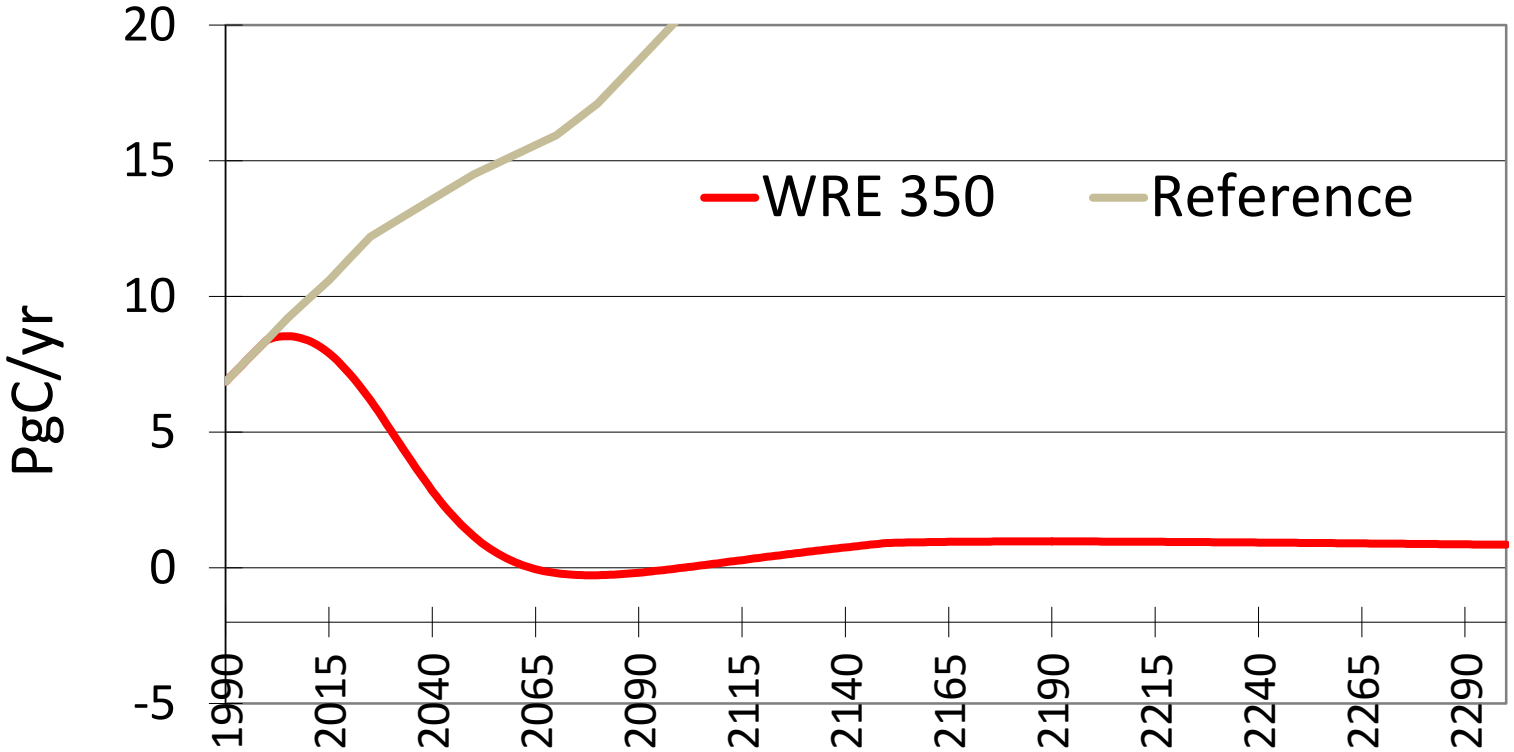
AN ULTRA-LOW LOW CARBON FUTURE:

THE IMPORTANCE OF ZERO CARBON BASELOAD AND DISPATCHABLE POWER

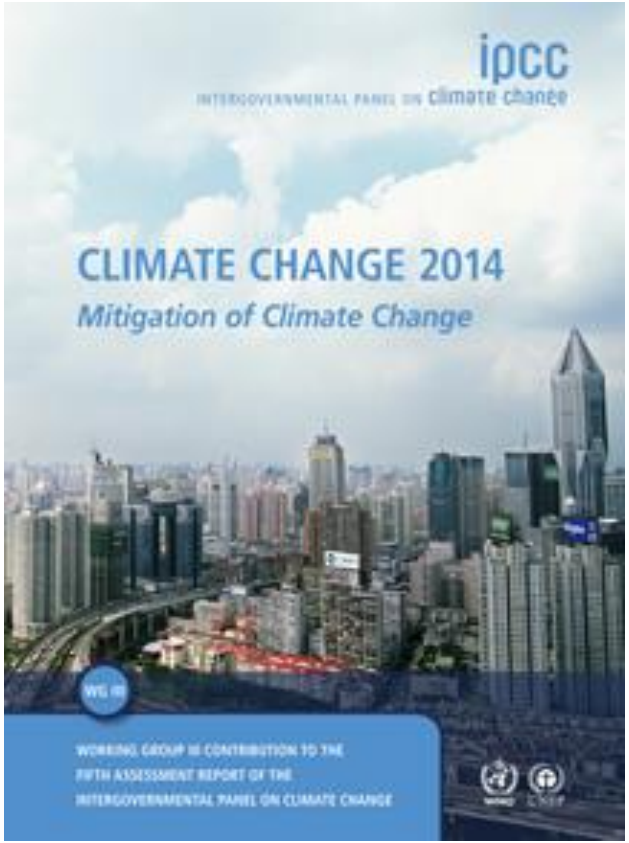
- STABILIZING CLIMATE MEANS ZERO EMISSIONS
- ZERO CARBON ON-DEMAND POWER SOURCES WILL LIKELY BE NEEDED
- FAILURE TO DEPLOY THEM COULD LEAD US TO DECARBONIZATION “DEAD ENDS”
- WE NEED TO TAKE ACTION TODAY TO CREATE BETTER, CHEAPER ON-DEMAND OPTIONS

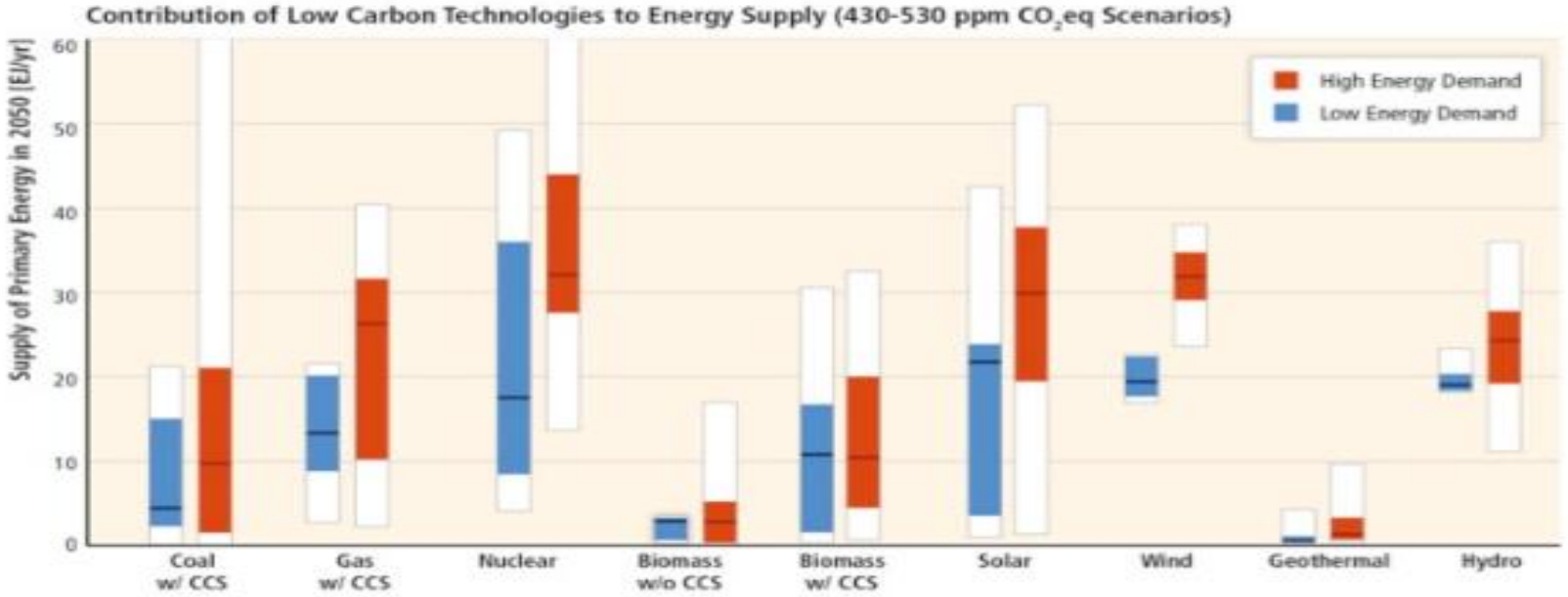
STABILIZING CLIMATE MEANS ZERO EMISSIONS



"No single mitigation option in the energy supply sector will be sufficient. Achieving deep cuts [in emissions] will require more intensive use of low-GHG technologies such as renewable energy, nuclear energy, and CCS."

