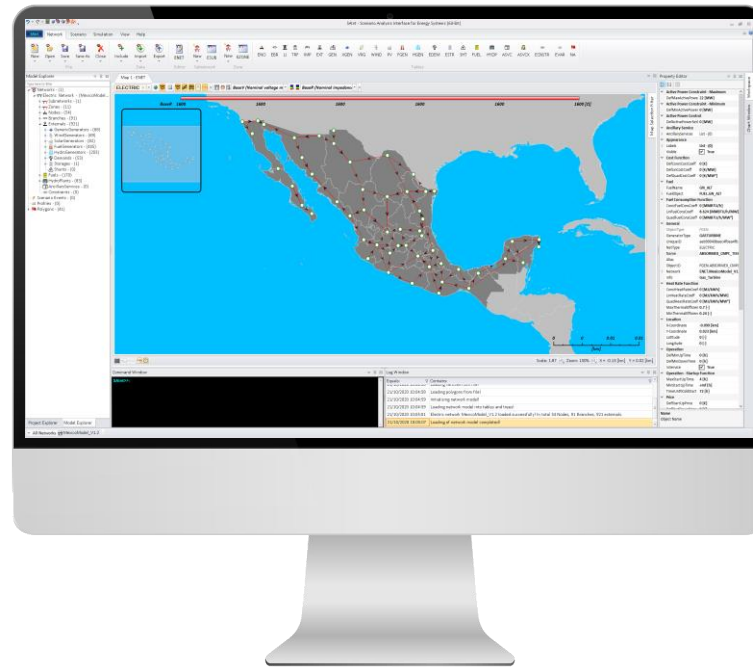


Power System Production Cost Modeling to Inform Electricity Planning & Regulation



Presentation to PERC
Dr. Carlo Brancucci
February 9th, 2021

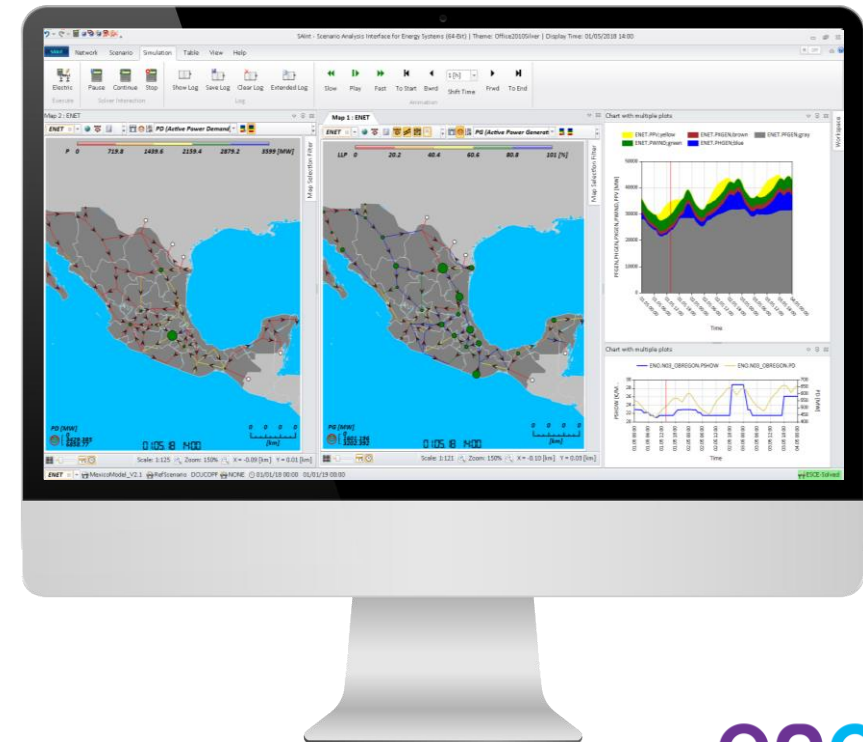
About encoord

encoord is a software company based in Denver, CO, USA, and Essen, Germany.

