21st Century POWER PARTNERSHIP

Accelerating the transformation of power systems

THE NEXT GENERATION OF PLANNING CHALLENGES AND OPPORTUNITIES FOR POWER SECTOR TRANSFORMATION

Dr. Douglas Arent

National Renewable Energy Laboratory

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CLEAN ENERGY MINISTERIAL

Accelerating the Transition to Clean Energy Technologies

A Holistic Approach to Power System Transformation

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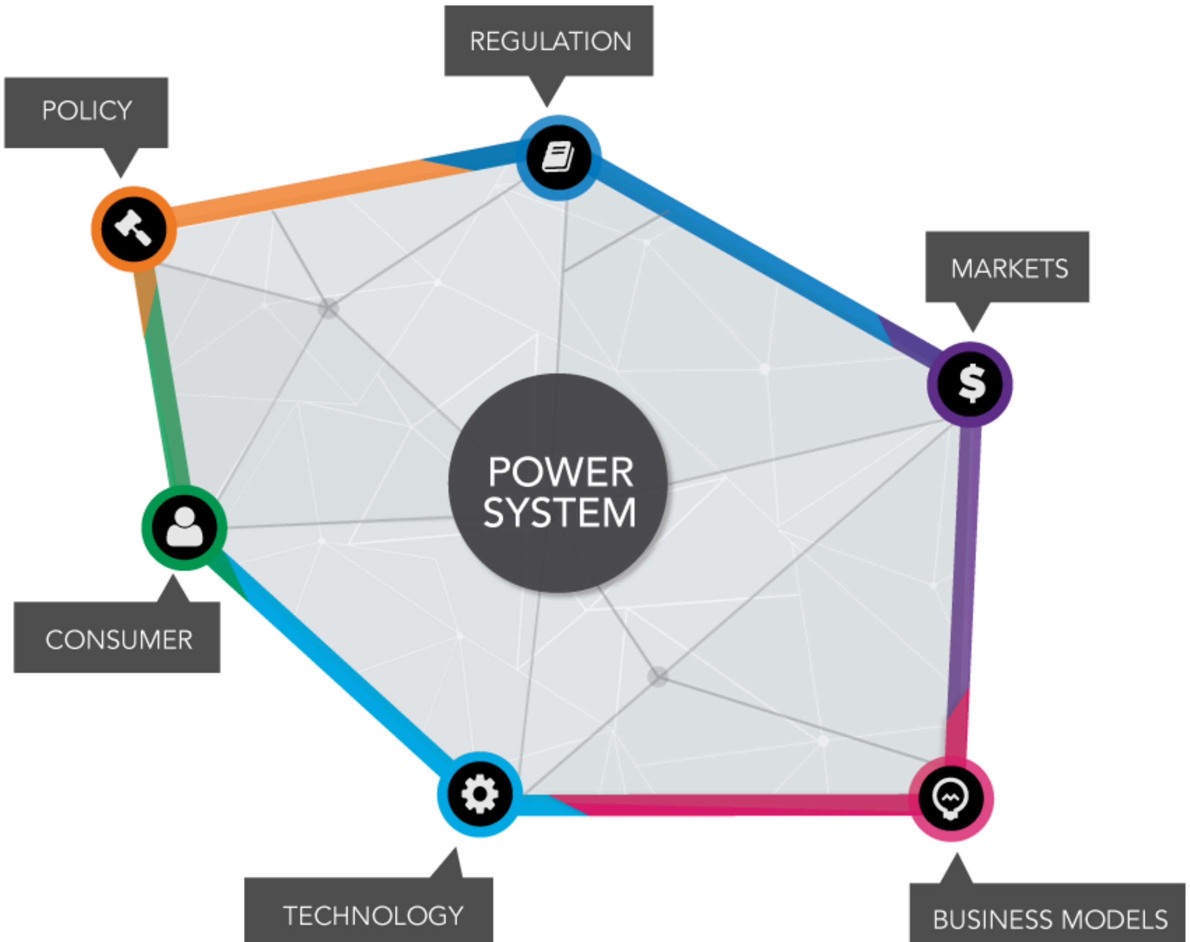
Power systems are *complex and dynamical…*

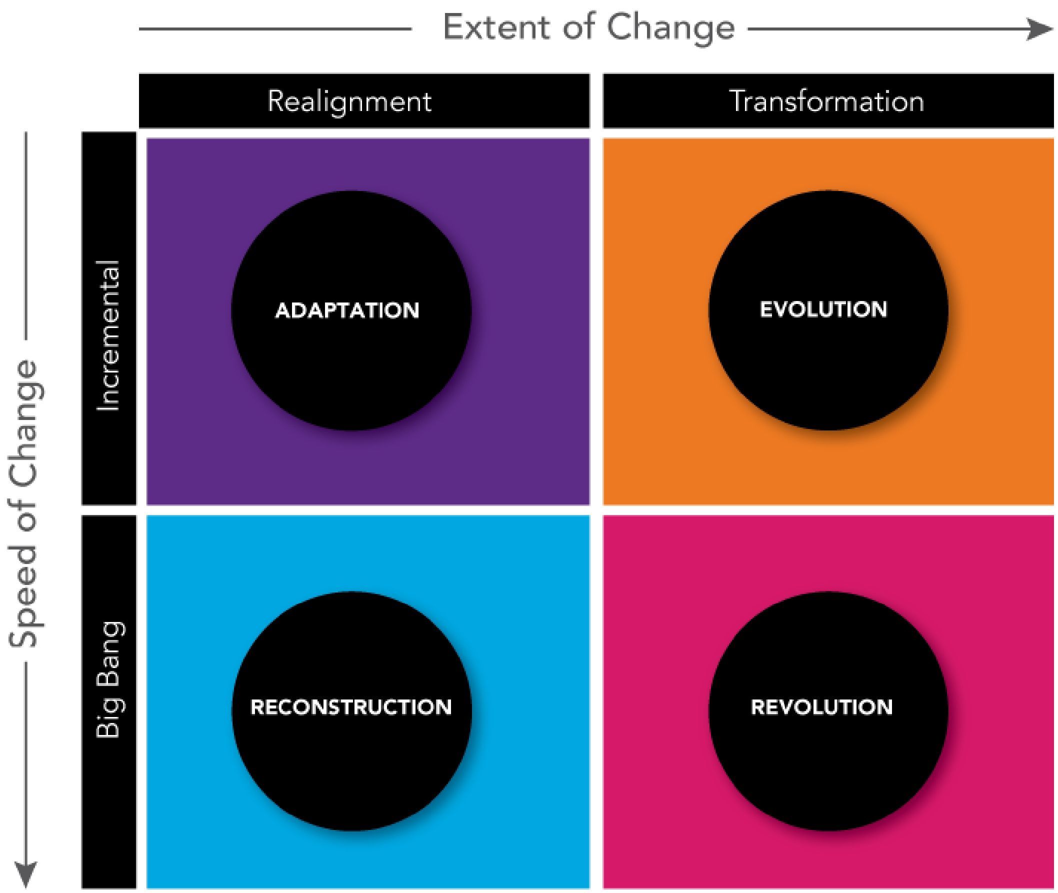


Extent and Speed of Transformation

Different *extent* and *speed* of change implies different modes of transformation: Adaptation, Evolution, Reconstruction, and Revolution.

Transformation is path-dependent

- Technological, financial and institutional legacies have important bearing on the rate and extent of change
- *Heavier legacies*: cautious incrementalism
- *Light legacies*: more rapid change.



Source: Power Systems of the Future (2015). A 21st Century Power Partnership Report: http://www.nrel.gov/docs/fy15osti/62611.pdf

Key Drivers Behind Next Generation Planning Questions

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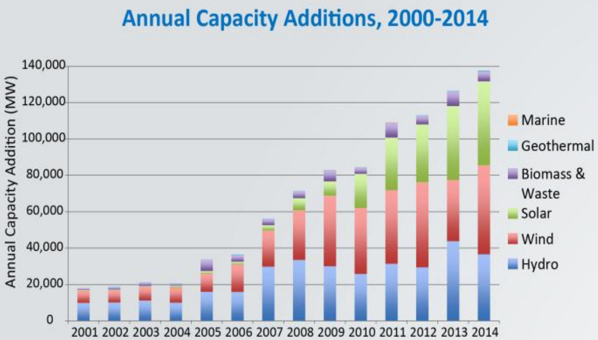
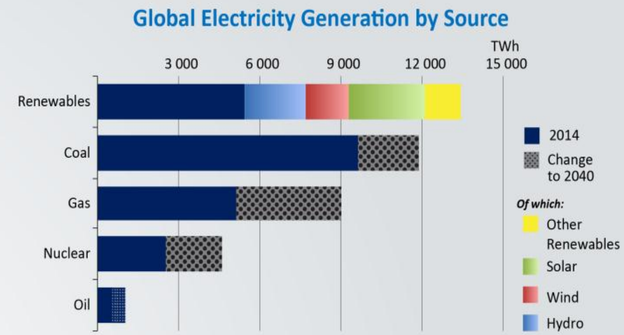
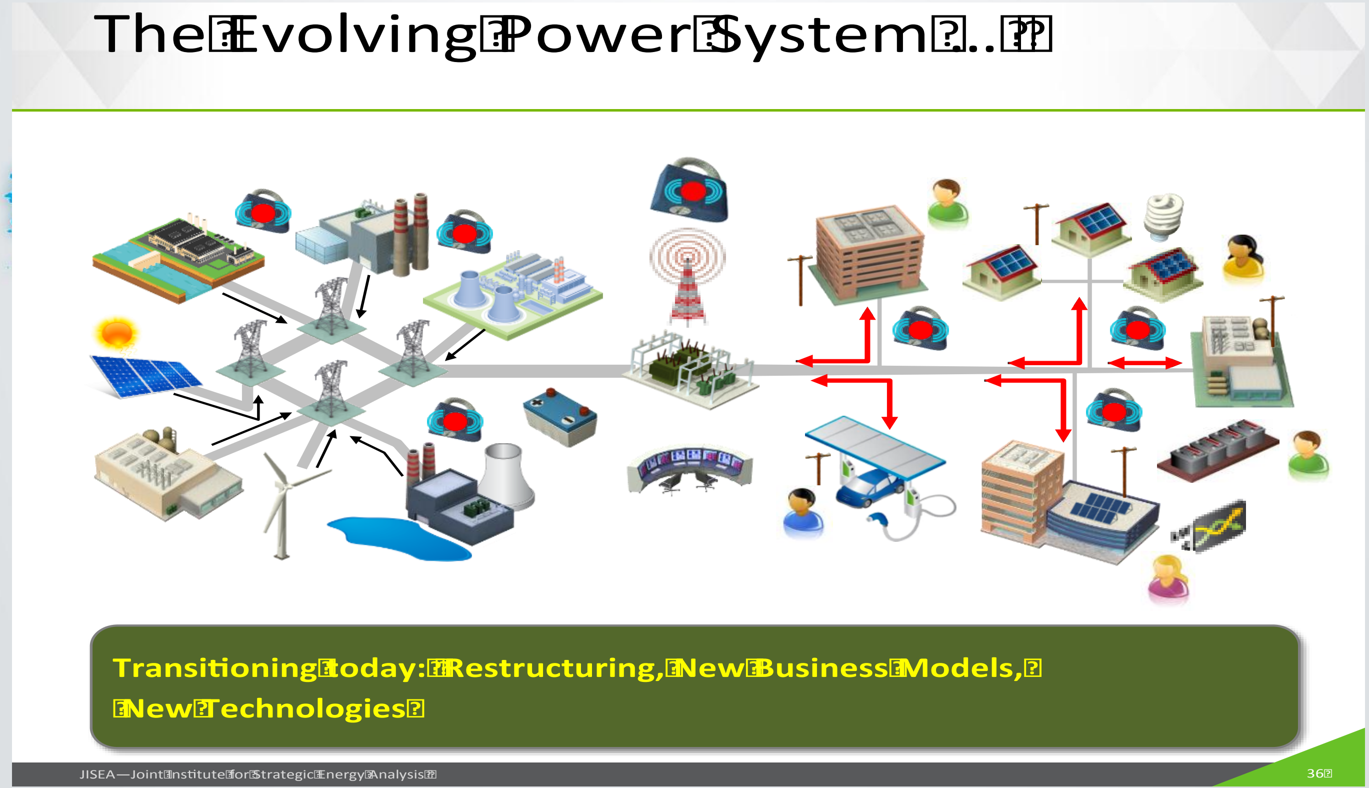
Renewable energy cost reductions	Increased interactions with other sectors
Data, intelligence, and system optimization innovations	Local and global environmental concerns over air emissions
Energy security, reliability, and resilience goals	Energy access imperatives
Evolving customer engagement	Increasingly diverse participation in power markets
A tale of two electricity demand forecasts	Revenue and investment challenges.

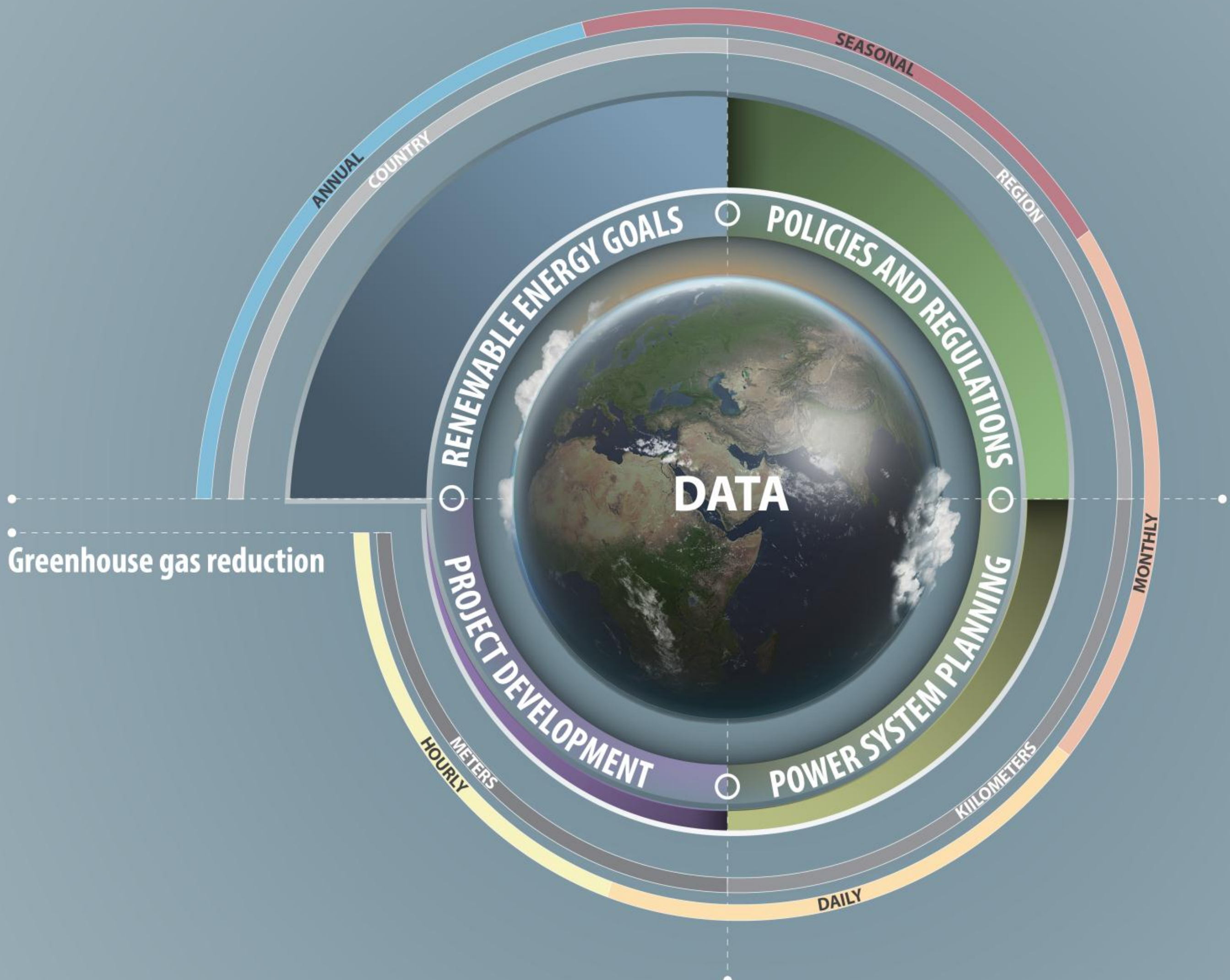
Evolving Power Systems Demand New Planning Approaches