-- IPCC, Assessment Report 5, Mitigation (2014)




Contribution of Low Carbon Technologies to Energy Supply (430-530 ppm CO_2eq Scenarios)
Supply of Primary Energy in 2050 (EJ/yr)
60
50
40
30
20
10
0
High Energy Demand
Low Energy Demand
Coal w/ CCS
Gas w/ CCS
Nuclear
Biomass w/o CCS
Biomass w/ CCS
Solar
Wind
Geothermal
Hydro


pathways to
deep decarbonization
2014 report
IDDRI

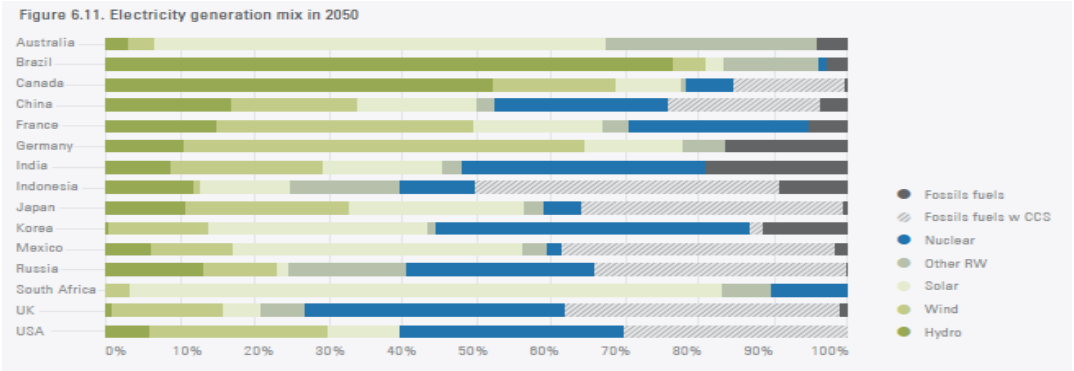
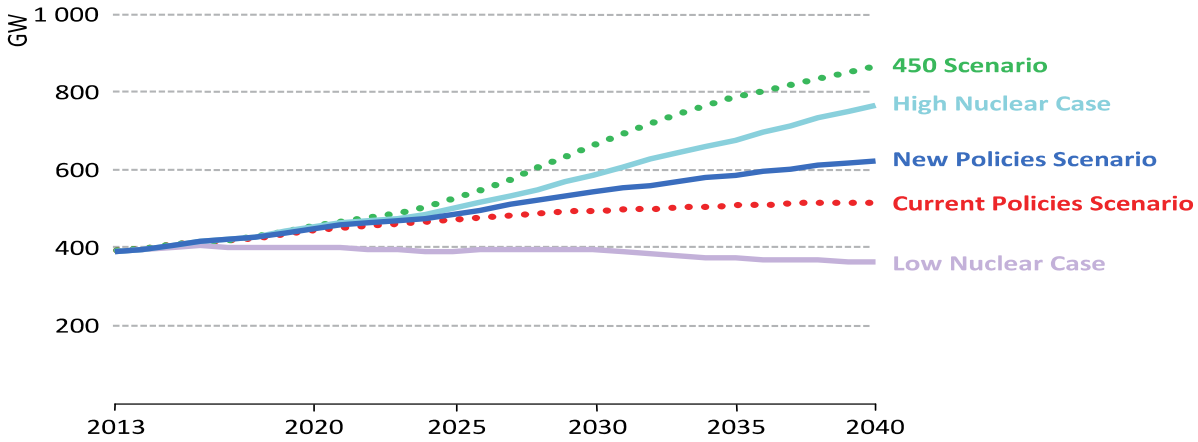


Figure 6.11. Electricity generation mix in 2050
Australia
Brazil
Canada
China
France
Germany
India
Indonesia
Japan
Korea
Mexico
Russia
South Africa
UK
USA
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Fossils fuels
Fossils fuels w CCS
Nuclear
Other RW
Solar
Wind
Hydro

International Energy Agency

Secure • Sustainable • Together



Intermittency

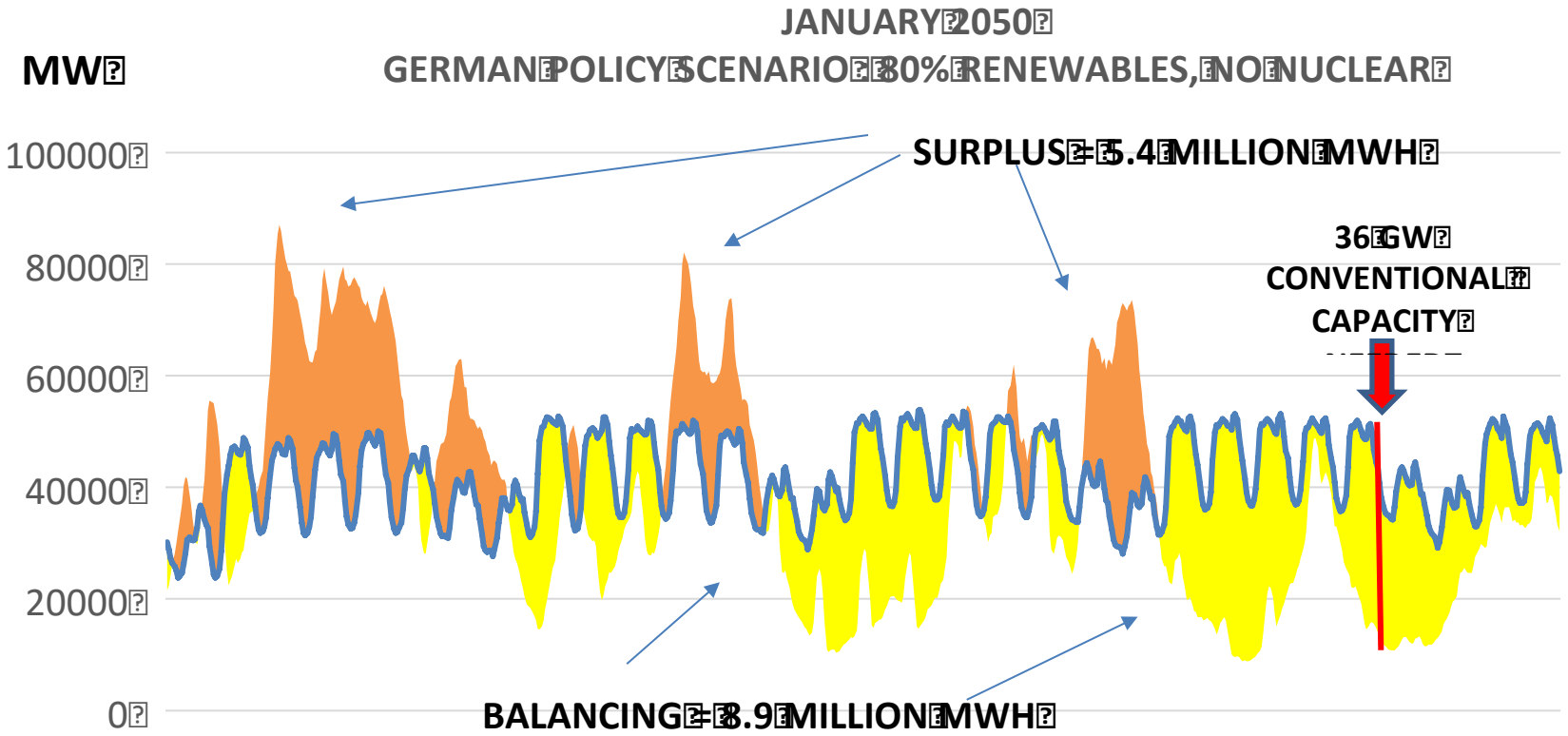
Conclusions from multiple studies

- High VRE systems are technically feasible but require significant dispatchable back-up capacity.
- This adds 50-100% to cost of decarbonization.
- Low cost storage, transmission and demand response do not FUNDAMENTALLY change the conclusion.
- This is due to large *weekly and seasonal variation* in VRE.
- High VRE systems have very big footprints, which may not be buildable or acceptable.
- ***Zero carbon baseload and dispatchable capacity (e.g. nuclear, decarbonized fossil) will likely be essential to deep carbon reductions.***

