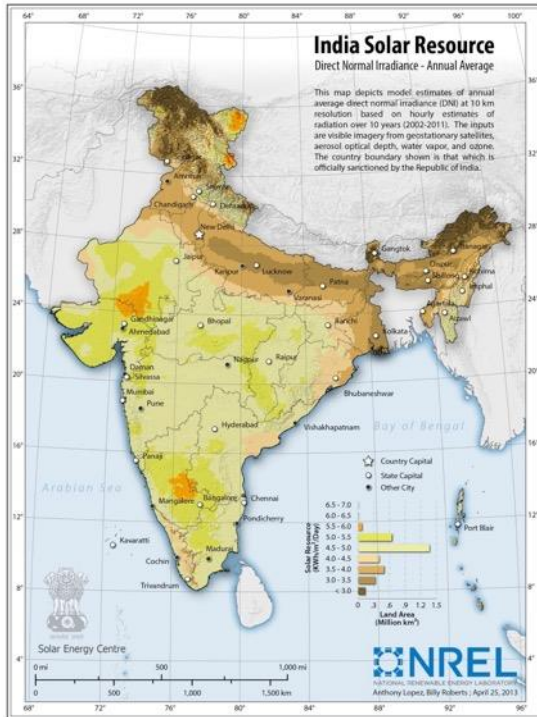


EASTERN RENEWABLE GENERATION INTEGRATION STUDY

GENERATION, REGIONAL FLOWS, & DISPATCH
ITx30

MAY 11 - MAY 13, 2026
HIGH VARIABLE GENERATION

India's 2022 100 GW Solar Goal Requires an Evolution in Power System Planning



Solar (and wind) generation is variable, uncertain, and location-constrained...

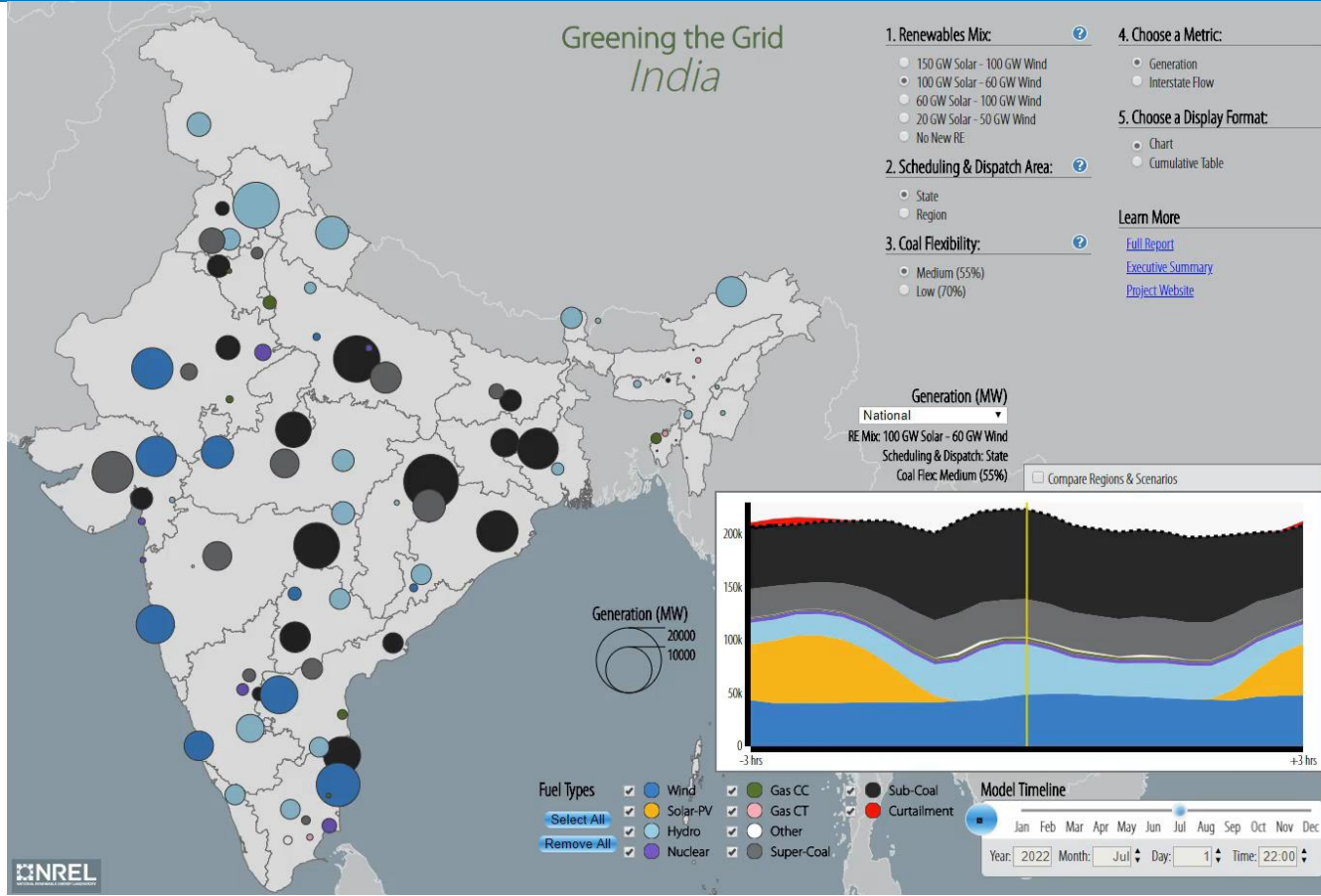
...raising new considerations for grid planning and operations