It All Starts with Data



Technology is Accelerating Faster than Ever

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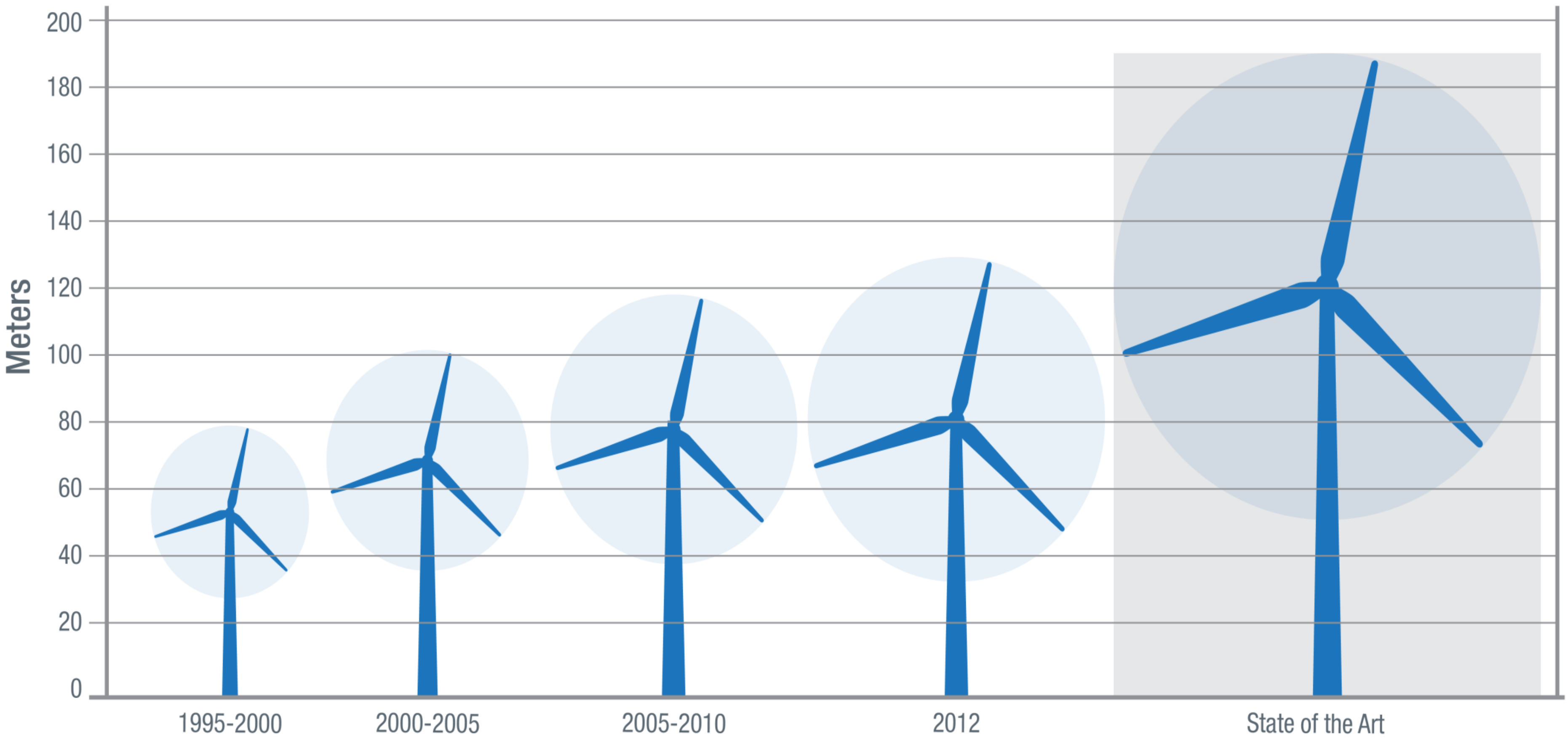

Technology Evolution Unleashes New Opportunities and Challenges

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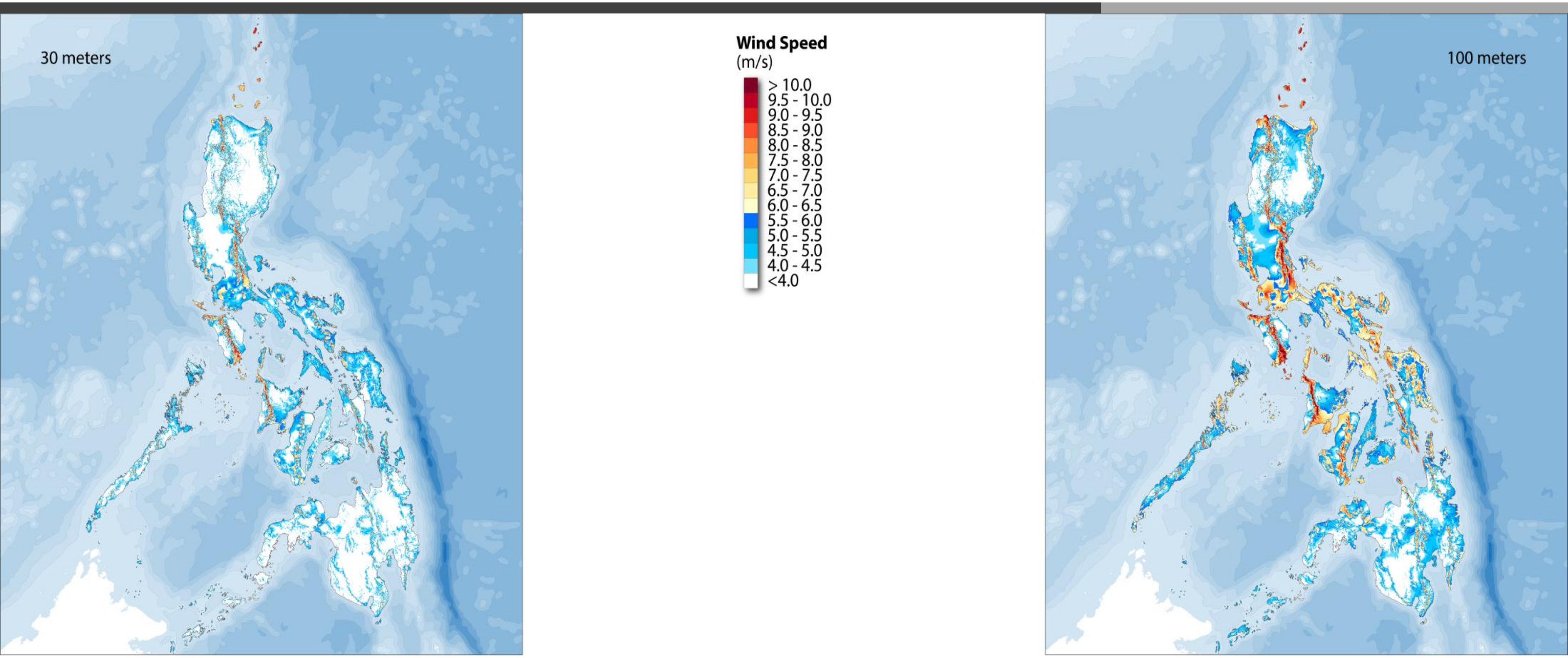
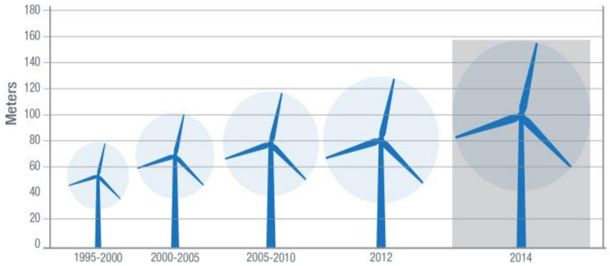
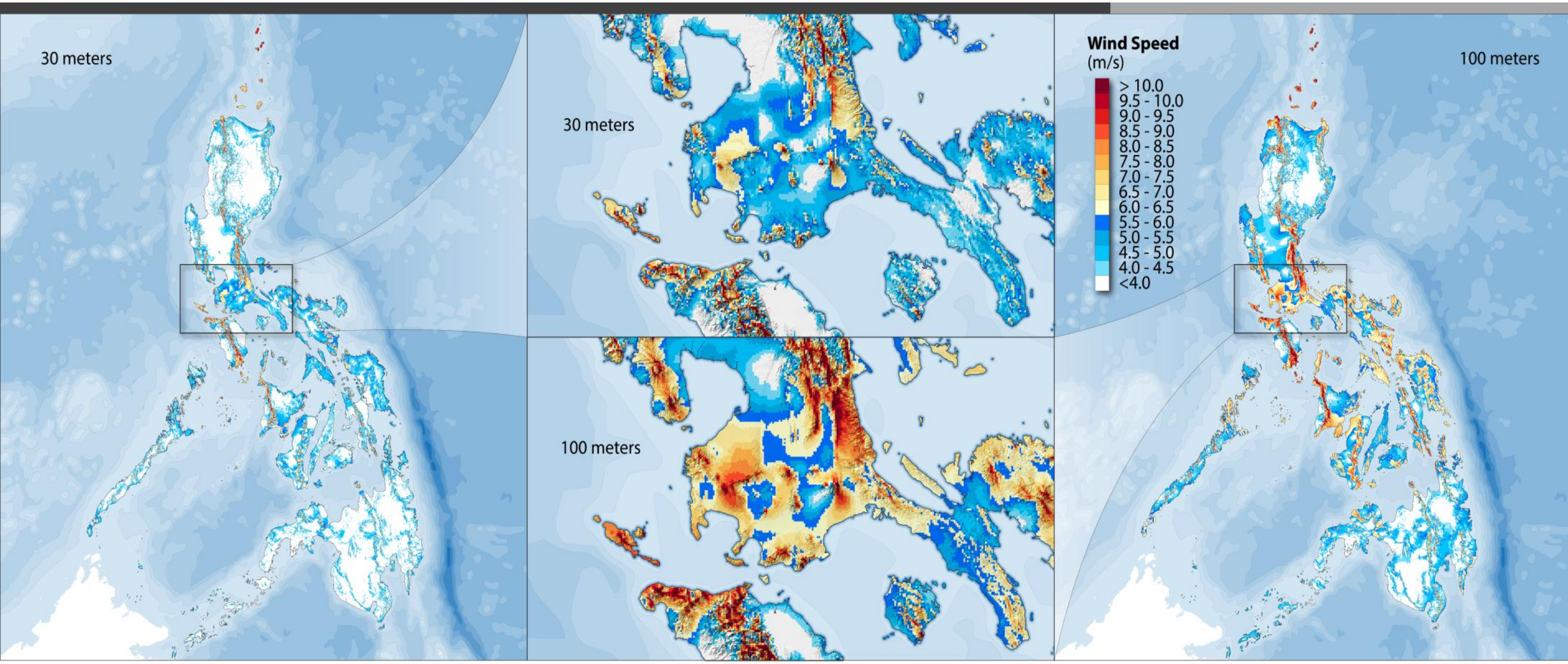
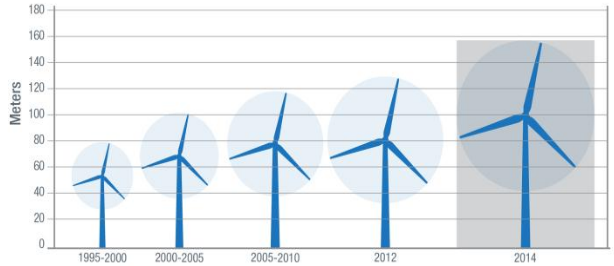


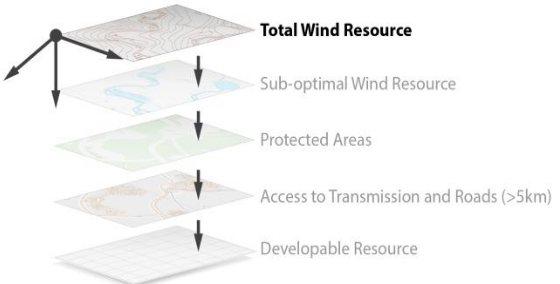


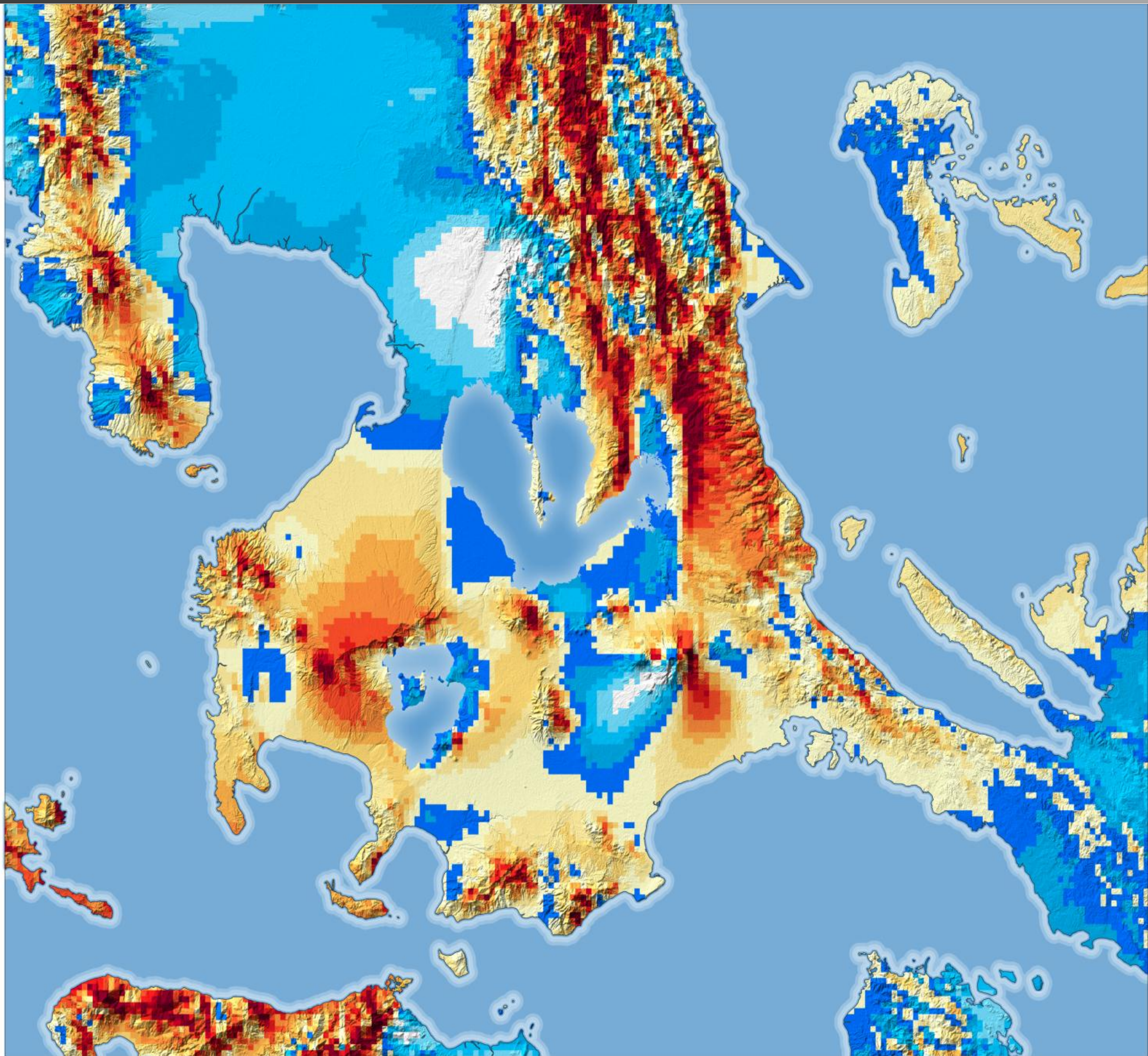
Technology Evolution Unleashes New Opportunities and Challenges