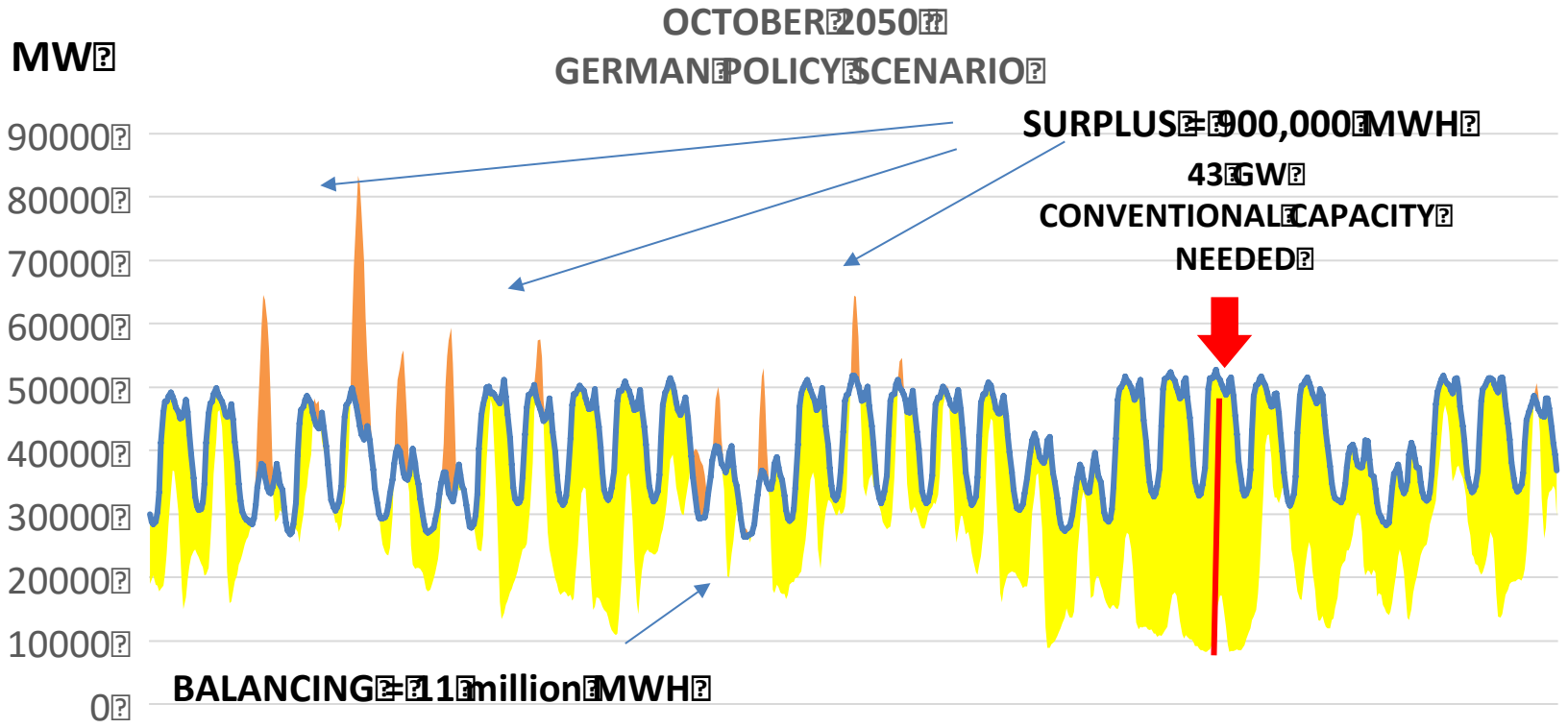
Germany case study

- Current German Policy
  - 80 GHG reduction below 1990 by 2050
  - 80 percent renewable electricity by 2050
  - 2050 electricity demand 25 percent below 2008
  - Accelerated nuclear phase-out by 2022