1. More flexibility is needed to balance supply and demand
2. More transmission might be necessary
3. Grid services (e.g. inertial response) from wind/solar or other equipment come at additional cost
4. Existing conventional generators are needed, but run less, affecting cost recovery

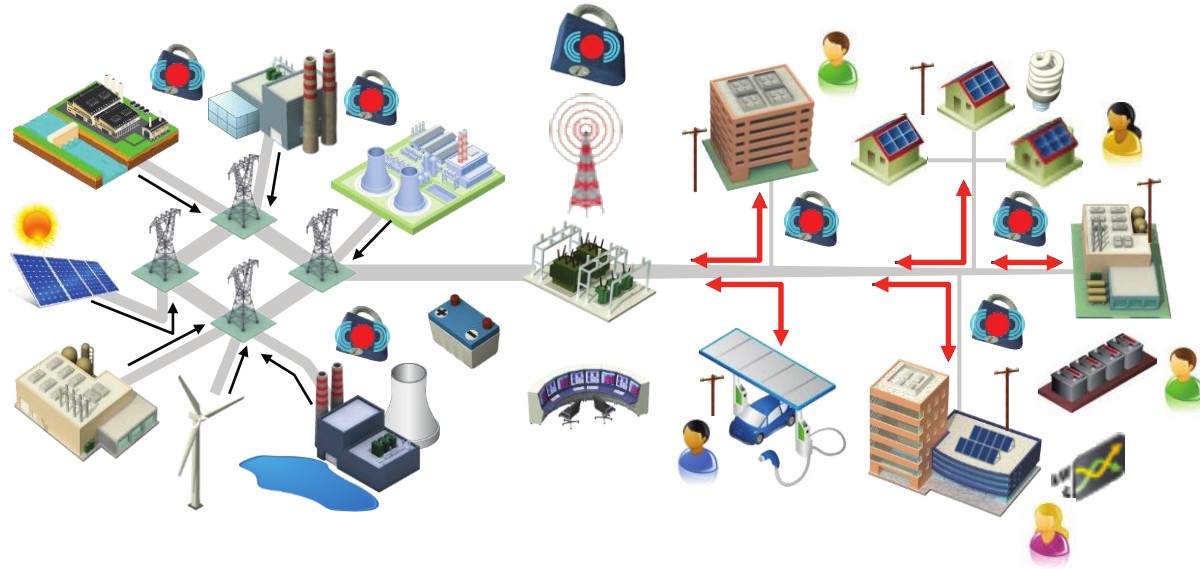


India's power system with 160 GW wind and solar— Achieving system balance every 15 minutes