Global Best Practices: Data, Tools, and Approaches





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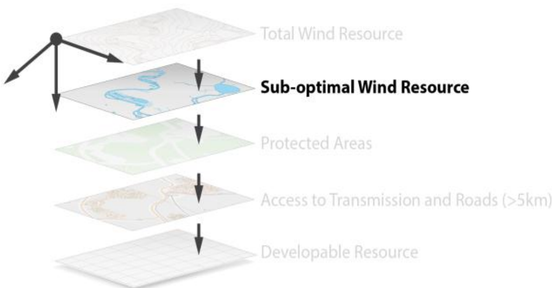

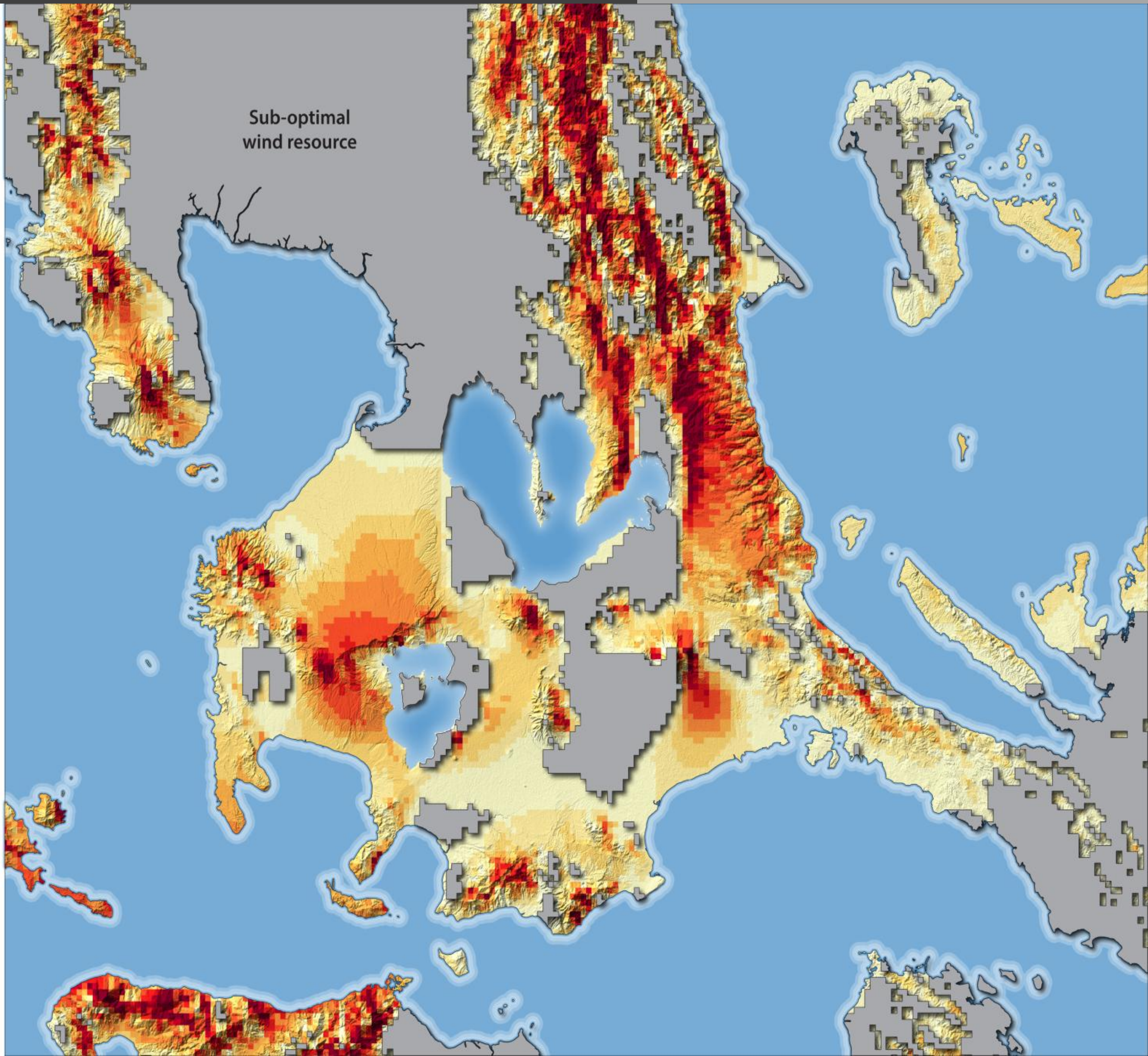

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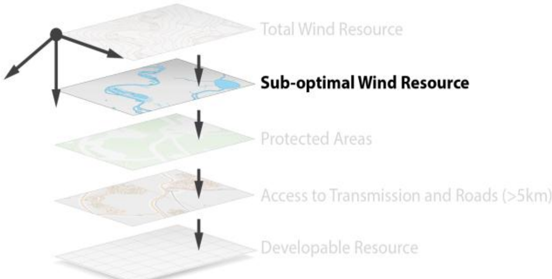
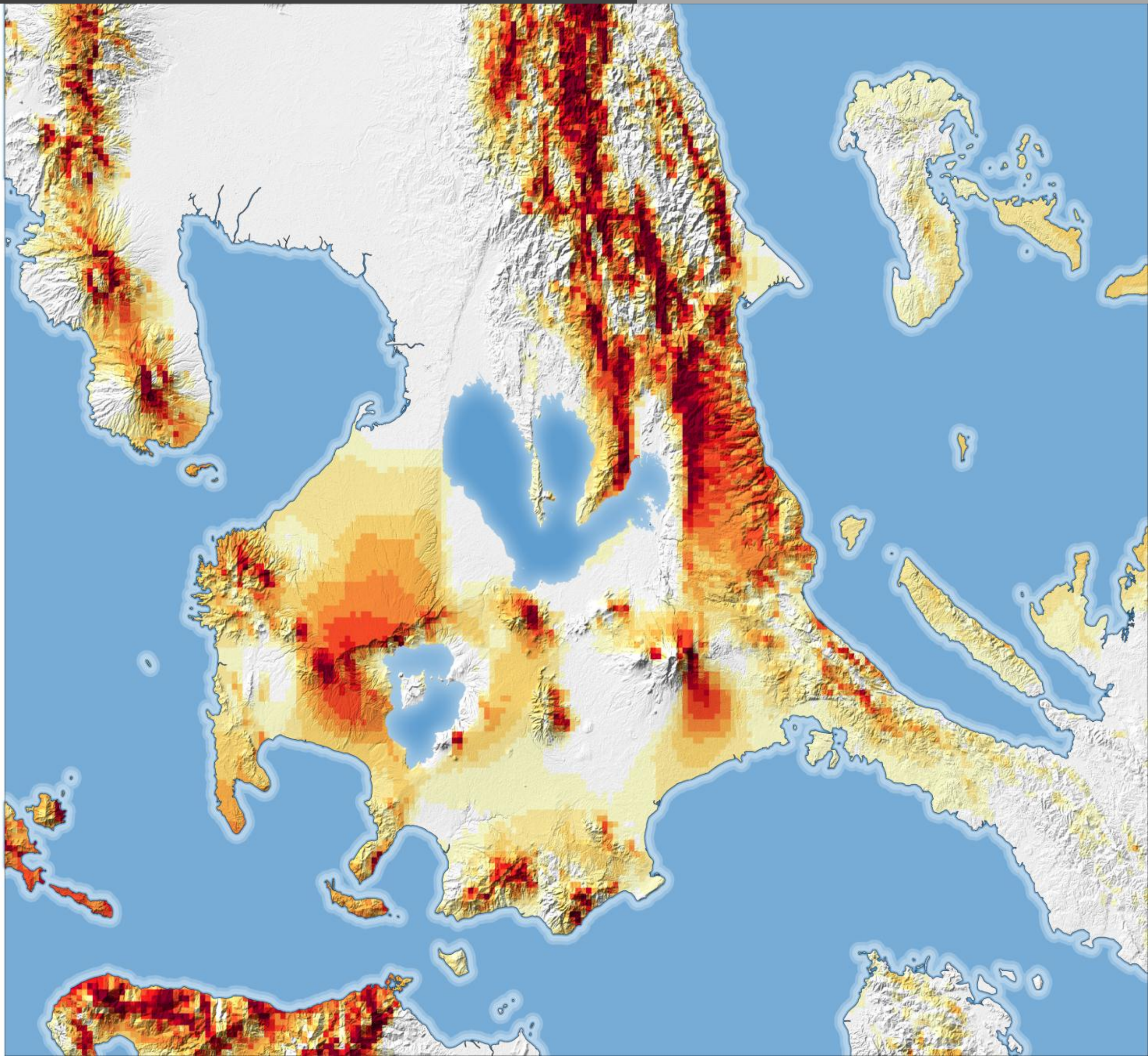
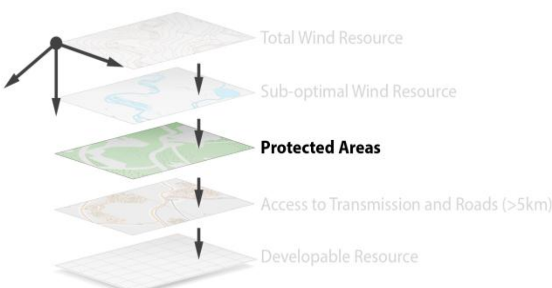
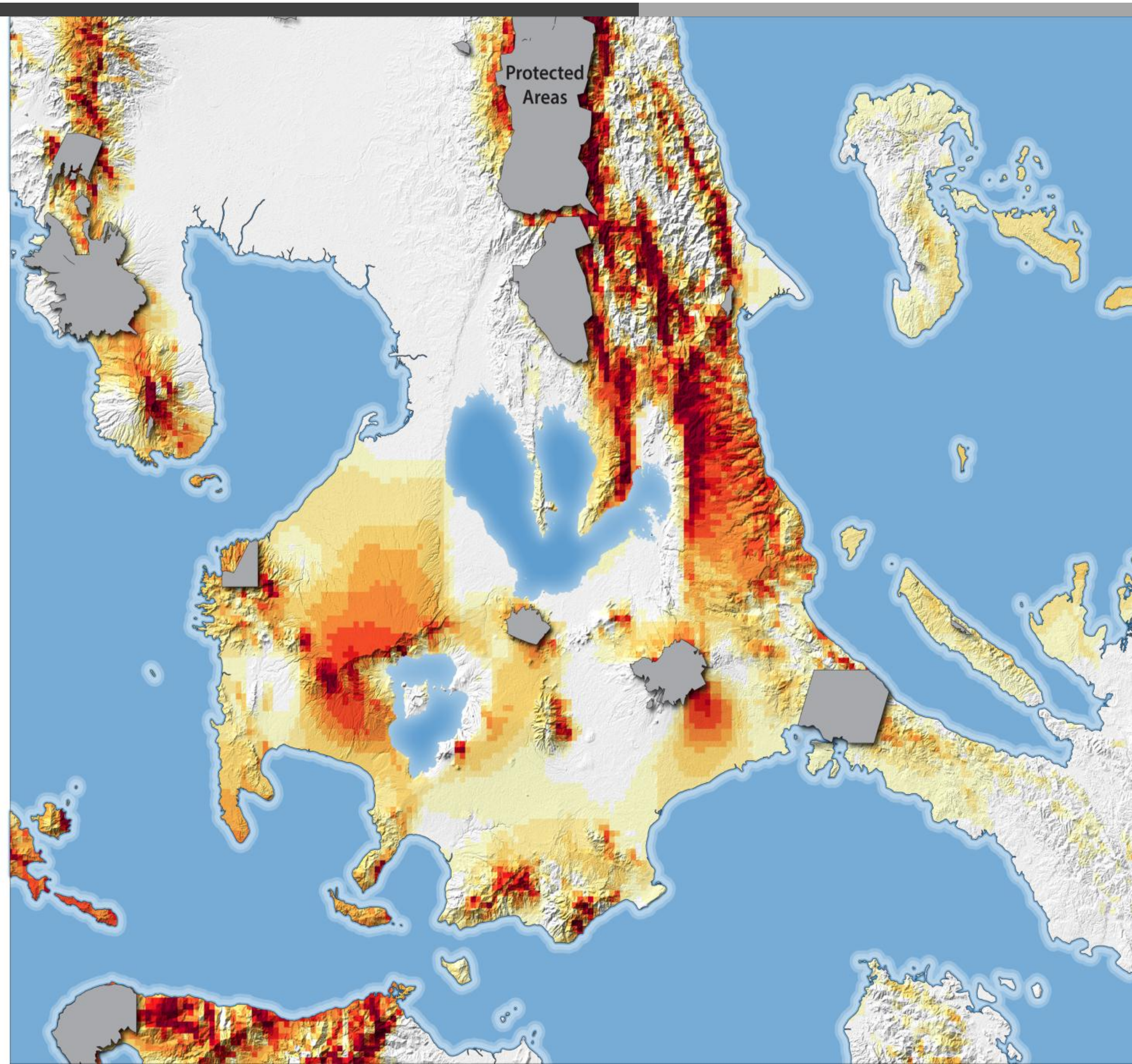




GLOBAL BEST PRACTICES: DATA, TOOLS, AND APPROACHES





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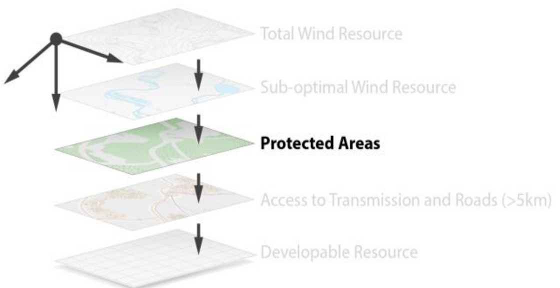