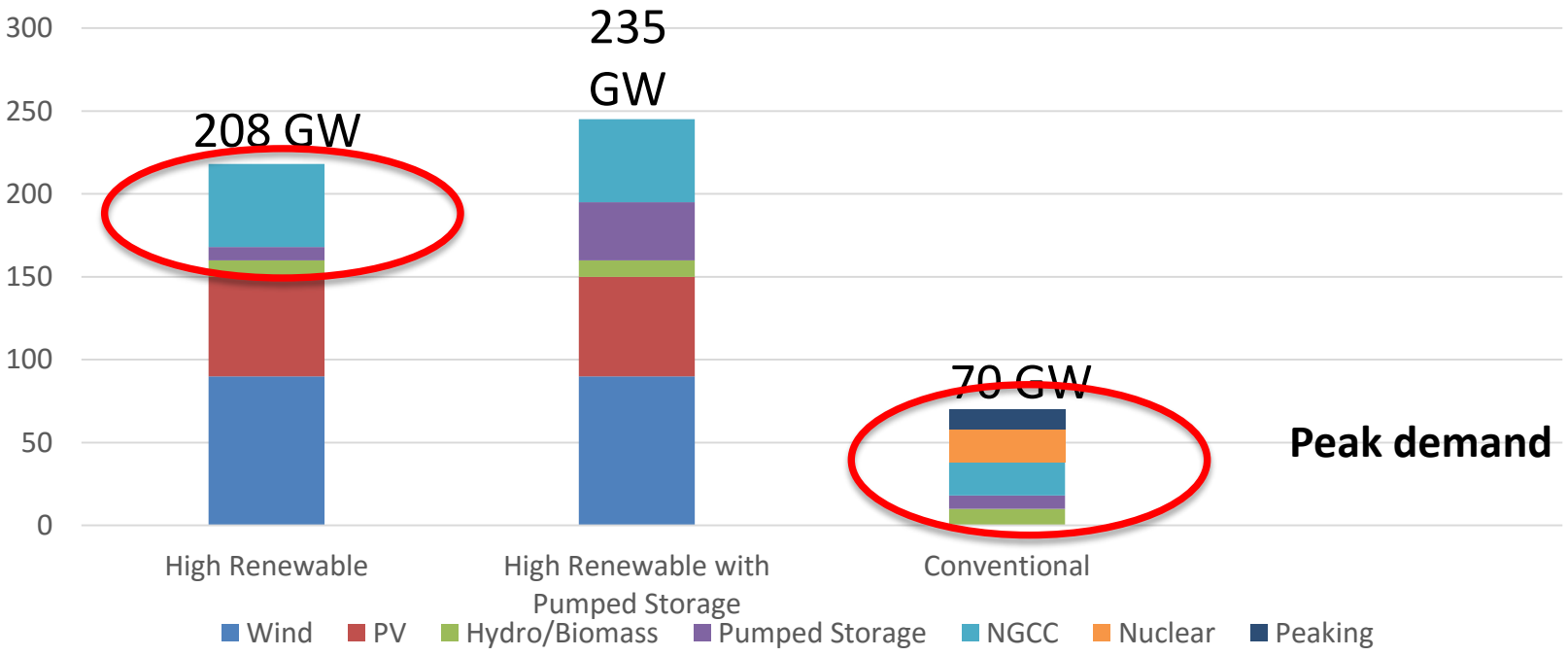
Modeled results: Jan. 2050

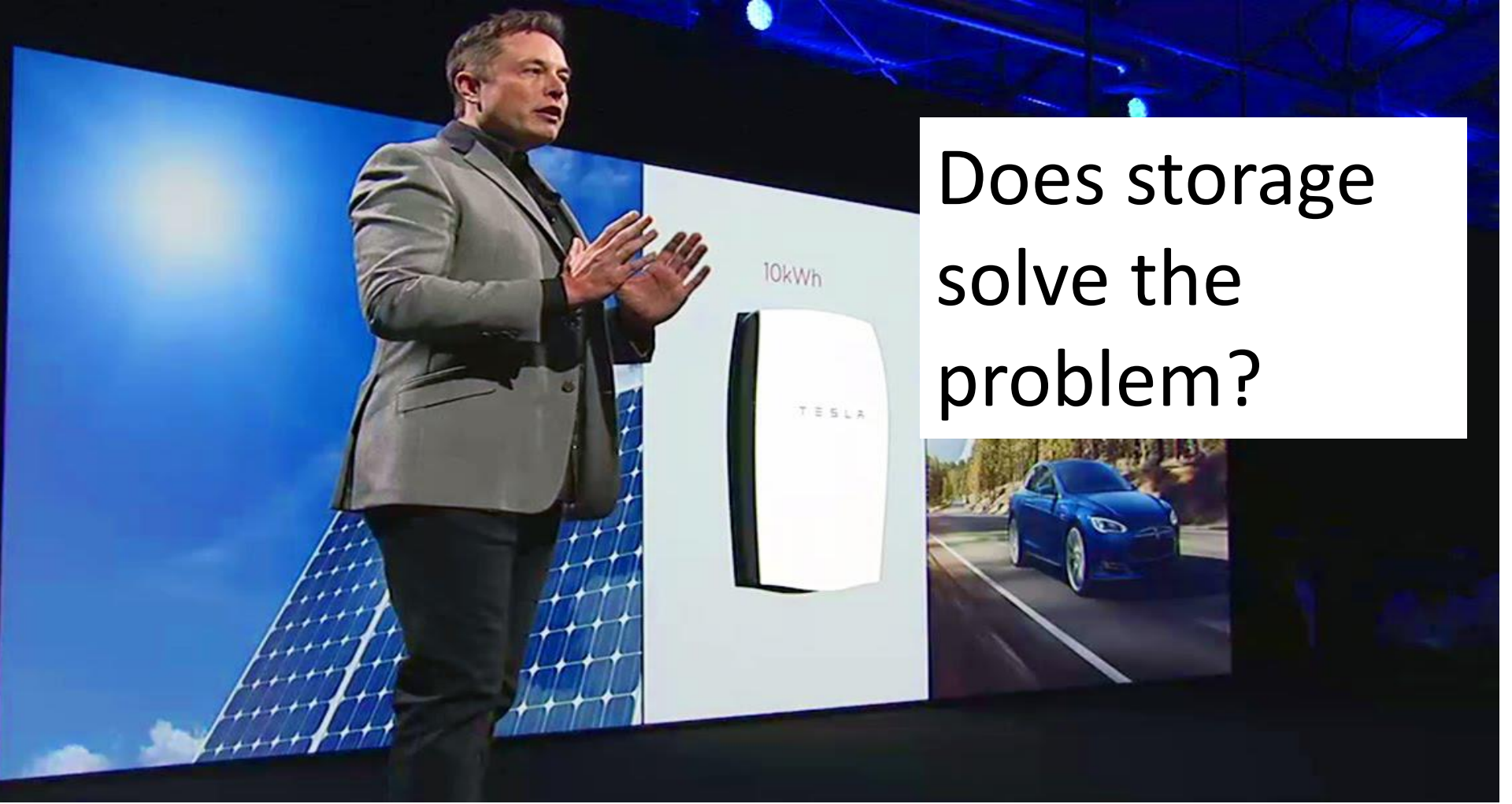


Modeled results: Oct. 2050



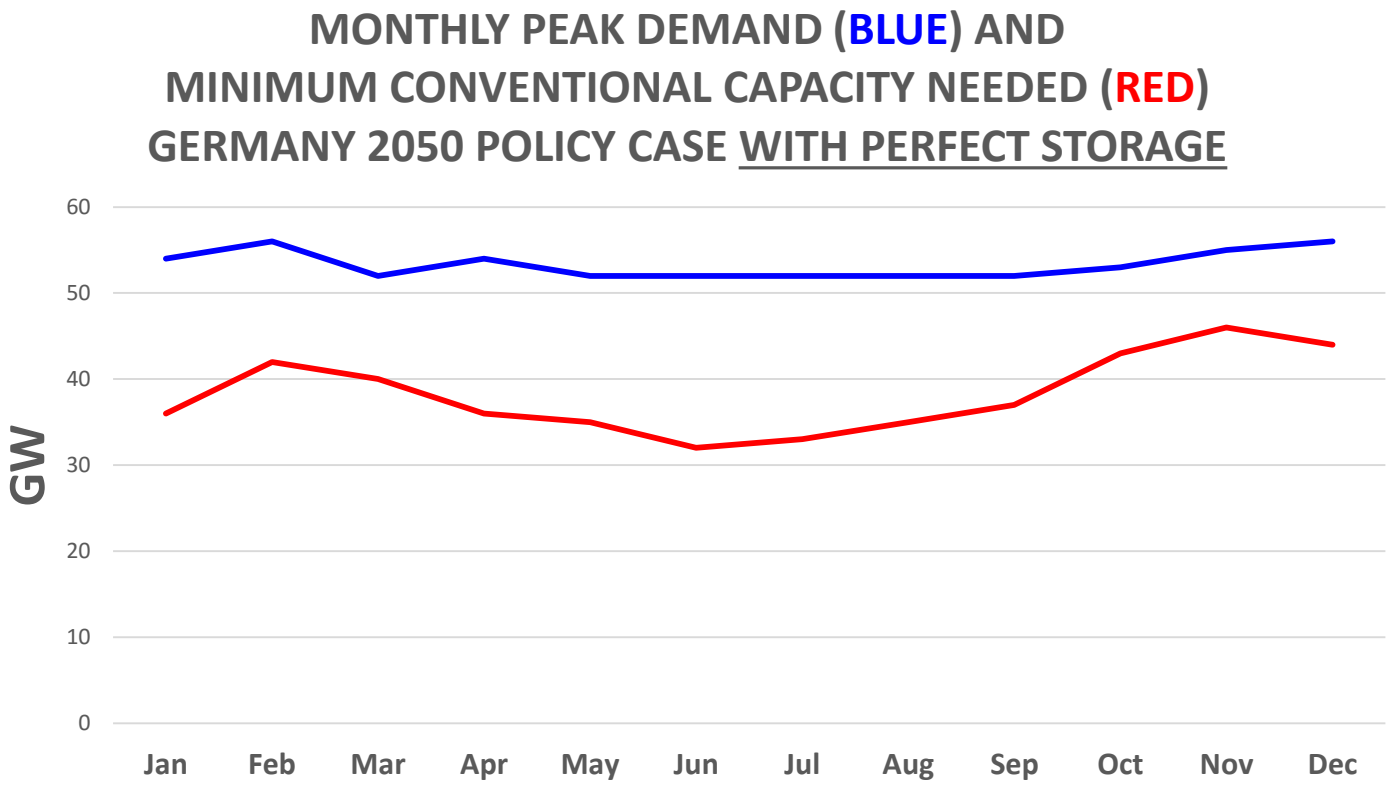
High VRE requires ~ same amount of non-VRE capacity as in low VRE case with nuclear





Does storage solve the problem?

Not really…..