Our core technology is the Scenario Analysis Interface for Energy Systems (SAInt), a software platform to model and plan energy networks & markets.

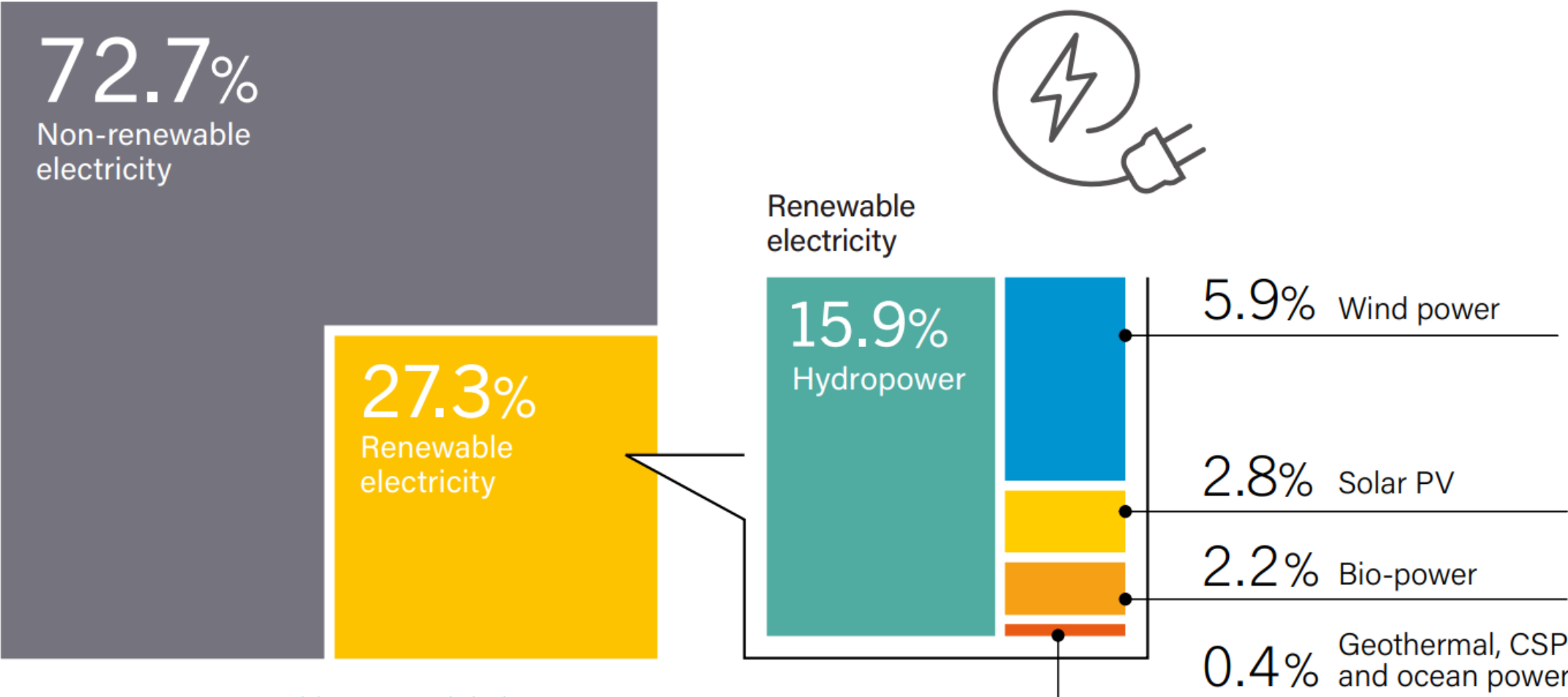
Applications

- Modeling of gas pipeline networks
- Modeling of coupled electricity and gas networks
- Modeling of electricity markets and of optimal power system operations