<http://www.nrel.gov/india-grid-integration>



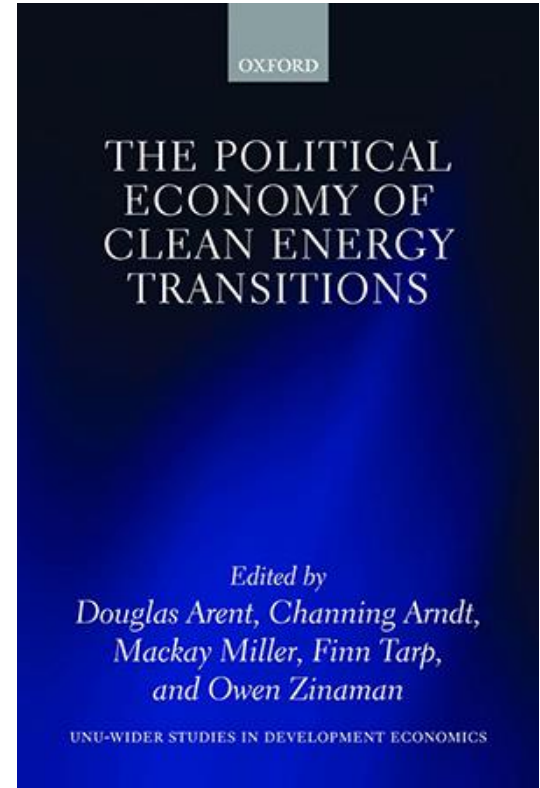
The Evolving Power System



Transitioning today: Restructuring,
New Business Models, New Technologies

A Few Takeaways

- Technology advances are changing the landscape
 - IT & ET & Business model Innovations...
 - Renewables offer domestic advantages with potential economy wide benefits:
 - Price certainty, trade, water/food, health...
- Policy, Finance/business models enable or hinder change
- Power Sector Structural reforms underway across the globe
- Innovation in Financing and Financial reforms continue to evolve to support creative business solutions



Human-Centered Innovation

It is not the essential nature of a technology that matters but its capacity to fit into the social, political, and economic conditions of the day.

—The Economist, March 12, 2012 “The Dream that Failed”



References and Resources

www.nrel.gov

www.21stcenturypower.org

www.cleanenergysolutions.org



Flexibility in 21st Century Power Systems

BY NREL
 Authors: Michael Ewing, Laboratory Assistant; Graham Rogers, Mike, Steve Collins, Michael Miller, Doug Sims, Steve Pomeroy, Kimberly Collier, David Little, and 17 others
 Published: 2014
 NREL/TP-6A200-6400
 DOI: 10.3390/energysystems6010001
 URL: <https://doi.org/10.3390/energysystems6010001>

Introduction

Flexibility of operation—the ability of a power system to respond to change in demand and supply characteristics of all power systems. Flexibility is especially prized in twenty-first century power grids, higher levels of grid-connected variable renewable energy (solar, wind and tidal).

All power systems have some inherent level of flexibility—designed to balance supply and demand at all times. Variability and uncertainty are not new to power systems. Natural loads change over time and in sometimes unpredictable ways, and conventional resources do not respond to variable renewable energy supply. However, it can make this balance harder to achieve. Both wind and solar generation nodes vary significantly over the course of hours to days, sometimes in a predictable fashion, but other unpredictably.

To illustrate how variable renewable energy can increase the need for flexibility, Figure 1 demonstrates how variable wind output impacts power system operation. The figure introduces the concept of “net load” which represents the demand that must be supplied by the conventional generation fleet. Part of the renewable energy is to be offset. The other part is the “gross” renewable demand, and shows the daily variability of demand on an hourly basis for one week. The green shows wind energy, and the orange represents the demand-less wind energy that

must be applied to the remaining generation. The combination of wind energy, the grid-wide output level of the remaining generation must show supply and demand to be lower than the energy in the system. Solar energy will cause a similar impact on the power system.

Because it can take several years to design and construct new generation, the planning, the first critical activity is to ensure that the future generation sufficient flexibility to meet the growth of variable renewable generation.

Therefore, this function may describe a work model to which some conventional generation government policy answers present future.

Competitive markets, there must be sufficient signals regarding the potential need for flexibility. The absence of other market planning or the clarity the existing power system may not be flexible to operate effectively.