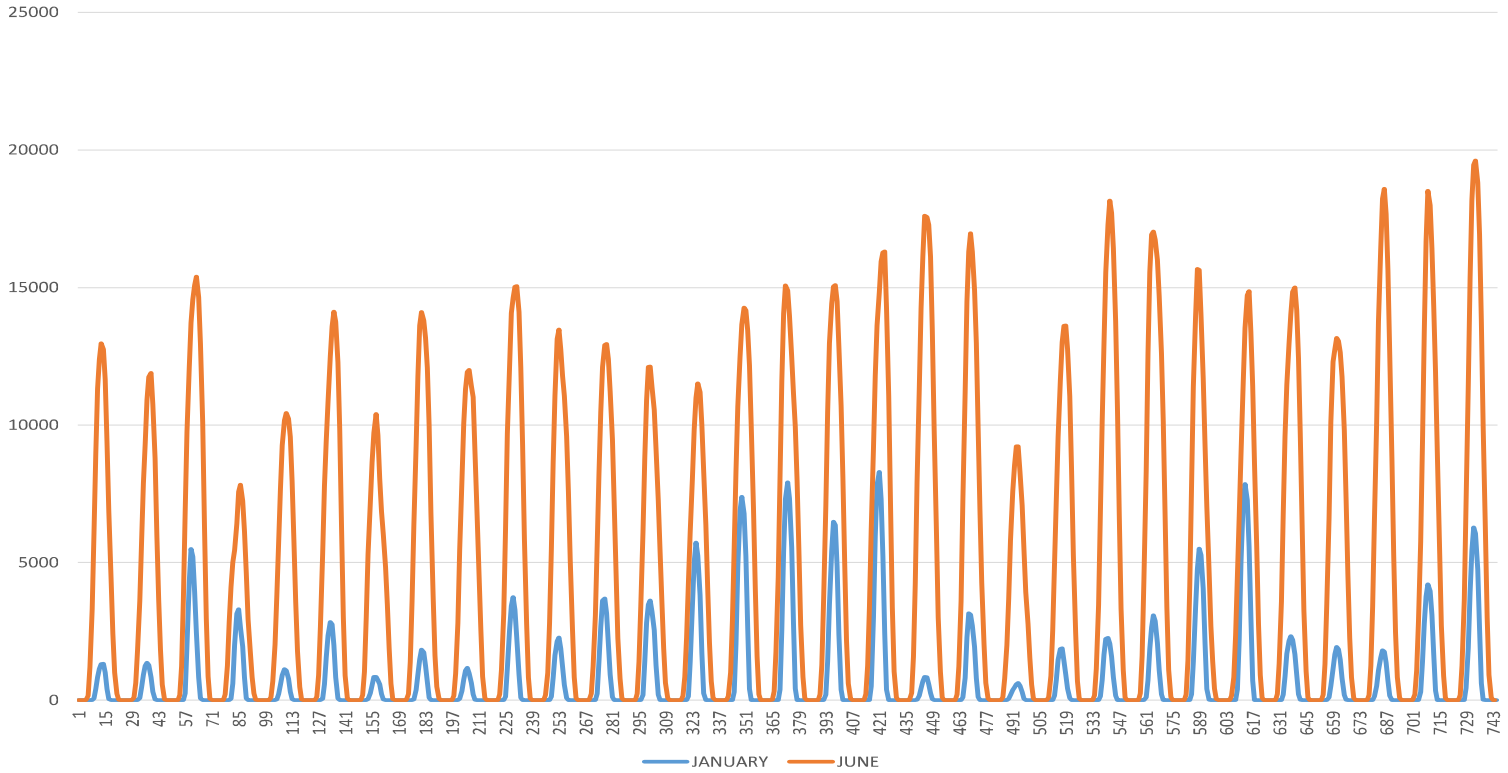

MONTHLY PEAK DEMAND (BLUE) AND
MINIMUM CONVENTIONAL CAPACITY NEEDED (RED)
GERMANY 2050 POLICY CASE WITH PERFECT STORAGE
GW
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

CLEANAIR TASK FORCE

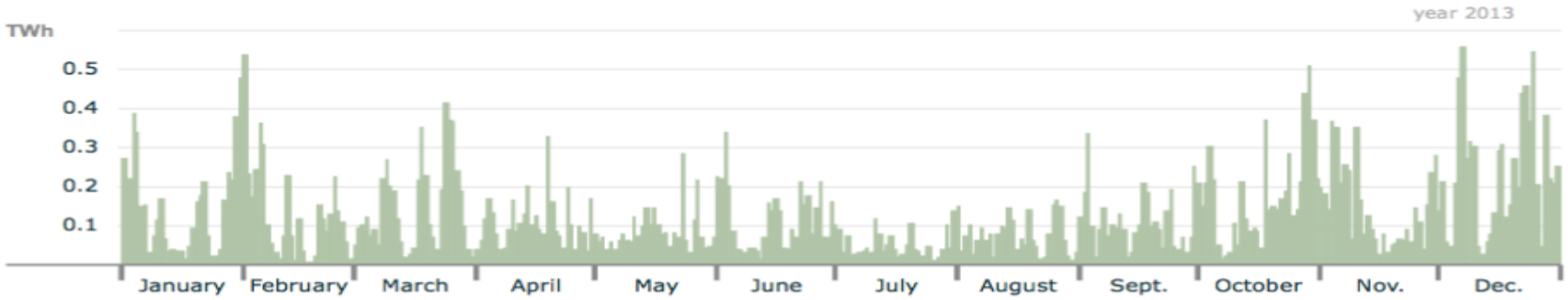
STORAGE CAN HELP ADDRESS ***DAILY*** FLUCTUATIONS