Global Electricity Generation

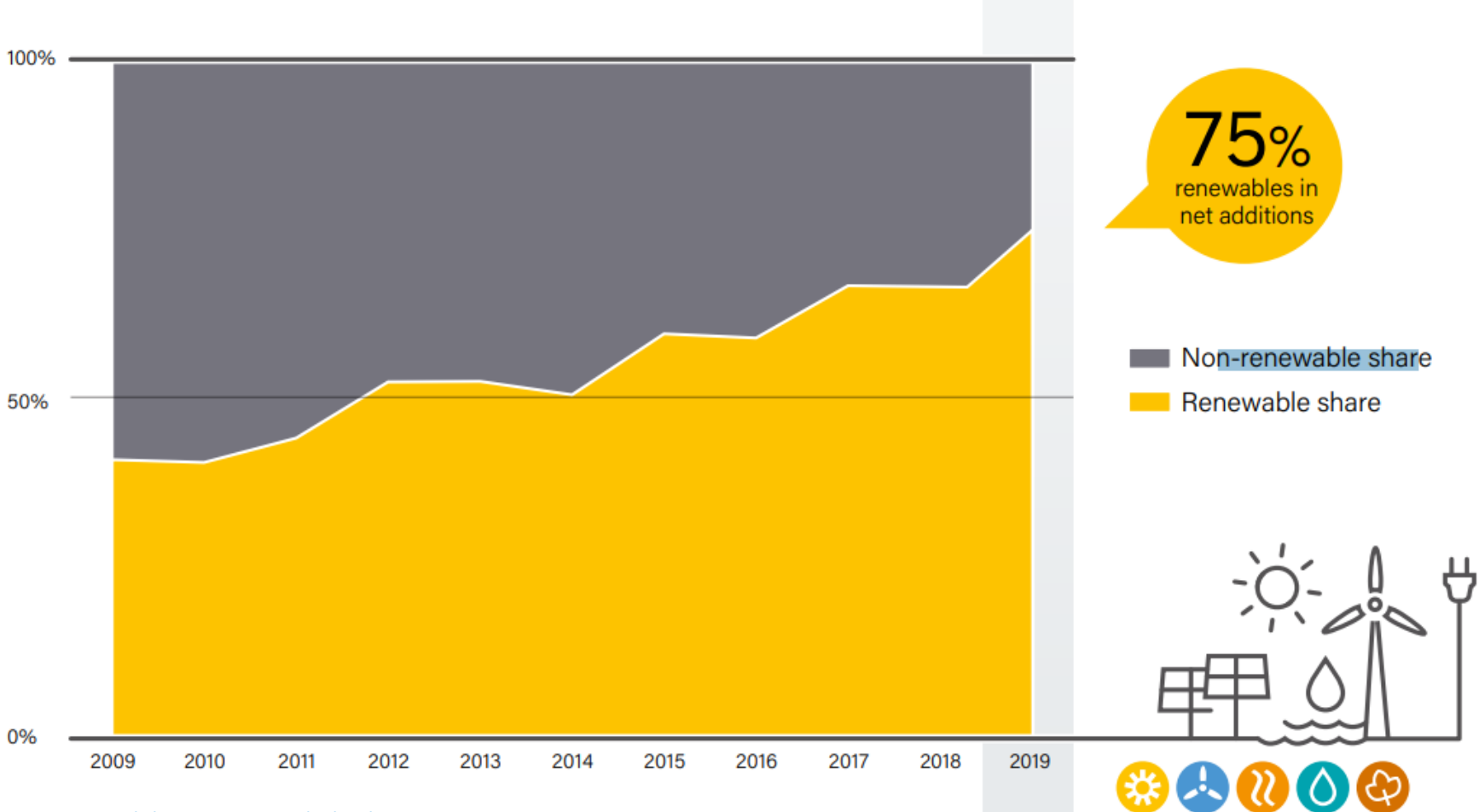
Estimated Renewable Energy Share of Global Electricity Production, End-2019