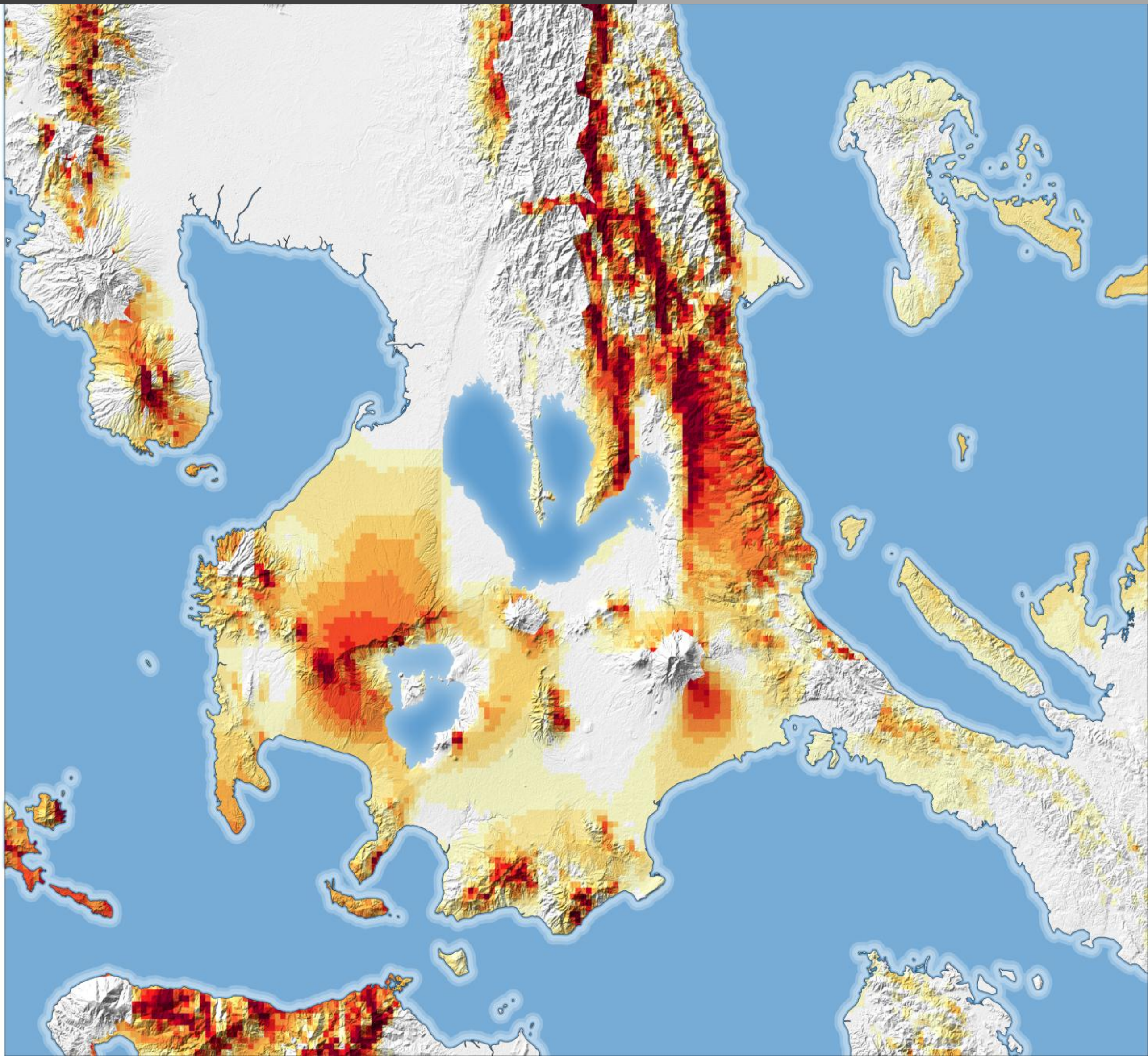

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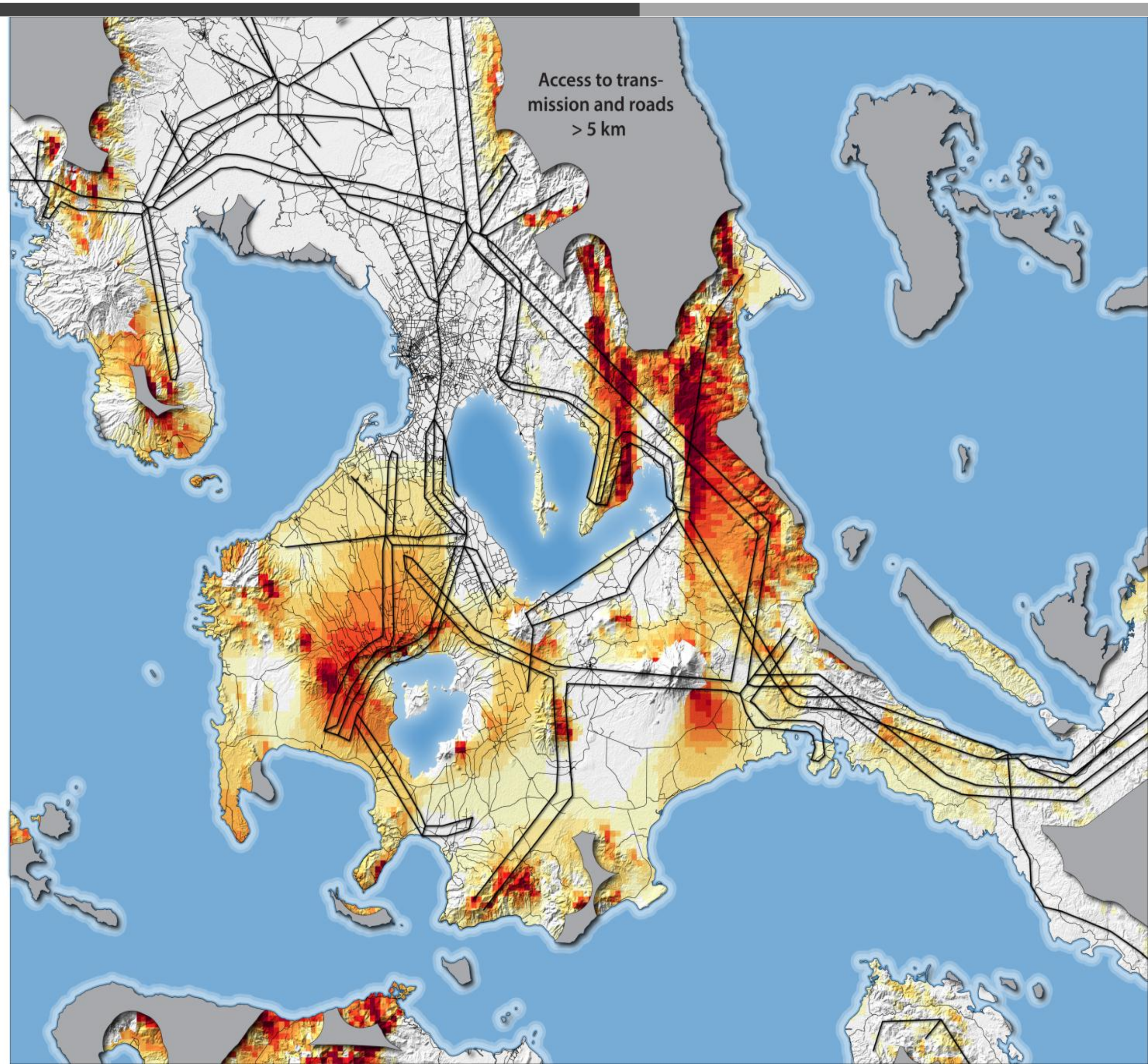

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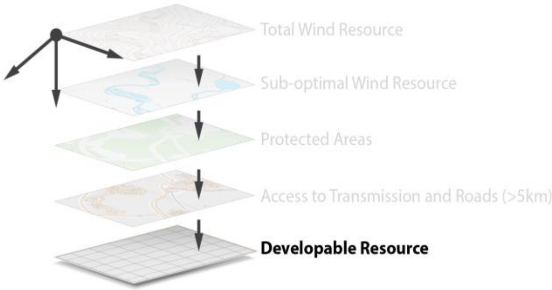
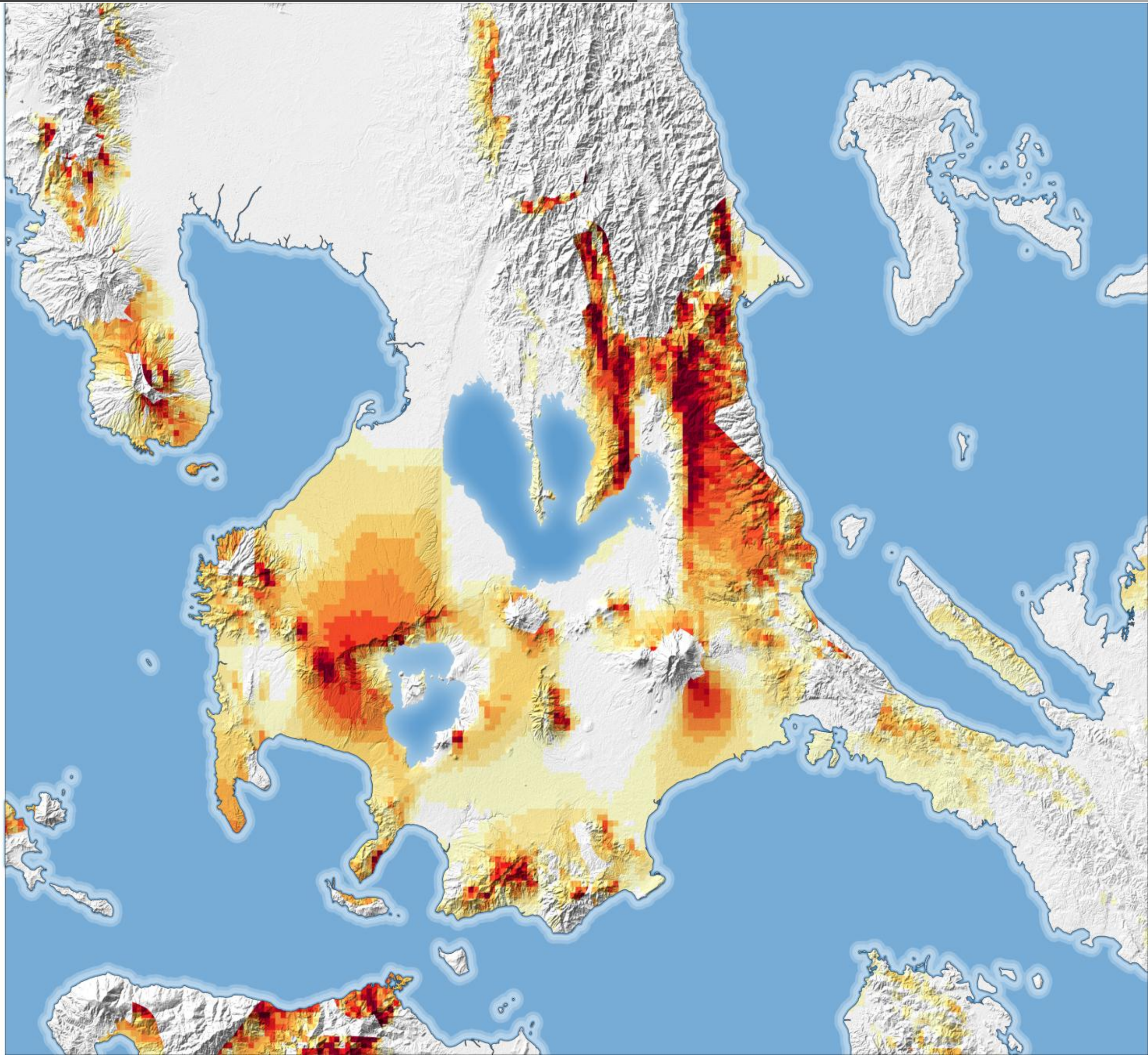
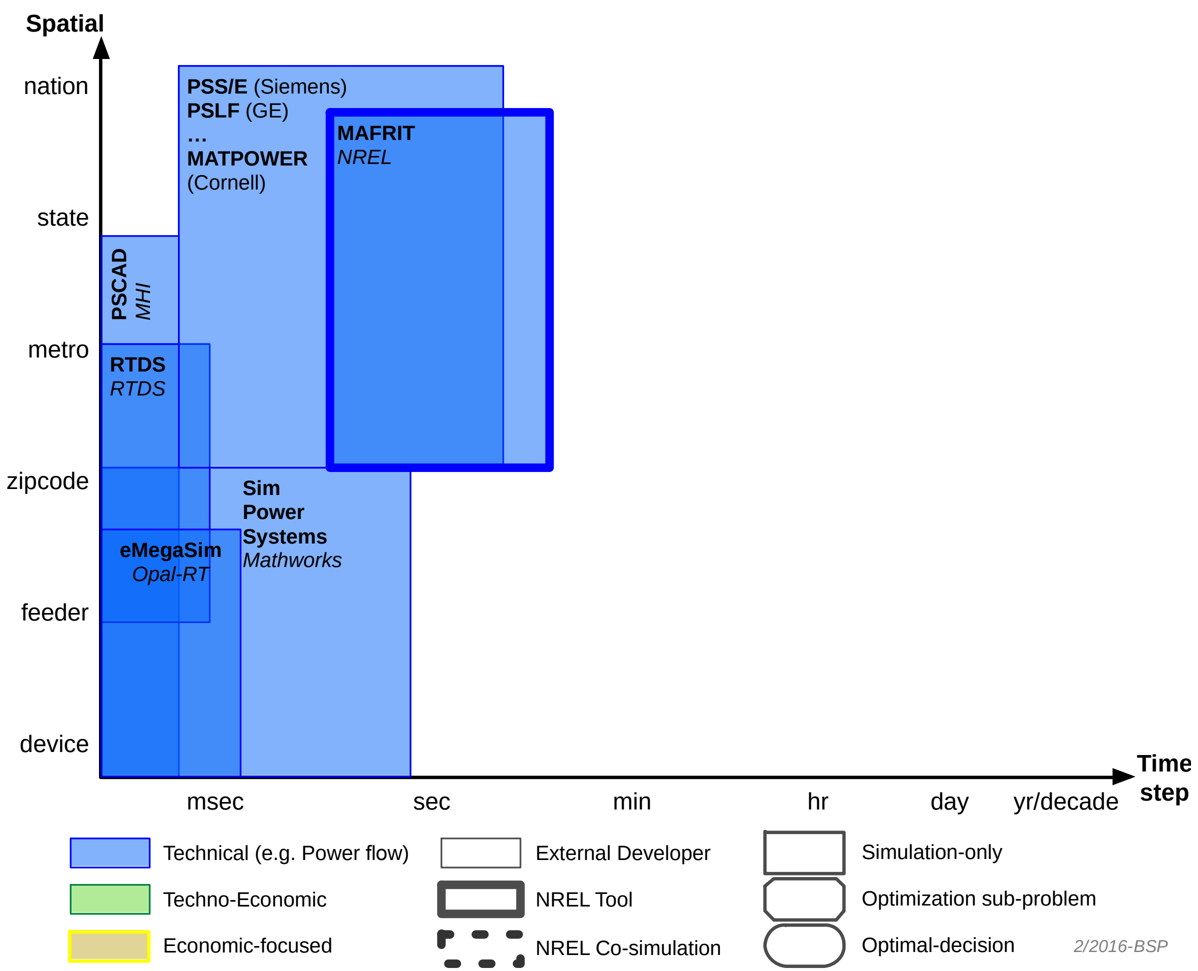




Tools: Dynamic Simulation



Real-time Simulation

- RTDS
- Opal-RT

Balanced AC Power flow

- PSLF
- PSS/E
- MATPOWER

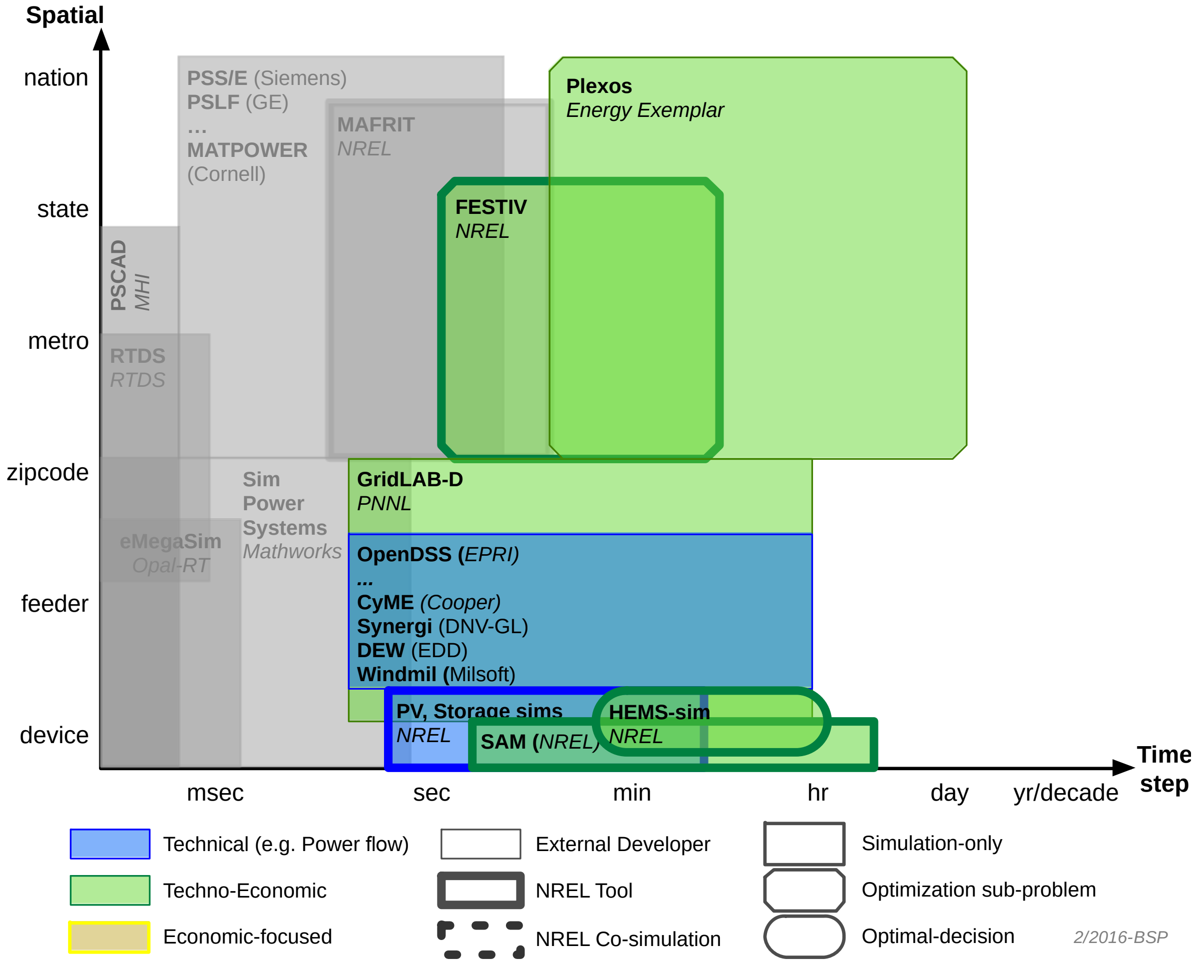
Unbalanced Transients

- PSCAD
- SimPower Systems

Frequency Nadir

- MAFRIT [1]