BUT DOES NOT SOLVE MULTI-WEEK AND SEASONAL VARIATION

GERMAN SOLAR VARIABILITY
JANUARY VS JUNE

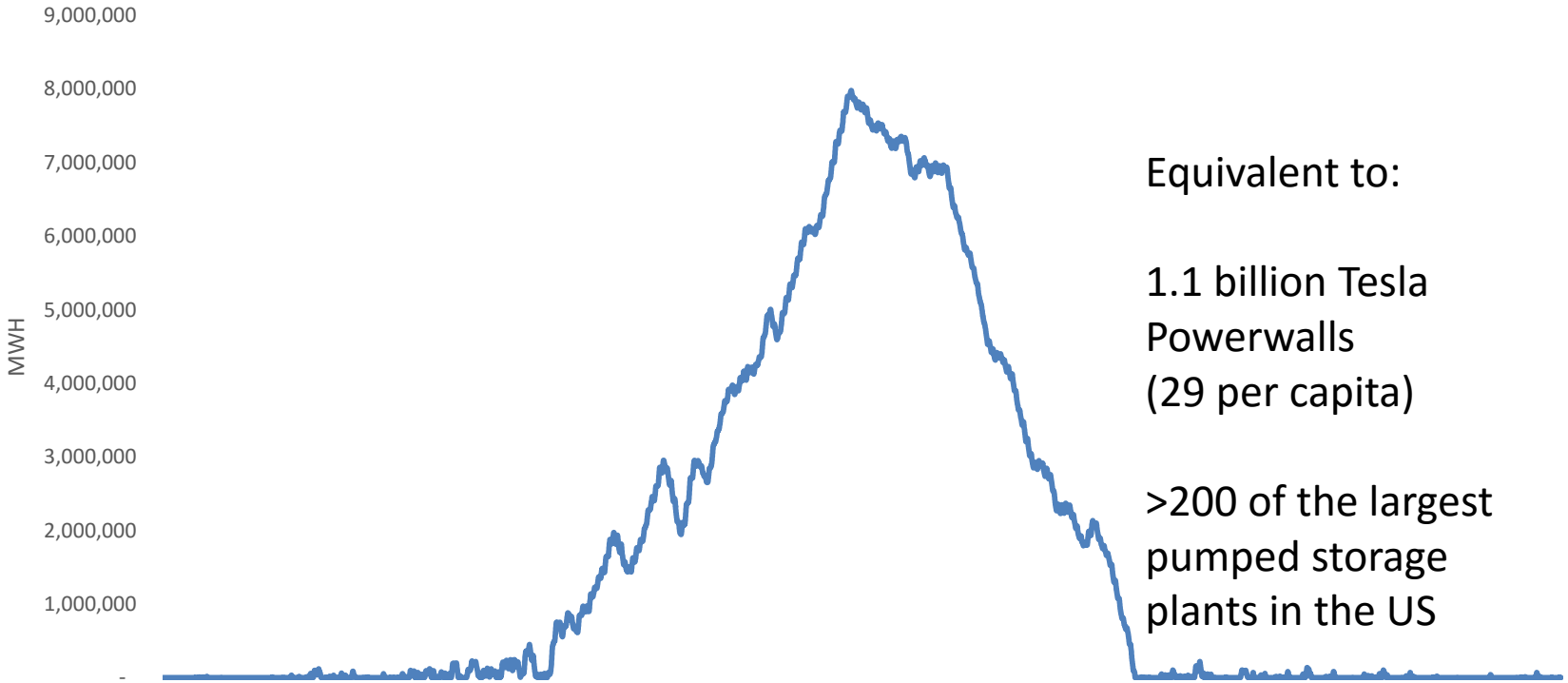


Daily Production Wind



CLEAN AIR TASK FORCE

CALIFORNIA CUMULATIVE SURPLUS
80 PERCENT RPS

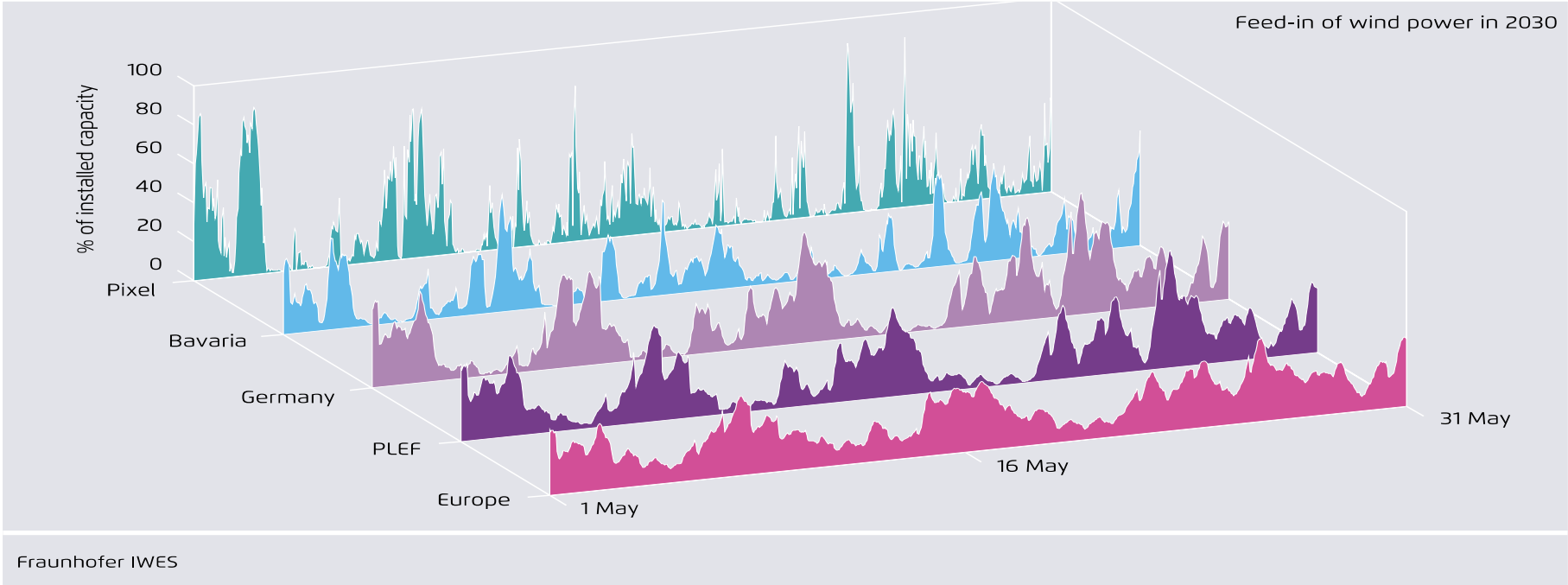


Equivalent to:

1.1 billion Tesla Powerwalls (29 per capita)

>200 of the largest pumped storage plants in the US

Transmission doesn't solve the problem



Simulated daily wind capacity factors across EU (May 2030)

“Demand response”

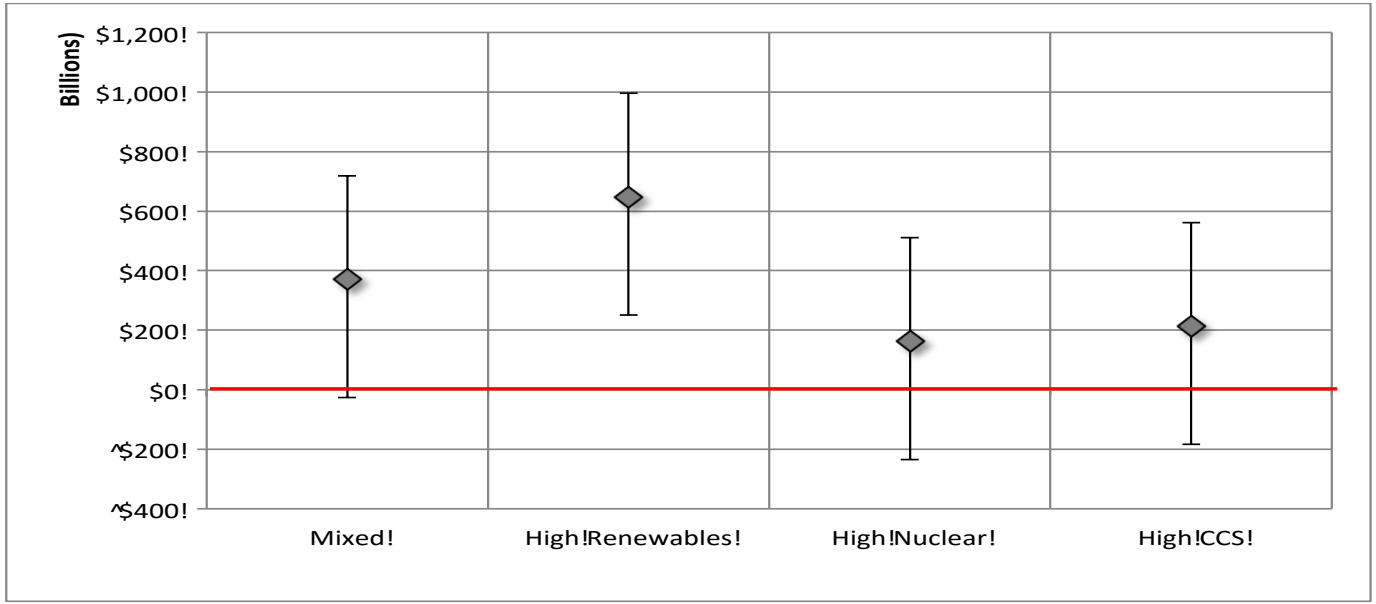
- Can substantial loads (e.g. industrial processes, heating and cooling, EV charging) be deferred ***over weeks or months***?
- Will major industrial capital investments be made to operate only at low capacity factor (i.e. at times when wind and sun surpluses are available)?

PJM DR 2009-2015

- Average curtailment 4 X per year
- Average duration = 3.5 hours
- Average annual total hours curtailed = 14 hours
- Average curtailment = 1% of peak
- How much far we extrapolate this to more hours, multi-day and week-long episodes?

Other analyses: UN DEEP DECARBONIZATION OF US

Figure 12. Incremental Energy System Costs in 2050



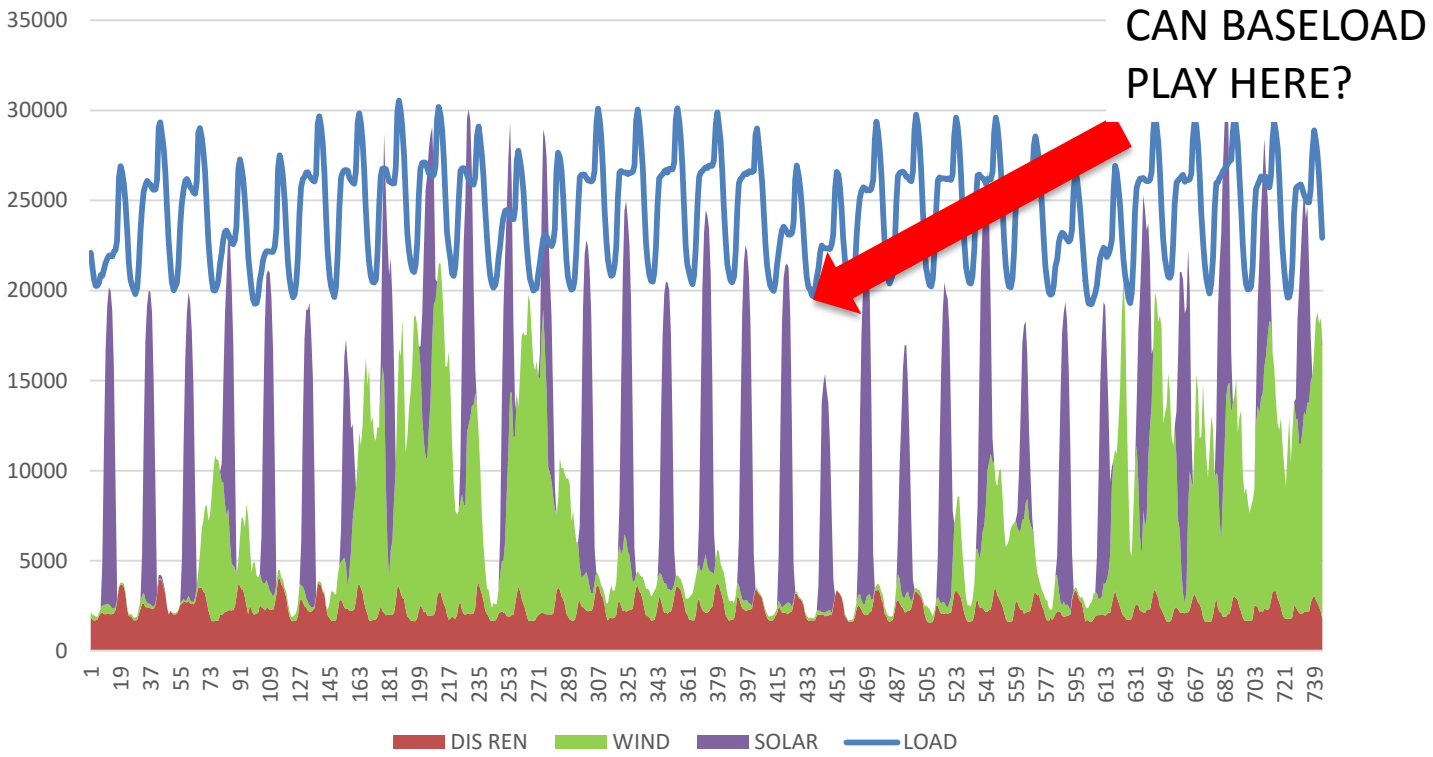
United Nations – IDDRI- Sustainable Solutions Network Deep Decarbonization Pathways Project – US Analysis (E3, LBL, PNNL, 2014)

CLEANAIR TASK FORCE

Even acknowledging the possible contribution of DSM, interconnectors and storage to firming up weather dependent renewables, a deep decarbonisation of the grid will need a significant penetration of zero carbon firm capacity.