Flexible Coal: Evolution from Baseload to Peaking Plant

The experience cited in this paper is a generating station with multiple units located in North America referred to as “Unit 1”.



Overview of Variable Renewable Energy Regulatory Issues

A CLEAN ENERGY REGULATORS INITIATIVE REPORT



to convert the ability to cycle on and off and to respond to more variable loads, proactive inspections and so on, may require the extent of the regulatory framework will likely depend on the type of plant operation elsewhere will likely depend on the type of plant operation as well as the extent of the regulatory framework.

TECHNOLOGY FRONTIERS

Making Coal Flexible: Getting From Baseload to Peaking Plant

By Joseph Cichras
 Lead Energy Analyst,
 National Energy Laboratory (NEL)

Delta Lee
 NREL Senior Advisor

Michael Kemer
 Director of Energy & Utility Studies, IHS Inc.

“Power systems with 20 percent or higher penetration of low-carbon energy, wind, solar, and other emerging technologies will face increasing challenges in meeting the ability to peak on an off as well as to respond to the variability of renewable energy with a set of operational strategies that are not currently in place. This report provides a framework for the development of such strategies to ensure that coal power plants can continue to provide a reliable and cost-effective source of power.”



The competitive market model is the primary mechanism for CO2 costs to be passed to consumers. The market model is the primary mechanism for CO2 costs to be passed to consumers.



Peer-to-Peer Consultations

Ancillary Services Power Exchange with India, Experience from South Africa, Europe & the United States

Challenges: International experience and expertise in power system transformation is an increasingly vital resource for national and subnational decision makers. Supporting global experience is not easy in support of national and subnational decision makers, the 21st Century Power Partnership regularly works with country partners to organize power-to-power consultations on critical issues. In March 2014, the 21st Century Power Partnership collaborated with the Regulatory Assistance Project to host two peer-to-peer exchanges

The 21st Century Power Partnership aims to accelerate the global transformation of power systems.

The Power Partnership is a multinational effort of the Clean Energy Ministers and aims to be a platform for public-private collaboration.

POWER SYSTEMS OF THE FUTURE

A 21st Century Power Partnership Thought Leadership Report

Research Highlights

There is not a one-size-fits-all approach to the regulation of variable renewable energy (VRE) but international experience reveals many approaches that are proving successful. Countries that have been successful in integrating VRE into their power systems have done so through a combination of public policy goals, and the political economy of power generation, including organization of the power system, identification of VRE resources, and identification of VRE resources and their characteristics.

Many variables shape the issues that arise in a given context, especially power system characteristics, geographic and spatial availability of renewable resources, institutional organization of the power system, public policy goals, and the political economy of power generation. Our common issue area in each stage of variable renewable energy deployment. The Power Partnership research published in 2014, classified four broad categories of regulatory issues:

- Facilitating New VRE Generation: In accordance with policy mandates, regulatory play a role in facilitating new VRE generation through various mechanisms, including setting tariffs, organizing auctions, and influencing grid codes and the interconnection of new VRE generation.
- Enabling Adaptive Grid Infrastructure: Regulations play a role in adapting the grid infrastructure to accommodate the characteristics of power systems, which is a dimension of VRE deployment and system integration.
- Ensuring Resilient and Secure Supply: Regulations play a role in ensuring the reliability and security of supply.

Variable Renewable Energy: A Regulatory Roadmap

Research Highlights

There are four domains are identified, and become more complex as VRE deployment levels grow.

Case Studies in Integrating Renewables Around the World

The Power Partnership surveyed regulatory experiences around the world from three continents, and presented findings from the United States, Canada, Australia, Denmark, Germany, Guatemala, India, Mexico, the United Kingdom, and the United States. Each case study is a study of each regulatory context and the resulting VRE deployment and growth.

Case Study in VRE Generation

Germany's system has a high level of VRE penetration through increased capacity for renewable generation and growth in deployment, and through increasing transportation options.

Challenges: To achieve aggressive renewable energy targets, Germany is looking to attract more power from offshore wind. The country is working to address a robust public utility. The country is working to address a robust public utility. The country is working to address a robust public utility.