Tools: Operations Simulation



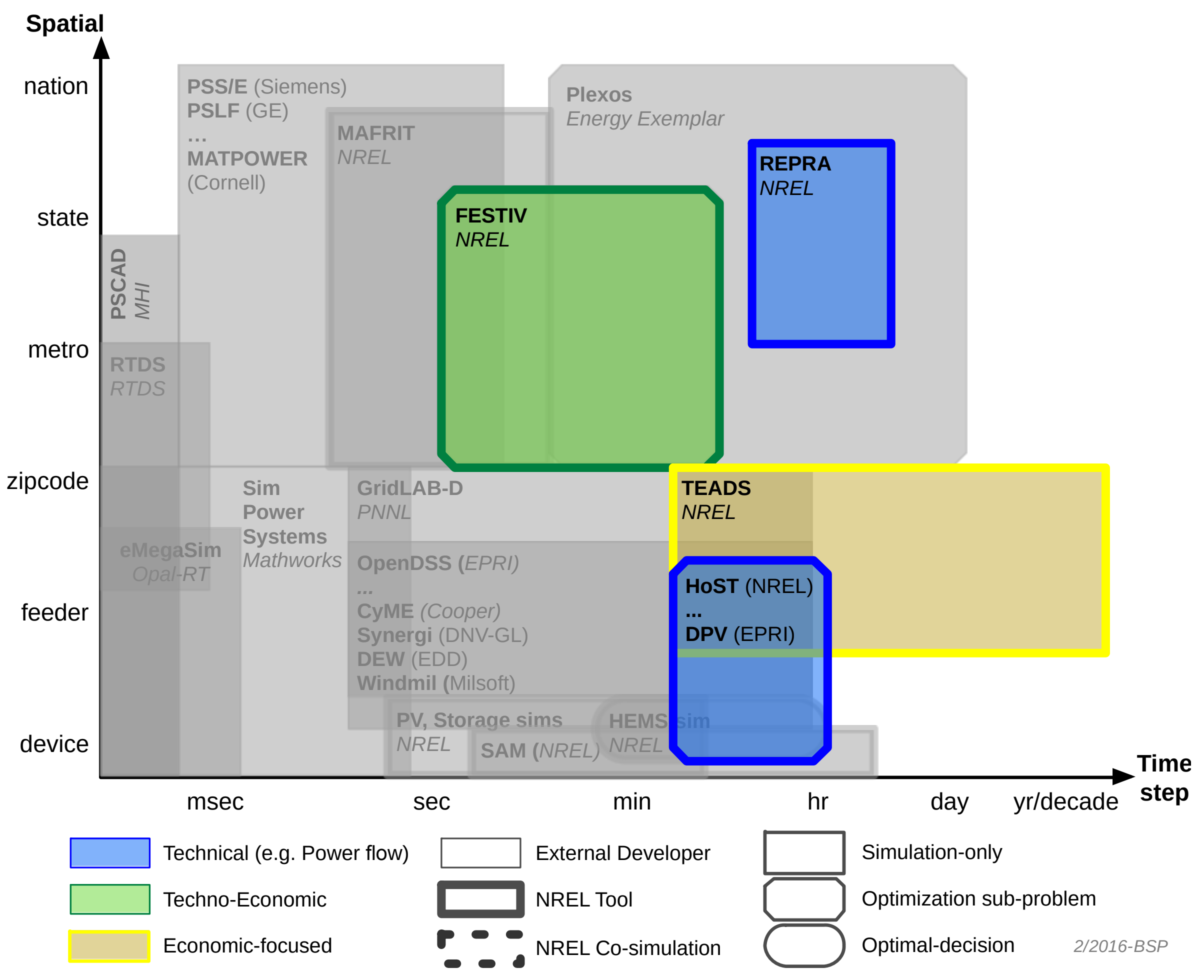
(Large) Production Cost
- Plexos

Market+ACG Simulation
- FESTIV [2]

3-ph AC distribution
- OpenDSS
- CyME
- Synergi
- DEW
- WindMil
- GridLAB-D

Device Simulation
- GridLAB-D
- PV, Storage models (project specific)
- Home Energy Management (HEMS) [3]
- System Advisor Model (SAM) [4]

Tools: Metric Assessment



System Adequacy

- REPRA [5]

Reserve Requirements

- FESTIV [2]

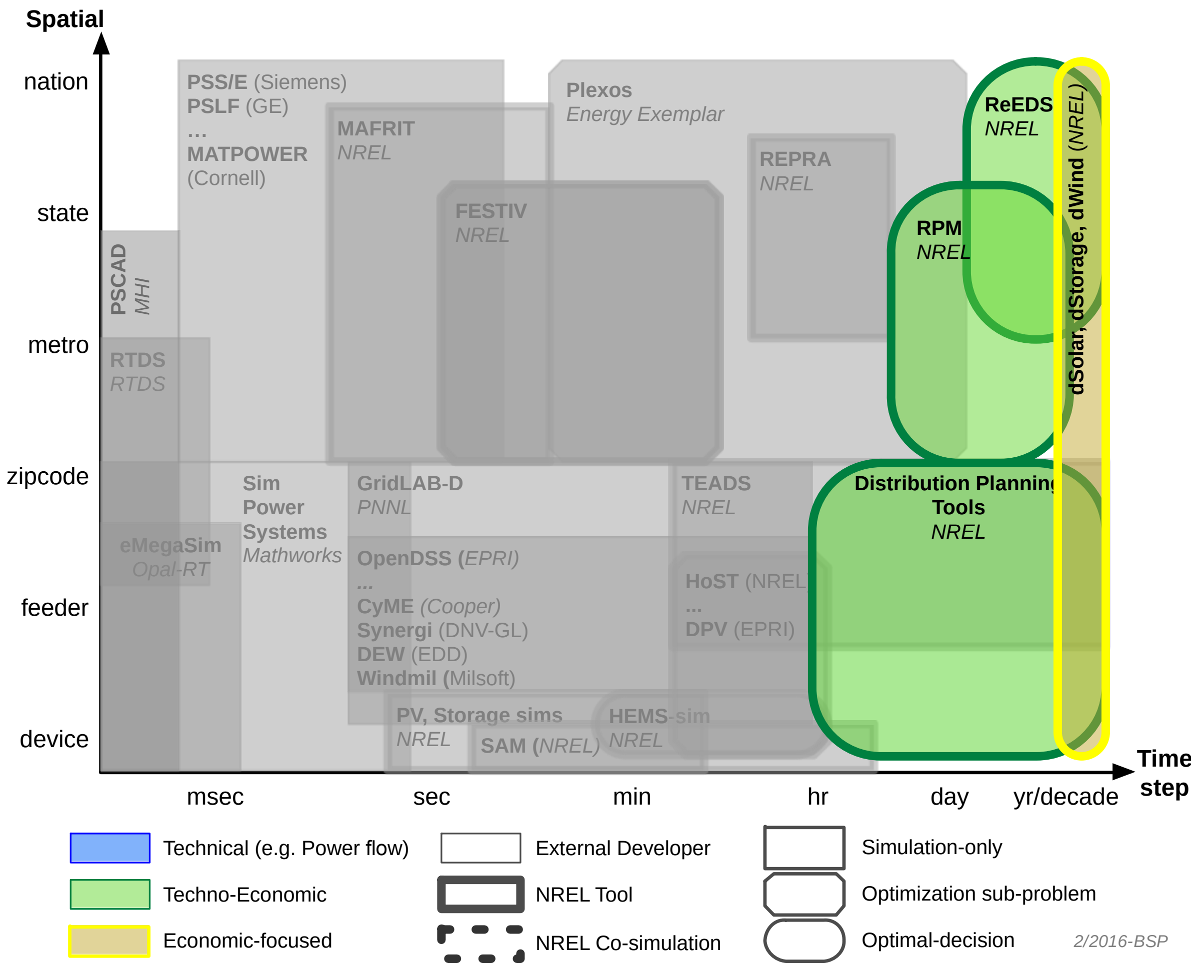
Distribution Cost-Benefit

- TEADS [6]

DER Hosting Capacity

- HoST [7]
- DPV

Tools: Planning & Trends



National Generation Planning w/Renewables

- ReEDS [8]

Regional Reliability Plans

- RPM [9]

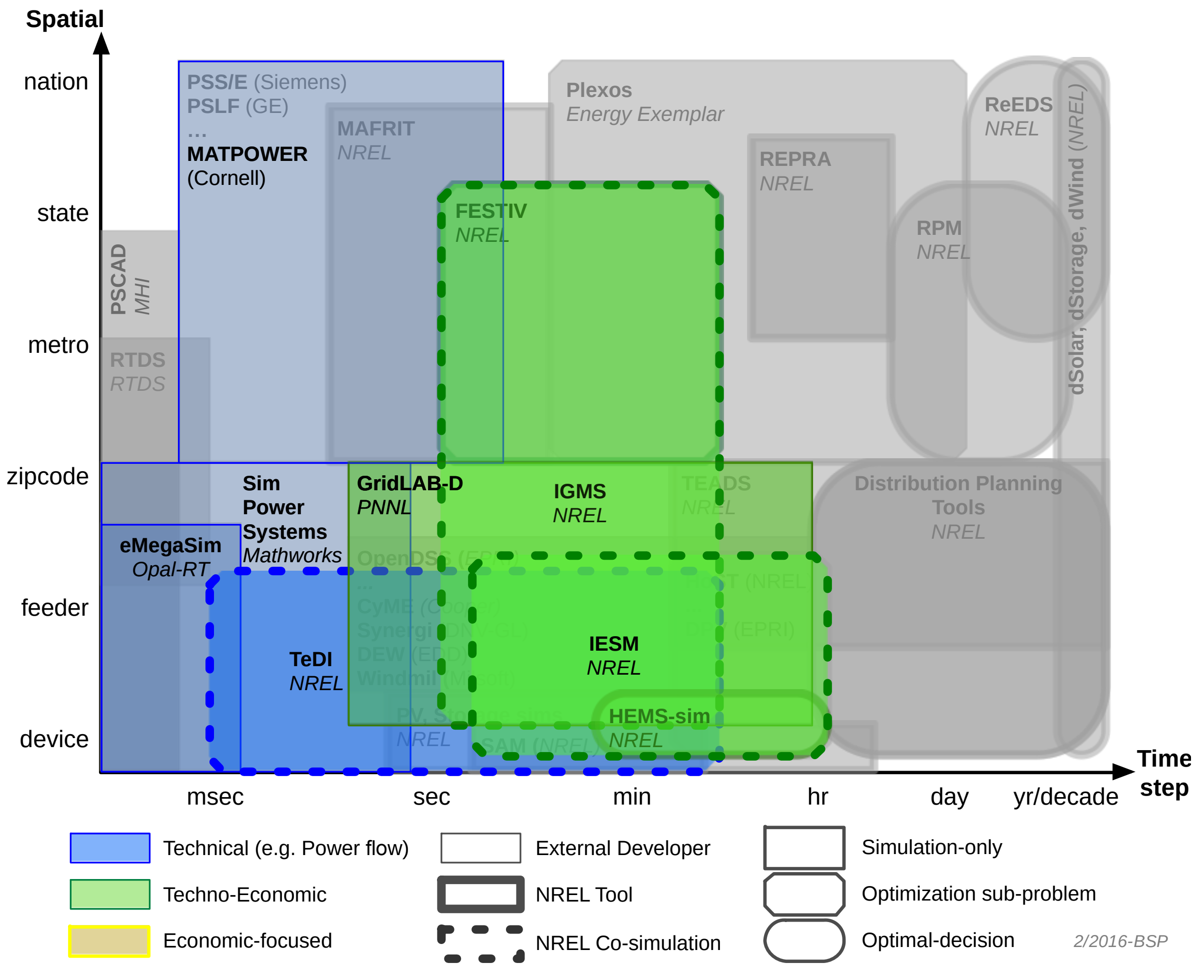
Distribution Planning

- Forward-looking Distribution Planning Tools

DER adoption patterns

- dSolar, dStorage, and dWind [10],[11]

Tools: Integrated Co-Simulation



Transmission + Distribution + End Use

- Integrated Grid Modeling System (IGMS) [12],[13]

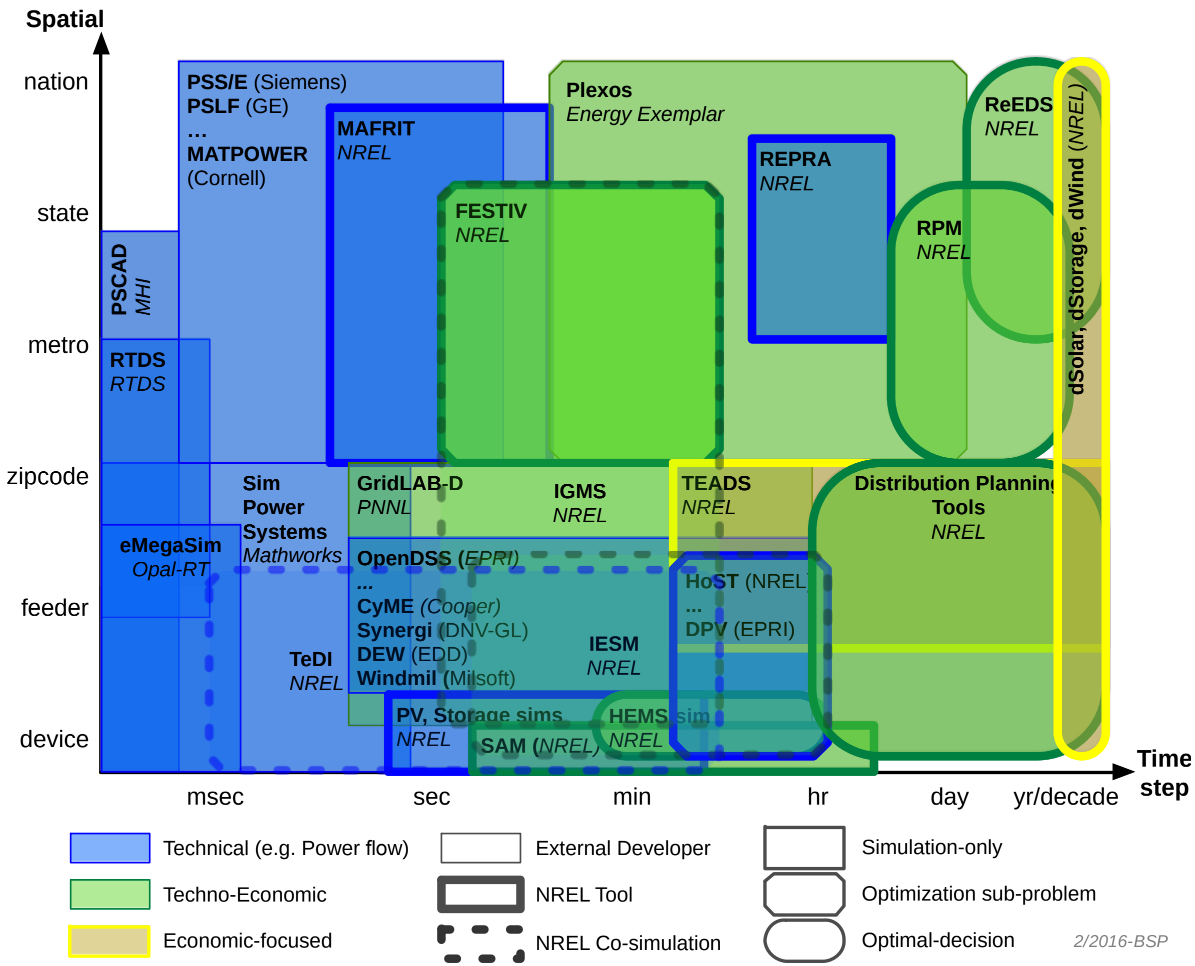
Distribution (Tariffs) + Home Energy Management (HEMS)