DOES TOO MUCH INTERMITTENCY CREATE DECARBONIZATION DEAD ENDS?

JANUARY CALIFORNIA POLICY CASE
80 PERCENT RPS
70 PERCENT CO_2 REDUCTION



Scaling rates and buildout

Energy & Environmental Science

ROYAL SOCIETY OF CHEMISTRY

PAPER

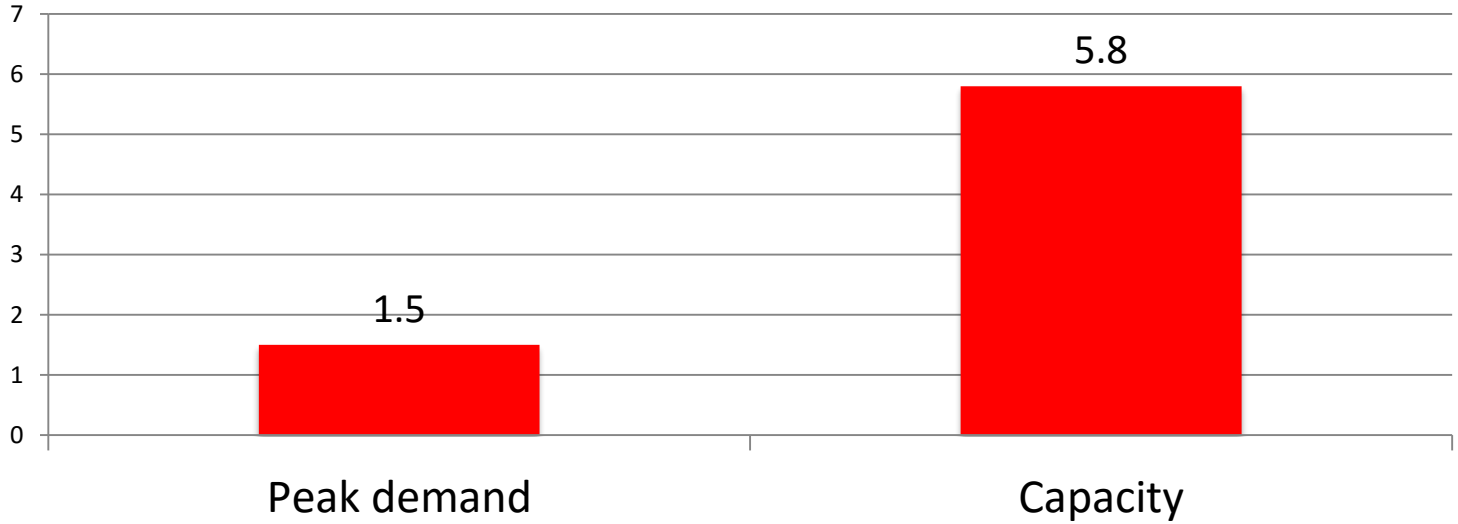
CrossMark click for updates

Cite this: *Energy Environ. Sci.*, 2015, **8**, 2093

100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States†

Mark Z. Jacobson,*[a] Mark A. Delucchi,[b] Guillaume Bazouin,[a] Zack A. F. Bauer,[a] Christa C. Heavey,[a] Emma Fisher,[a] Sean B. Morris,[a] Diniana J. Y. Piekutowski,[a] Taylor A. Vencill[a] and Tim W. Yeskoo[a]

Build out required (TW)



- 1,670 offshore wind farms the size of Cape Wind (92 per coastal state) AND
- 2,400 Tehachapi-size wind farms onshore (or about 50 per state) AND
- 27,000 megawatts of wave machines (zero exist today) AND
- 227 Gigawatts of concentrated solar plants (or 580 Ivanpah-sized plants at 392 ME each, or 10 plus per state) to produce energy, and an additional 136 GW (7 per state) just for storage AND
- 2,300 GW of central solar PV plant, or 1,200 times more central PV capacity than exists today AND
- Additional 469 GW of solar thermal storage, or roughly 1.5 times the capacity of US coal AND
- 68% of all energy loads are made flexible by being coupled to thermal energy storage, mostly underground thermal energy storage -- enough storage to store 1.5-2 months of today's electricity consumption with capacity equal to 1 TW, or all of the US grid.

CAN THIS ALL BE ***TECHNICALLY*** ACCOMPLISHED?

PROBABLY

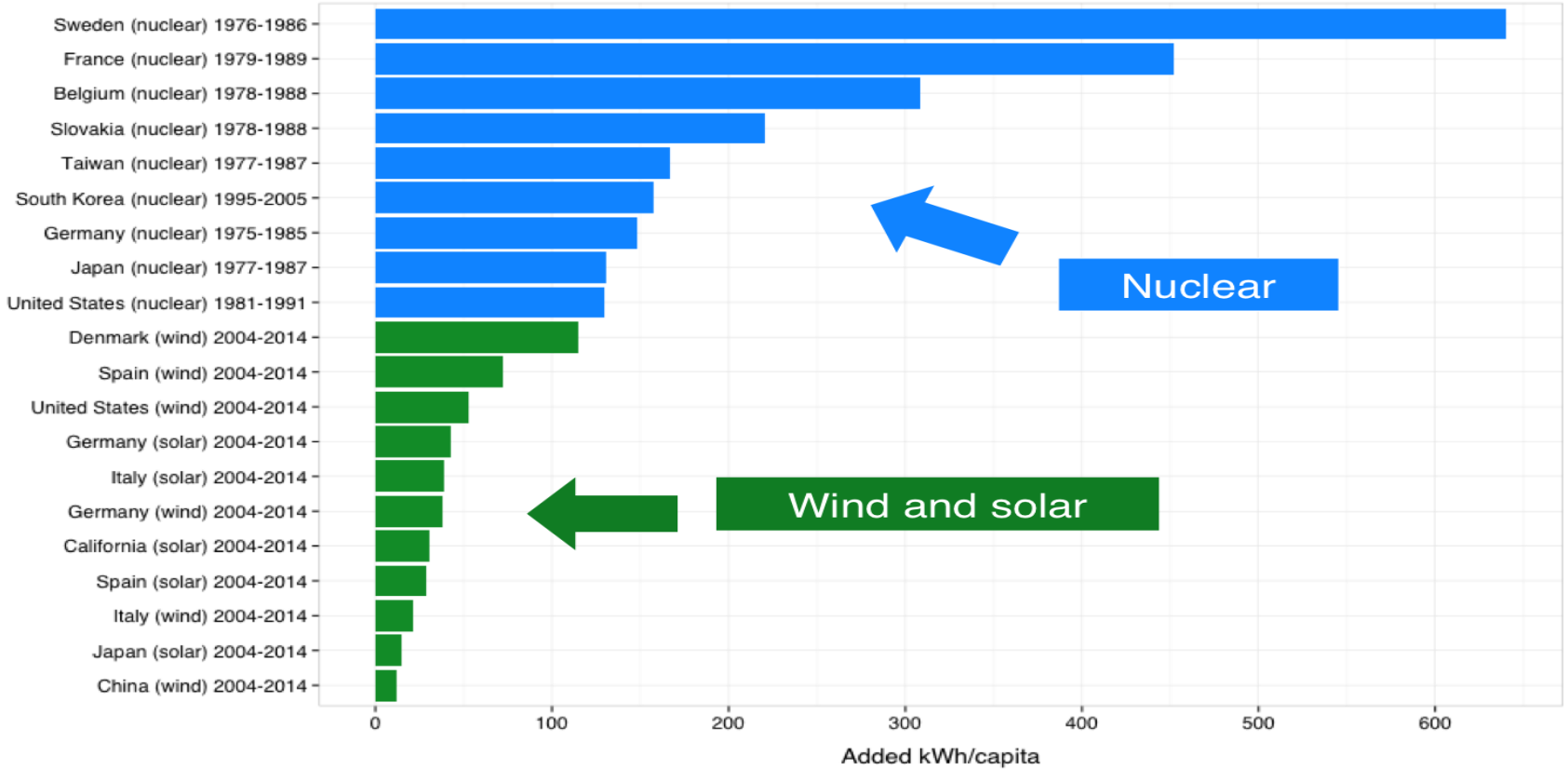
DO WE WANT TO BET THE PLANET THAT IT WILL BE?