- Integrated Energy Systems Model (IESM) [3],[14]

Grid Simulation + Power Hardware-in-the-Loop

- Testbed for Distributed Integration (TeDI) [15]

Tools: A Comprehensive Suite

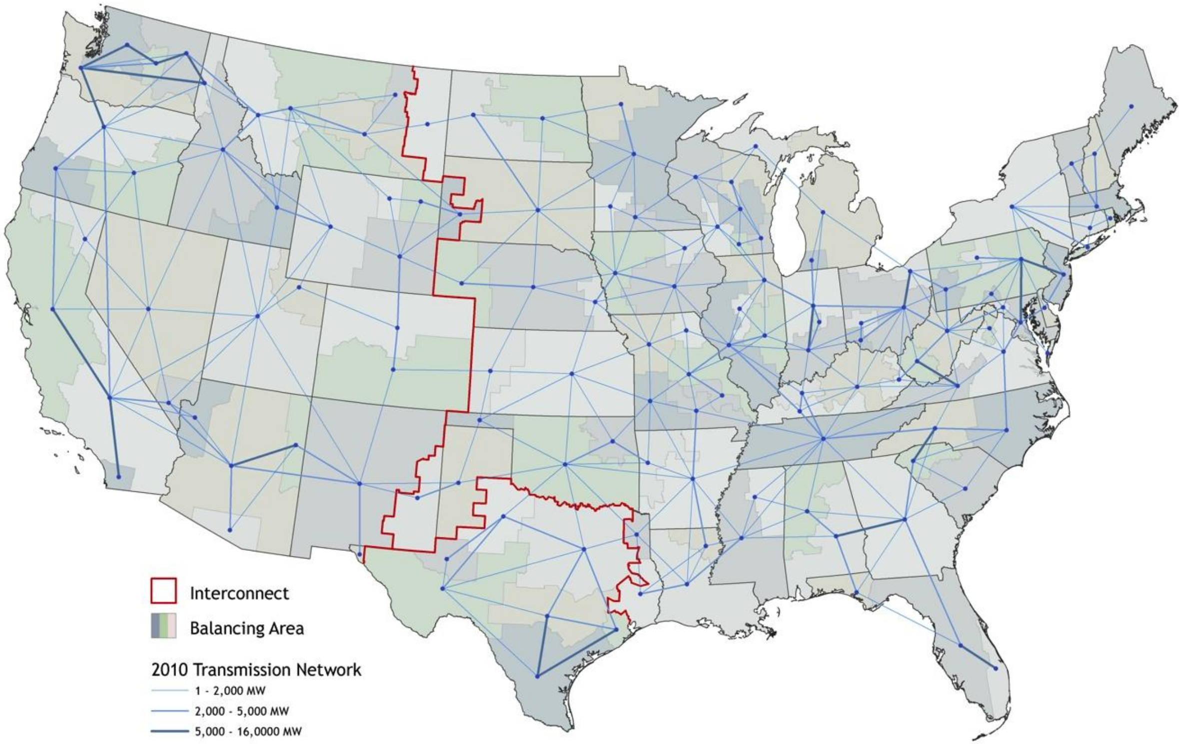


- Markets
- Transmission
- Distribution
- Devices
- Hardware
- Co-simulation

- Transient
- Dynamic
- Steady-State
- Planning

- Technical
- Economic
- Techno-economic

State of the Art Tools: Regional Energy Deployment System (ReEDS) Model



- Optimization model of U.S. Electricity Sector
- 134 Balancing Areas
- 356 Wind/CSP regions
- Explicit consideration of RE integration issues

- Solves combined capacity expansion and dispatch out to 2050 under different assumptions
  - Economic
  - Technology
  - Policy

GOOD DATA INFORMS GOOD POLICY: LONG-TERM SCENARIO PLANNING

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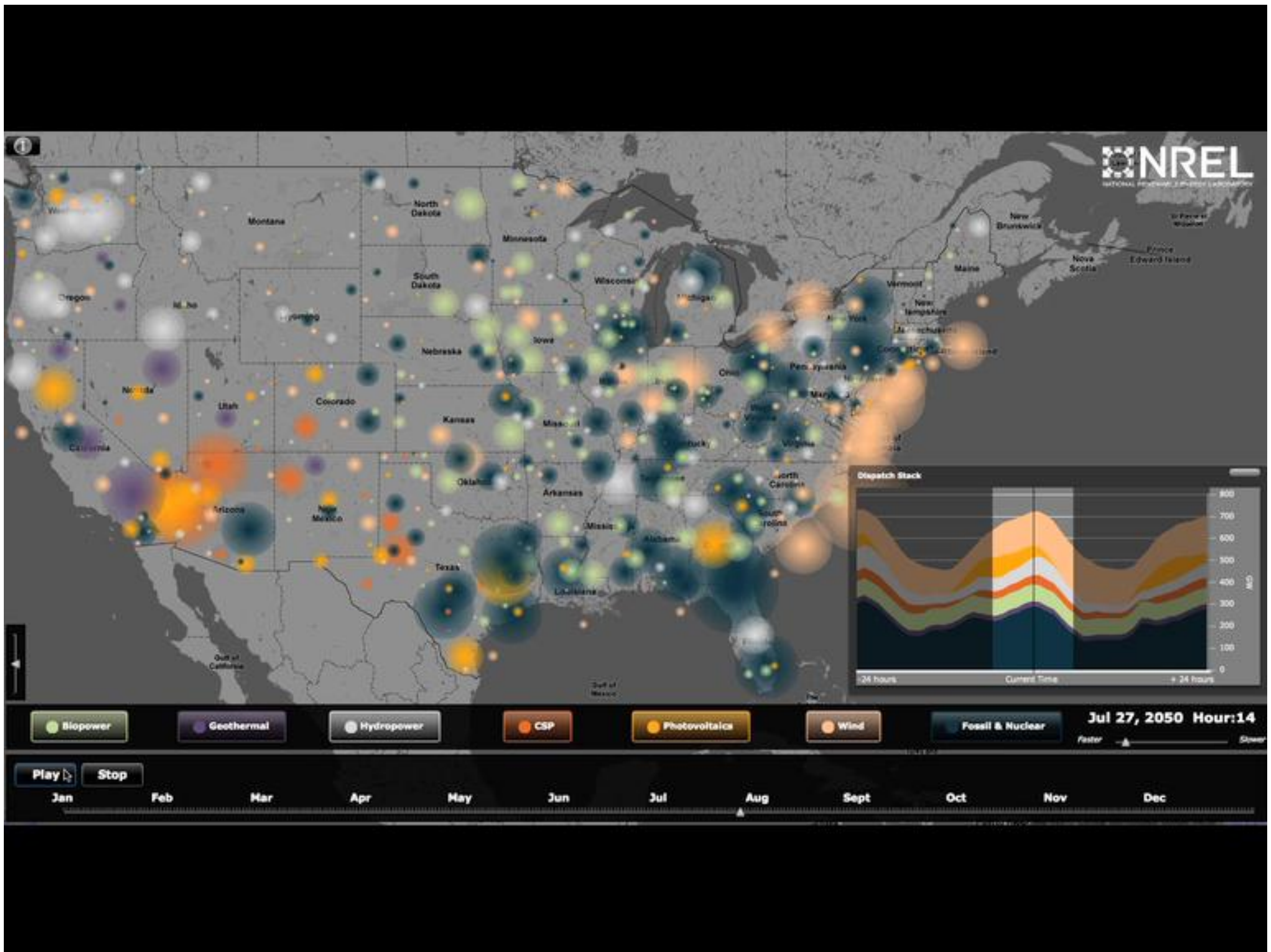
NREL Renewable Electricity Futures Study Capacity Expansion Scenario Model – 80% RETs



Understanding Institutional Options: Insights from the Low Carbon Grid Study (CA)

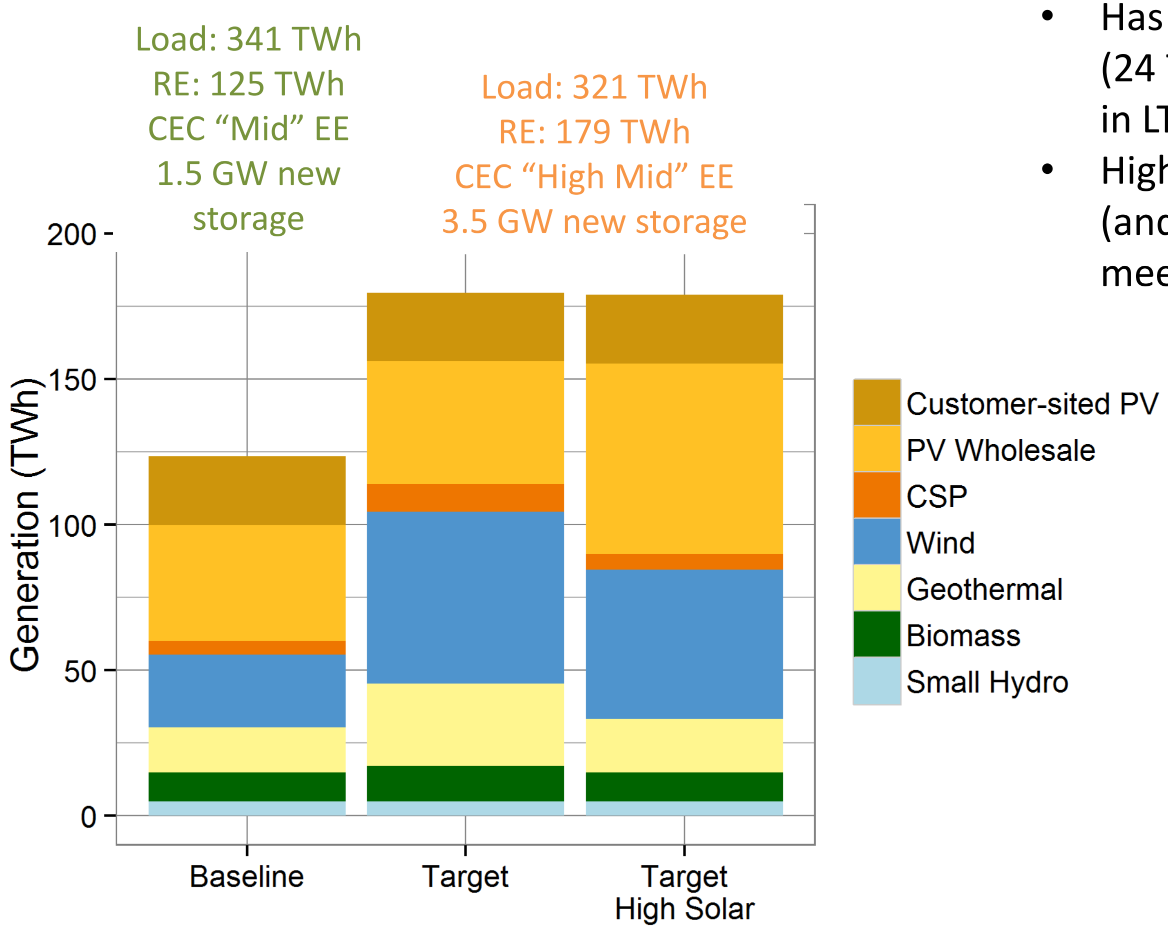
Premise

This study, the *California 2030 Low-Carbon Grid Study* (LCGS), sets out to answer questions about the feasibility of achieving a cost-effective, reliable, and highly decarbonized electric sector in California, in the year 2030 (mid-term to 2050 goals).

Objectives

- Provide an economic assessment of the impact of reducing California's electric sector emissions 50% below 2012 levels by 2030.
- Provide an analysis of integration issues that could arise from the high penetrations of renewables employed to achieve this reduction.
    - Perform sensitivity analysis to understand the drivers behind these challenges (and potential solutions)
- Provide an estimate of potential curtailment under deep reductions scenarios.

Renewable portfolios in each case



Baseline Case is similar to LTPP 2014 33% Case

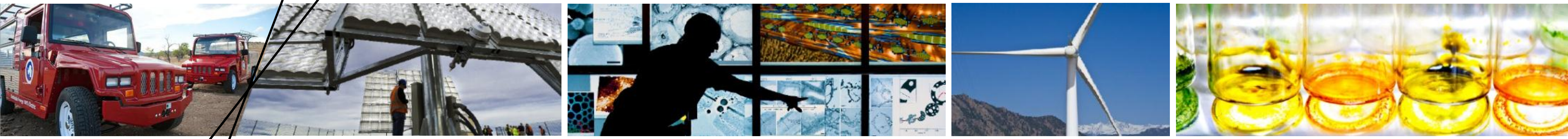
- Has higher penetration of rooftop PV (24 TWh in LCGS compared to 7.7 TWh in LTPP)
- Higher overall load to represent 2030 (and higher PV penetration to continue meeting RPS)

Modeling done using PLEXOS unit commitment and dispatch tool

Grid Flexibility Assumptions

Conventional flexibility	Enhanced flexibility
70% of out-of-state (CA-entitled) renewable, nuclear, and hydro generation must be imported	Only physical limitation on imports and exports
25% of generation in California balancing authorities must come from local fossil-fueled and hydro sources	No minimum local generation requirements
1.5 GW battery storage to meet CPUC requirement	1.5 GW battery storage, 1 GW new pumped hydro, and 1.2 GW new out-of-state compressed air energy storage
Limits on ability of hydro and pumped storage for providing ancillary services (AS provision from hydro tuned to CAISO 2013)	Less strict limits on hydro and pumped storage for providing ancillary services

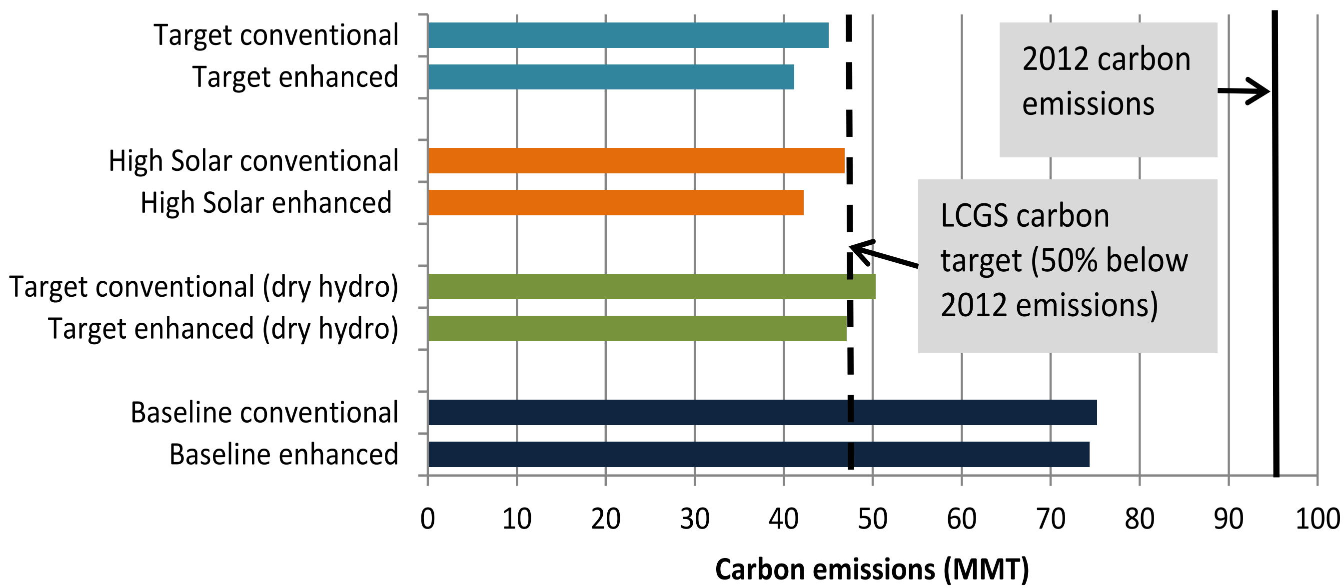
- It was interesting to test this “suite” of assumptions because the impact of two flexibility constraints can be much larger than the sum of individual impacts



Key Results from Low Carbon Grid Study

California can achieve a 50% reduction in CO2 levels by 2030 in the electric sector under a wide variety of scenarios

- Emissions vary based on portfolio and institutional framework/flexibility
- All scenarios meet 50% carbon reduction target except dry hydro with conventional grid flexibility assumptions



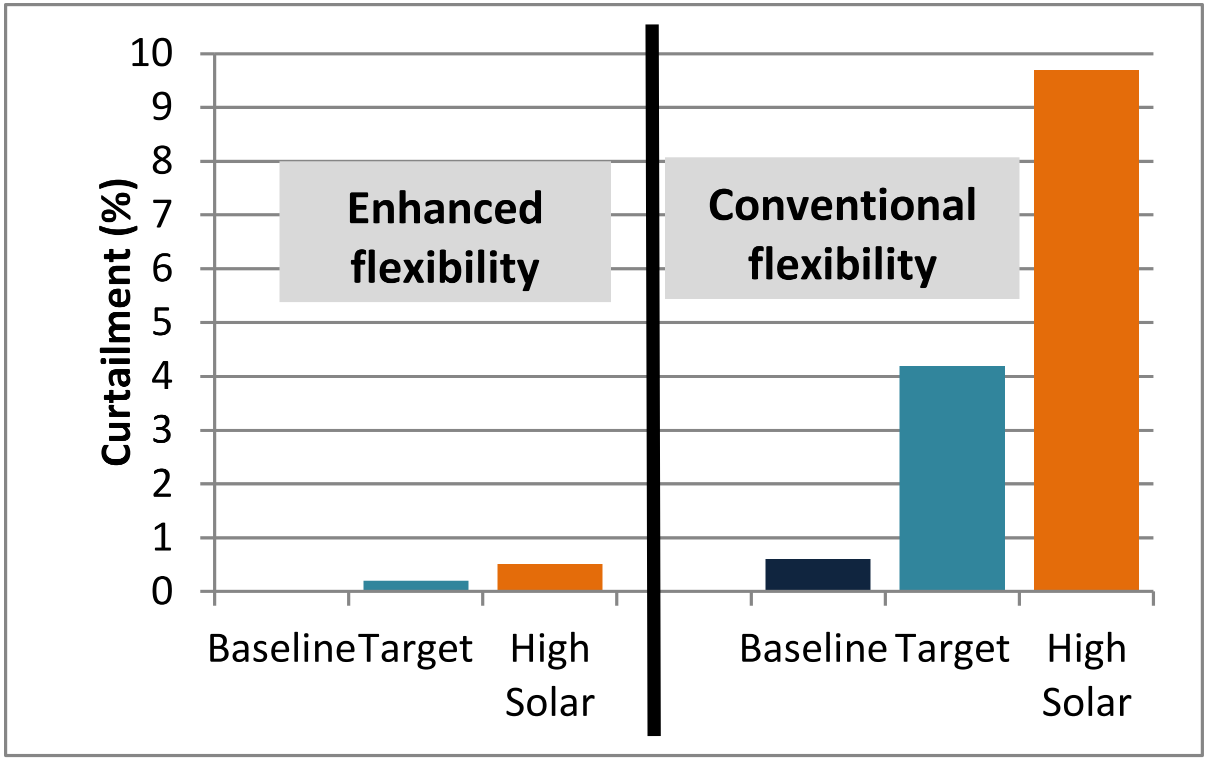
The value of renewable energy and energy efficiency depends on the rest of the system and the institutional framework

- Reduction in production cost (not including capital costs) compared to Baseline Enhanced Flexibility scenario

Portfolio	Conventional flexibility	Enhanced flexibility
Baseline	-$65m	0
Target	$4,300m	$4,850m

- Conventional grid flexibility increases costs by $65m in Baseline portfolio but $550m in the Target portfolio
- Gas price ~$7/mmbtu

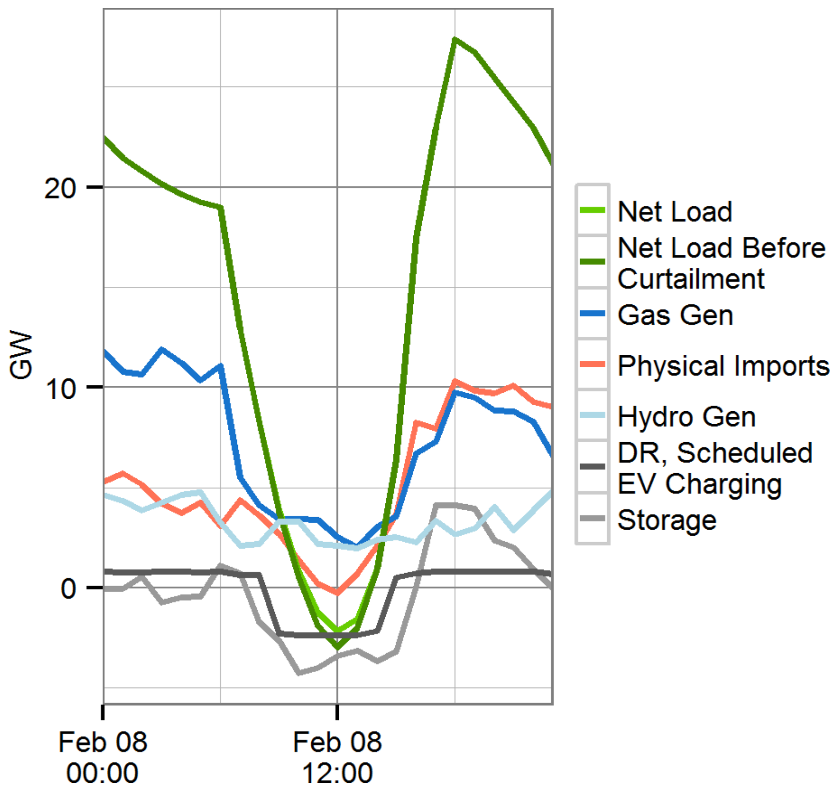
Curtailment in a low carbon grid could be less than 1% or nearly 10%, depending on the institutional framework and portfolio of technologies



- Combination of 25% local generation requirement and 70% import requirement drives curtailment (along with less diverse portfolio)

A variety of technologies provide flexibility during difficult operating periods

Dispatch of key categories during steepest net load ramp of the year



Technology	**MW ramp between 3 and 4 pm**
Physical imports	4550 MW
Storage	3230 MW
Gas fleet dispatch	3150 MW
Demand response (mostly schedulable electric vehicle charging)	240 MW
Hydro generation dispatch	-250 MW

Distribution of ramping resources is different during other steep ramps, but the same 5 resources are key

Good Data Informs Good Policy: Regional Integration Studies

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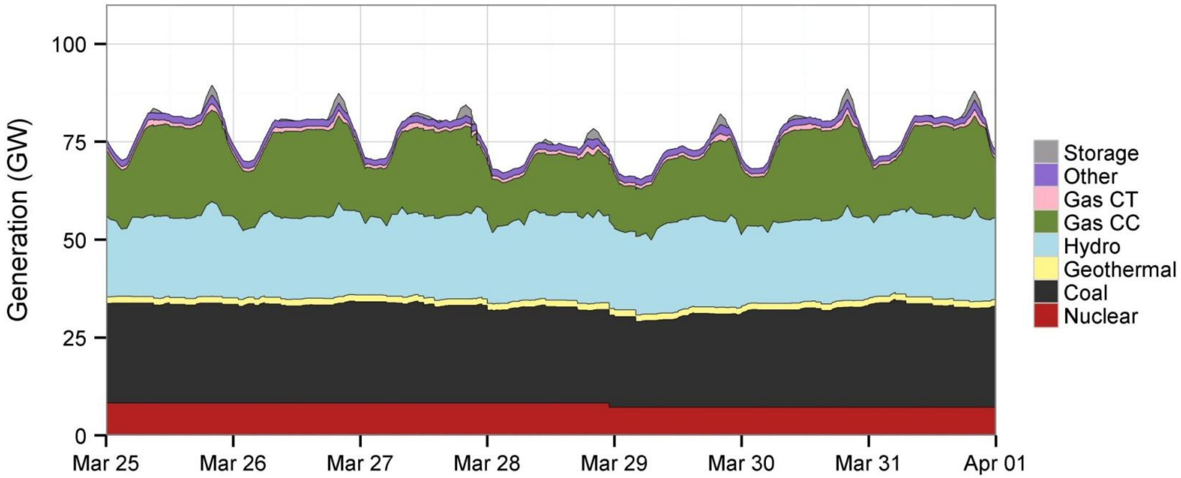
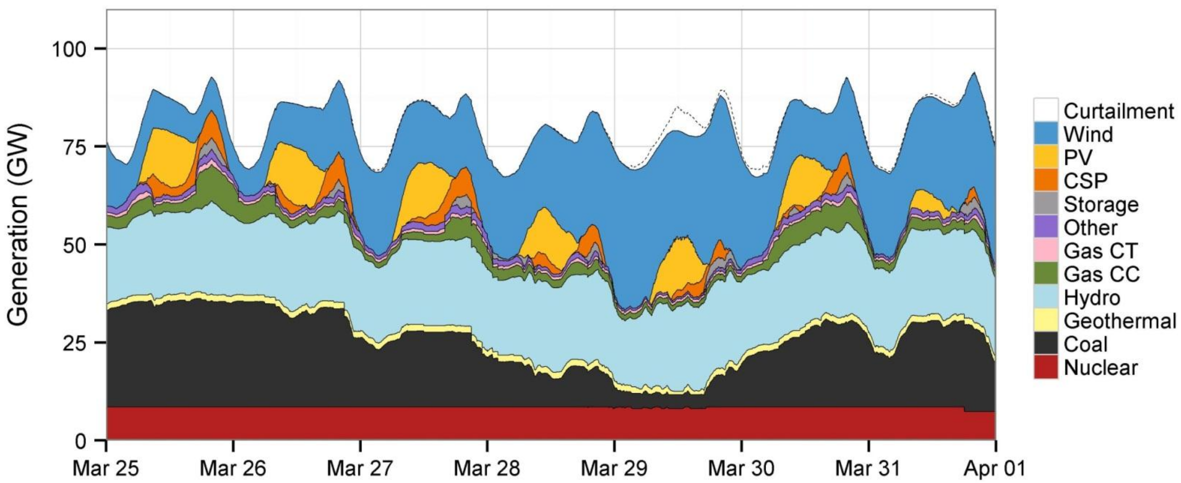
Western Wind and Solar Integration Study (WWSIS)

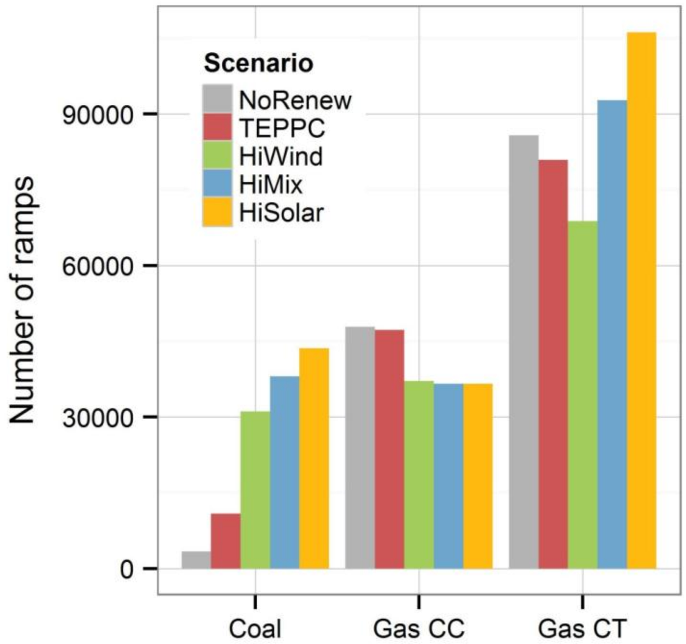
0% wind and solar



33% wind and solar

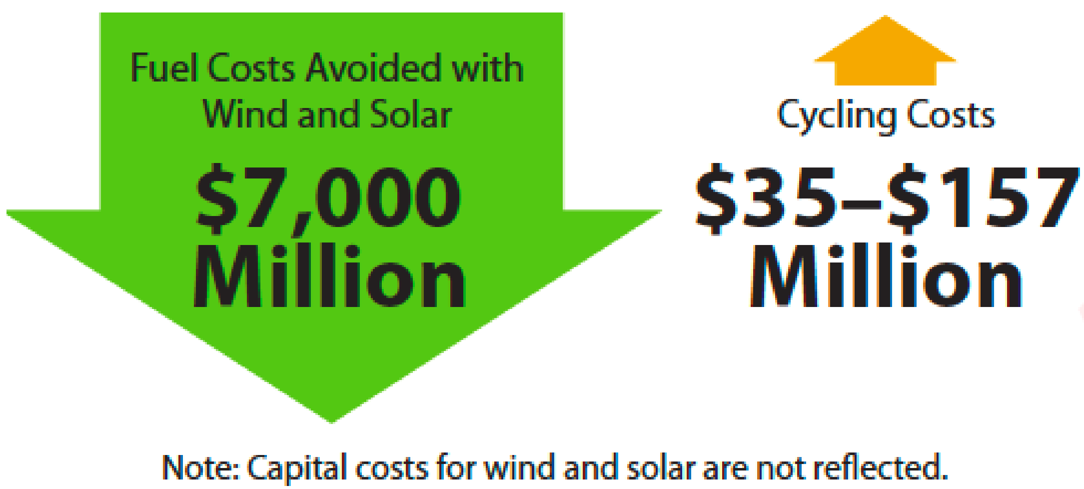


Good Data Informs Good Policy: Regional Integration Studies



Biggest cycling change is the coal units are ramped 10 times more in the 33% cases compared to the 0% case

Western Wind and Solar Integration Study (WWSIS)



From a system perspective, cycling costs are relatively small

33% Wind/Solar scenarios

IMPLICATIONS FOR CURRENT ASSETS

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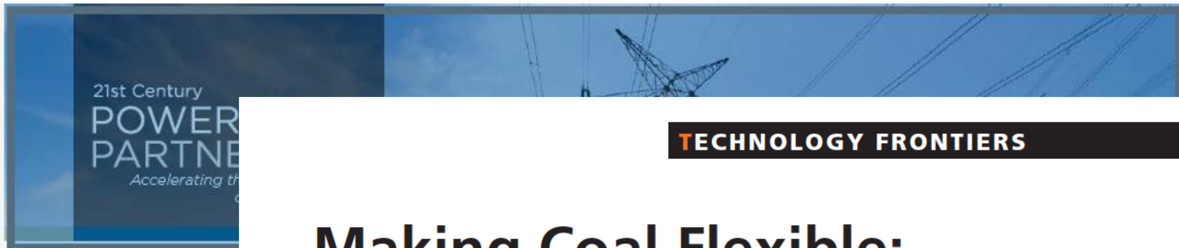

Flexib
Evolution
The experience cit
to here as the CGS
Jaquelin Cochran,[a]
[a] National Renewable E

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TECHNOLOGY FRONTIERS

Making Coal Flexible:
Getting From Baseload to Peaking Plant

By Jaquelin Cochran
Senior Energy Analyst,
National Renewable Energy Laboratory (NREL)

Debra Lew
Independent Consultant

Nikhil Kumar
Director of Energy & Utility Analytics, Intertek

We have used a case study of this CGS to evaluate how power plants intended to run at baseload can evolve to serve other system needs. The CGS case illustrates the types of changes that may occur in global power systems, especially those with legacy plants. CGS's experiences challenge conventional wisdom about the limitations of coal-fired power plants and help policymakers better understand how to formulate policy and make investment decisions in the transformation toward power systems in a carbon-constrained world.