PROBABLY NOT

WHAT ABOUT NUCLEAR?

Low-carbon electricity supply: Nuclear has scaled much faster

(average annual increase in zero-carbon kilowatt hours per capita during peak decade for nuclear (blue) and renewable (green) electricity generation)



*For nuclear, the 10-year period of most rapid scale-up; for solar and wind, the most recent 10-year period.

BARRIERS

- MORE EXPENSIVE THAN FOSSIL ENERGY IN MOST MARKETS
- TIME TO BUILD
- PUBLIC PERCEPTION AROUND:
  - SAFETY
  - WASTE
- PROLIFERATION CONCERNS

Nuclear innovation

CLEANAIR TASK FORCE


CCS
SaskPower
Boundary Dam

BARRIERS

- COST
- (EVEN THOUGH LESS EXPENSIVE IN $/TON THAN MANY MORE EXPENSIVE THAN FOSSIL ENERGY IN MOST MARKETS)
- “IT DOESN’T PRODUCE POWER, IT’S A BACK END CONTROL.”
- “IT PROLONGS THE LIFE OF FOSSIL ENERGY”

Policies for zero carbon capacity

#1 Up-front RD and D investment to accelerate better, less expensive zero carbon on-demand power options (better storage, CCS, advanced nuclear)

#2 Zero carbon capacity procurement incentives

- Long run zero carbon capacity market auctions?
- Incentives for procurement of long-run firm zero carbon energy?
- In generation-regulated jurisdictions, resource procurement adders for capacity and dispatchability value?
- Special set aside procurements of zero carbon capacity, similar to California's solicitation of energy storage?

#3 Making clean energy policies technology-neutral. Policies to consider would include:

- Allowing nuclear and CCS to participate in state clean energy or RPS programs
- Technology-neutral federal tax incentives such as the ITC and PTC.
- Revisiting nuclear-discriminatory provisions in the CPP.

www.zerocarbongrid.org

Thank you!

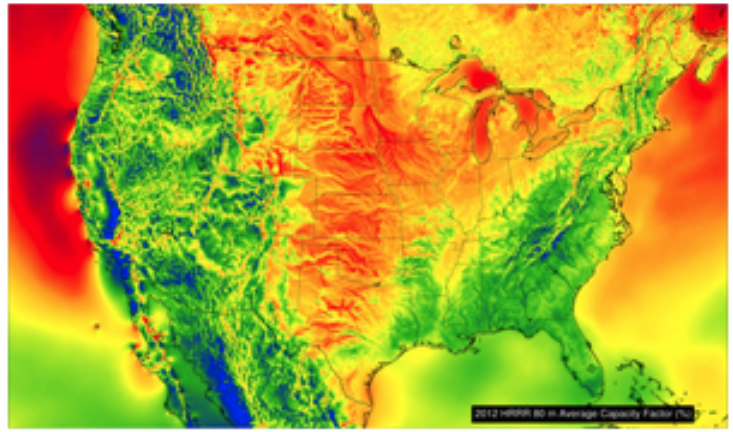
ADDITIONAL MATERIAL

Rapid, affordable energy transformation possible

NOAA, CIRES study: Wind, sun could eclipse fossil fuels for electric power by 2030

January 25, 2016

The United States could slash greenhouse gas emissions from power production by up to 78 percent below 1990 levels within 15 years while meeting increased demand, according to a new study by NOAA and University of Colorado Boulder researchers.



A high-resolution map based on NOAA weather data shows a snapshot of wind energy potential across the United States in 2012. (Credit: Image by Chris Clack/CIRES)

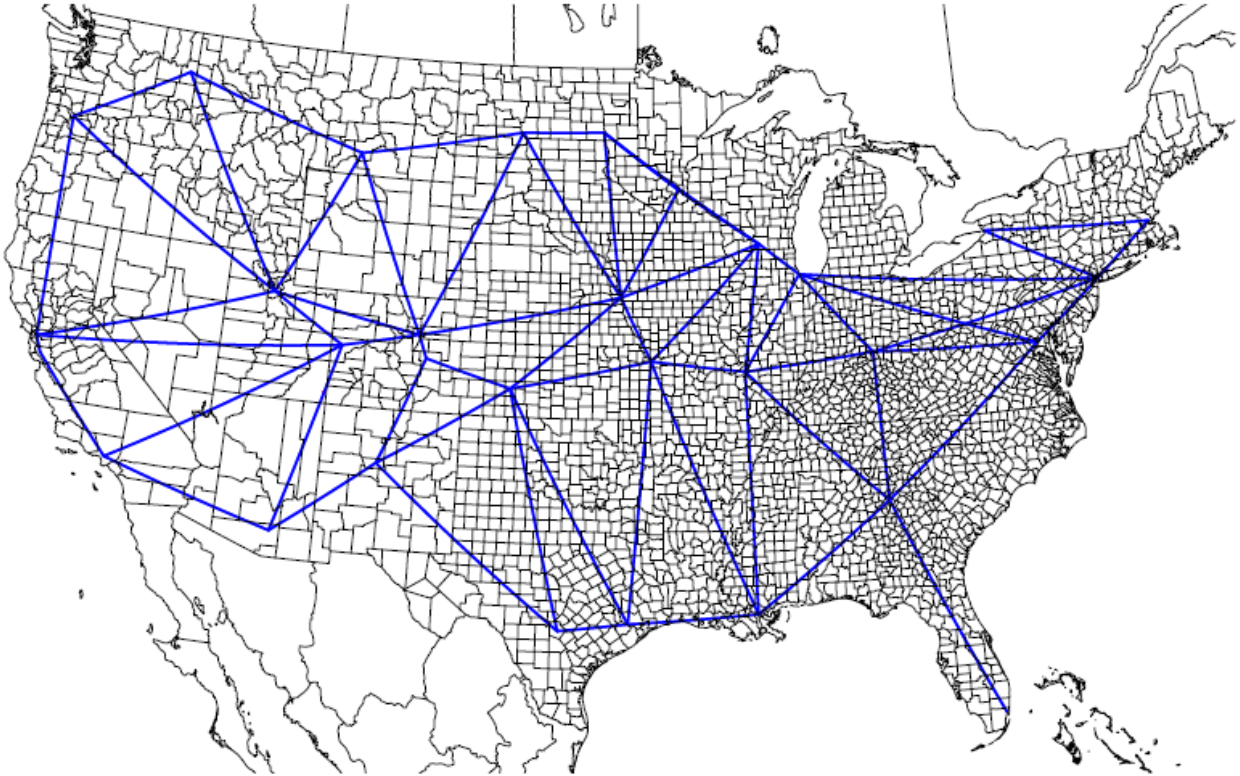
The study used a sophisticated mathematical model to evaluate future cost, demand, generation and transmission scenarios. It found that with improvements in transmission infrastructure, weather-driven renewable resources could supply most of the nation's electricity at costs similar to today's.

"Our research shows a transition to a reliable, low-

Clack Paper Highlights

- Low cost renewables high cost natural gas (LRHG) with the US operating as a single market is the scenario that got the most publicity
  - Gas = $11.10/MMBtu
  - Requires >22,000 mile HVDC
  - Total wind and solar = 55 percent of system energy
  - Curtailment for wind and solar is 7.6 percent of total generation
  - Carbon reduction is 78 percent
- LRHG with current transmission
  - Total wind and solar = 37 percent of system energy
  - Curtailment of wind and solar = 12 percent
  - Carbon reduction is 43 percent

CLEAN AIR TASK FORCE



Notes on the high (55%) wind and solar scenario

- Relies on 100 GW of nuclear – all existing plants must continue to run or be replaced
- Relies on 460 GW of gas to balance system – more than installed today
- Costs of nuclear and gas capacity are excluded from cost calculation
- All wind and solar plants optimally cited, regardless of political or land use constraints

Portland Press Herald

CLEAN AIR TASK FORCE

Maine’s high court puts end to Bowers Mountain wind power plan

The project in Penobscot County was first proposed six years ago, but never won regulators' approval – a decision affirmed Thursday by the Maine Supreme Judicial Court.

BY MATT BYRNE STAFF WRITER

December 3, 2015