"Strategic modifications, proactive

Power systems in the 21st century—with higher penetration of low-carbon energy, smart grids, and other emerging technologies—will favor resources that have l
costs and provide system flexibility (see Figure 1).
ity includes the ability to cycle on and off as well a
minimum loads to complement variations in outp
penetration of renewable energy. With a lack of ge
ence in the industry, questions remain about bot
coal-fired power plants in this scenario and whet
continue to operate cost-effectively if they cycle ro

To demonstrate that coal-fired power plants can b
ble resources, we discuss experiences from an actu

技术前沿 TECHNOLOGY FRONTIERS

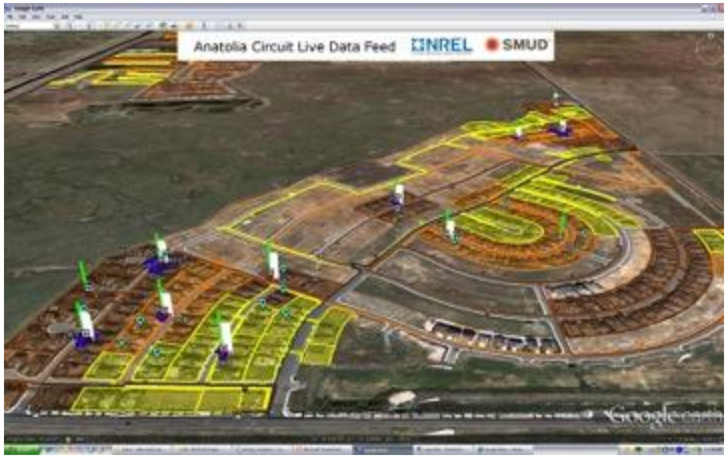
提高燃煤电厂弹性：从基荷电力到调峰电力

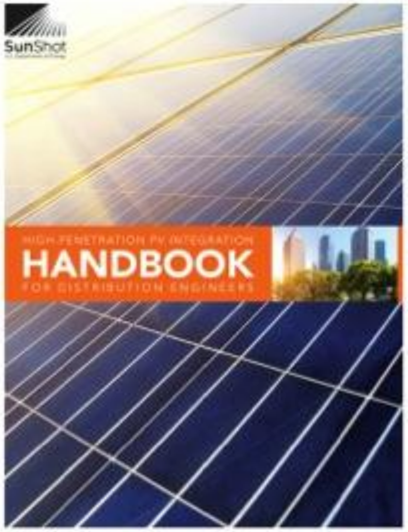
杰奎琳・科克兰（Jaquelin Cochran），美国国家可再生能源实验室（National Renewable Energy Laboratory）高级能源分析师
黛布拉・卢（Debra Lew） 独立咨询师
尼基尔・库马尔（Nikhil Kumar） 天祥集团（Intertek）能源及公共事业分析部总监

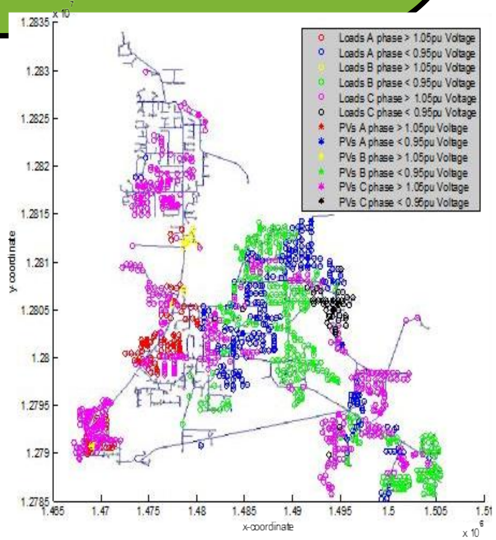
Distribution Planning Studies

- Implications of Future Advances in Distributed energy resources (DERs): Solar, Wind, electric vehicles, buildings, etc.
- Blending commercial analysis packages (e.g. CyME, Synergi, DEW, Windmil) with open source and NREL developed tools.
- Past and existing projects with: Duke Energy, SCE, So Cal Gas, SDG&E, PG&E, SMUD, APS, HECO, National Grid, Xcel Energy, Pepco, ConEd, EPRI, CPUC, et al.

KEY APPLICATION:
Southern California Edison (SCE) High Penetration Solar PV Integration Project
NREL staff partnered with SCE to install 500 MW of utility-scale distribution-connected PV and to develop new best practices for utility planning engineers and developing methods to mitigate impacts using advanced inverters; HECO new DG PV Inverter specs…



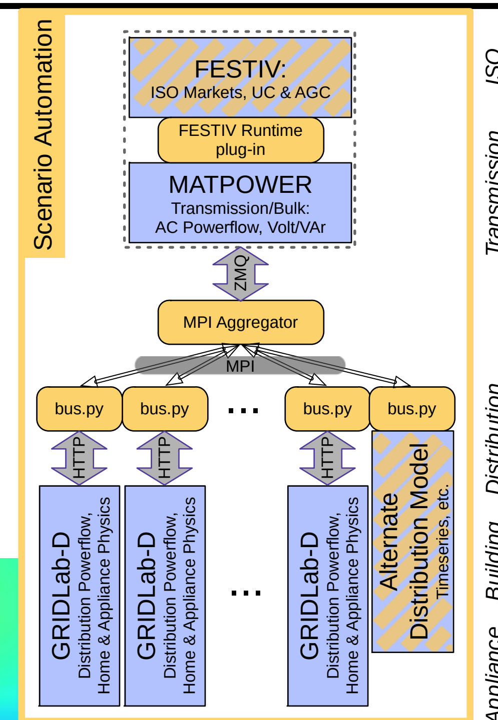




Integrated T&D Grid Modeling System (IGMS)

Summary

A next-generation analysis framework for full-scale transmission & distribution modeling that supports millions of highly distributed energy resources.



End-to-End T&D Modeling Capability

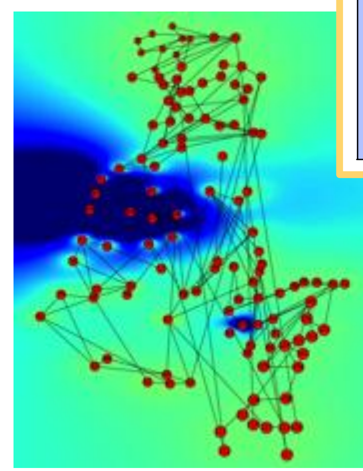
- **Generation:** Energy/reserve dispatch
- **Transmission**: AC Powerflow (bulk transmission)
- **Distribution**: Full power flow for 100s-1000s of distribution feeders
- **End-use**: Models of buildings, end-use loads, DERs

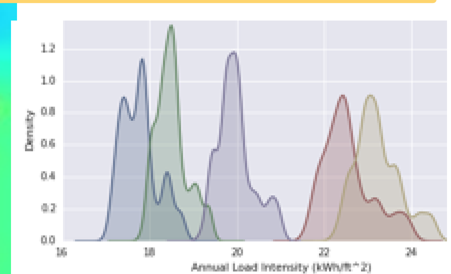
Example Applications

- Analyze distributed PV support for grid operations
- Simulate smart grid, storage, and demand response

Highlights

- **Successful Medium Scale Run(s): 118 Transmission buses, 743 Distribution Feeders, >1M total buses, >600k homes**

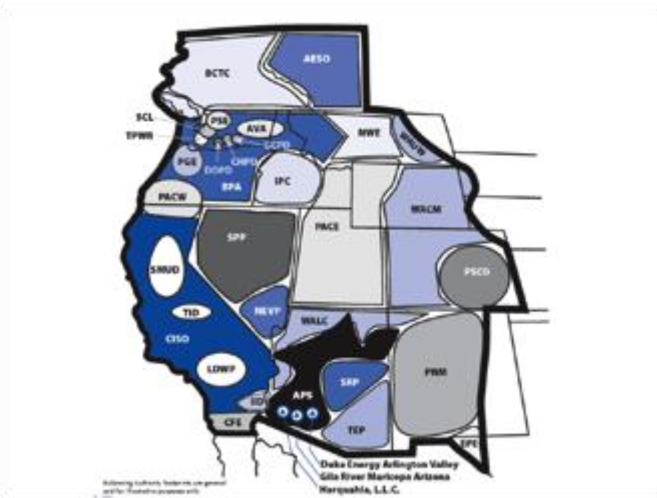


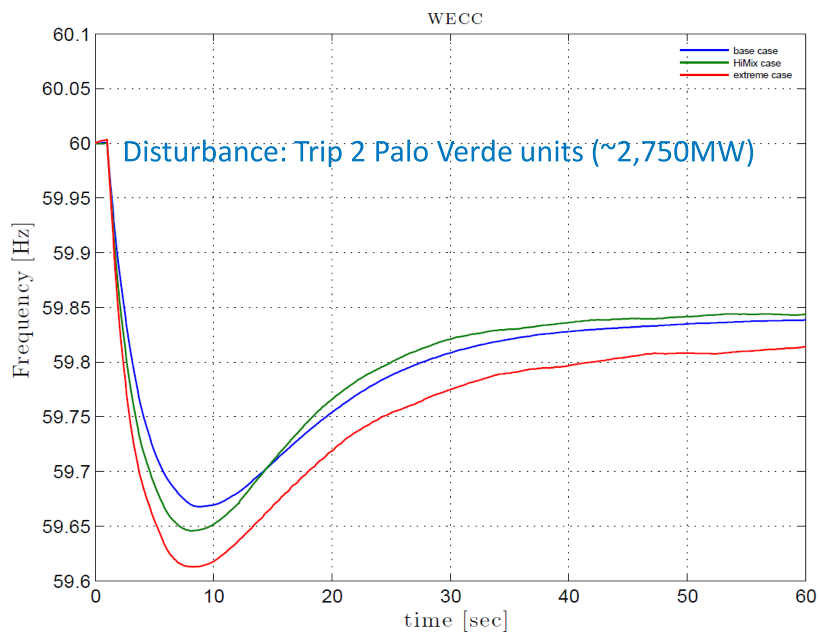


NREL's Integrated Grid Modeling System (IGMS) provides a first-of-a-kind co-simulation with transmission-level systems, 1000s of distribution feeders, and 1Ms of DERs

WWSIS- Phase 3: Frequency Stability

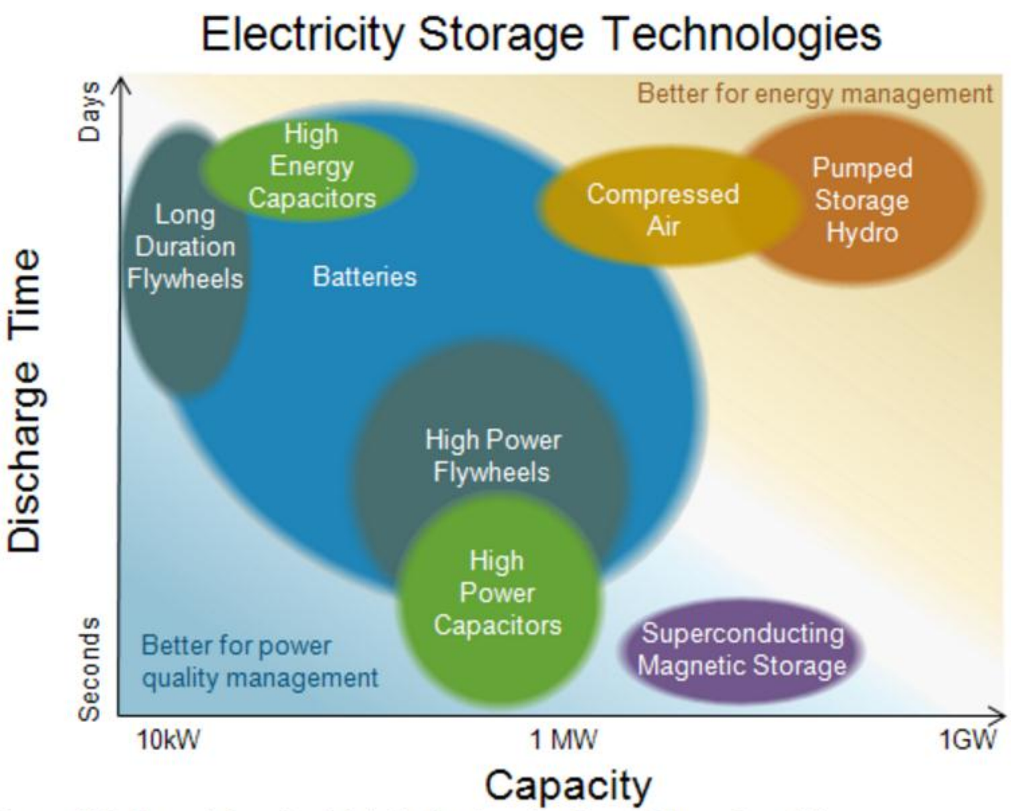
- **What is the impact of high penetration wind and solar on specific aspects of reliability of the Western Interconnection?**
  - **i.e. "will the system successfully serve customer loads for the first minute after a big disturbance"**
- **What mitigation means are effective in addressing any adverse impact?**





Interconnection frequency response > 840 MW/0.1Hz threshold in all cases. No under-frequency load shedding (UFLS).

Planning Considerations for Storage



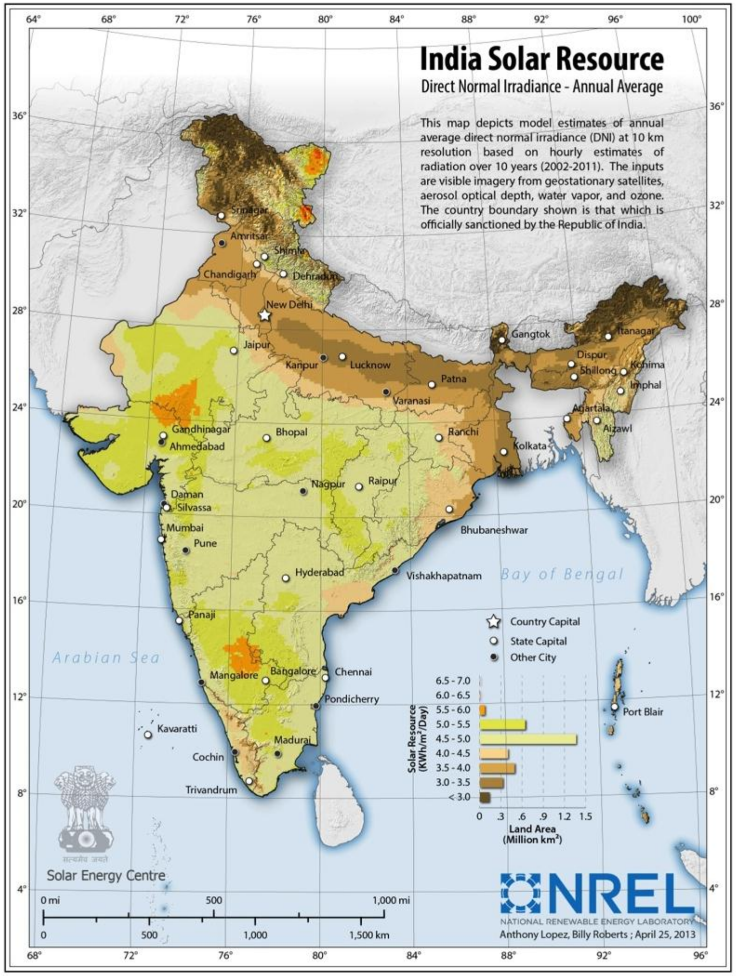
Source: U.S. Energy Information Administration, based on Energy Storage Association.

Shipping containers filled with lithium batteries on Kauai, Hawaii USA
(Source: *Technology Review* 2015)

21CPP Partner Examples: India's 2022 100 GW Solar Goal Requires an Evolution in Power System Planning

21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems

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

Energy Reform in Mexico Triggers Shifts In Planning

21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems

- Energy Sector Reform in 2014
- New independent system and market operator (CENACE)
- Creation of independent regulator (CRE)
- Retention of strong central government role for power sector planning

SUMMARY

- Credible, objective, science based analysis can inform planning decisions.
- Data is critical
- State of the art knowledge is a “must have”
- Institutional Frameworks are as important- or more—than technology innovation
- A robust stakeholder process builds confidence in the data, methods and outcomes
- Leveraging best practices offers real opportunity for expeditious adoption and learning.

Support for Power System Planning: Technical and Policy Assistance

Provides **technical assistance** to countries – modelling, road-mapping, integration

Knowledge development & sharing – report publication and dissemination

Organizes **global networks of expertise** – such as today's program

Supports governments in developing **policy, program and finance solutions** for clean energy deployment

Ask-an-Expert – **no-cost, tailored assistance** from global experts

PowerAfrica partnership - **targeted support for sub-Saharan African** countries

THANK YOU

Dr. Douglas Arent

National Renewable Energy Laboratory

Doug.Arent@nrel.gov