Source: REN21, [Renewables 2020 Global Status Report](#)

New Generation Capacity

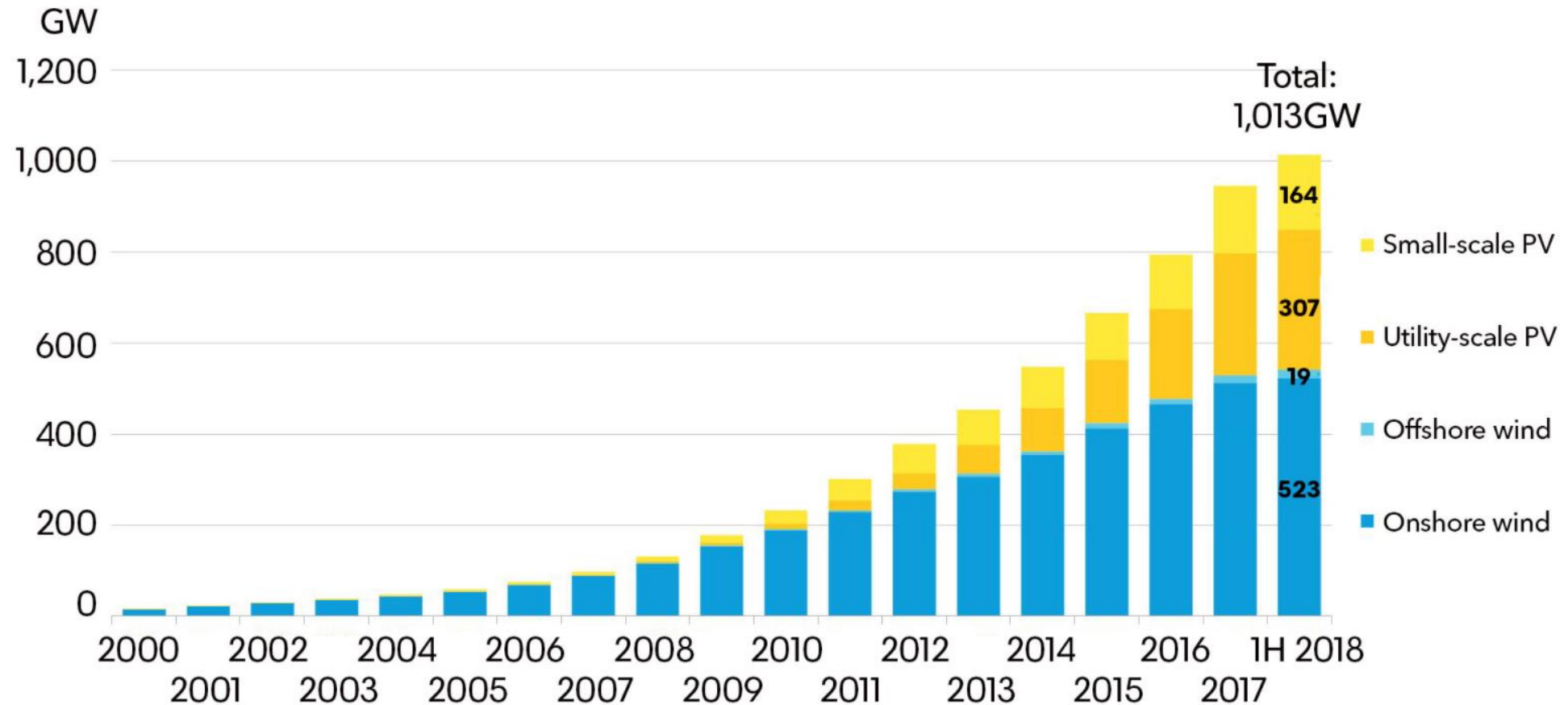
Renewable and Non-renewable Shares of Net Annual Additions in Power Generating Capacity



Source: REN21, [Renewables 2020 Global Status Report](#)

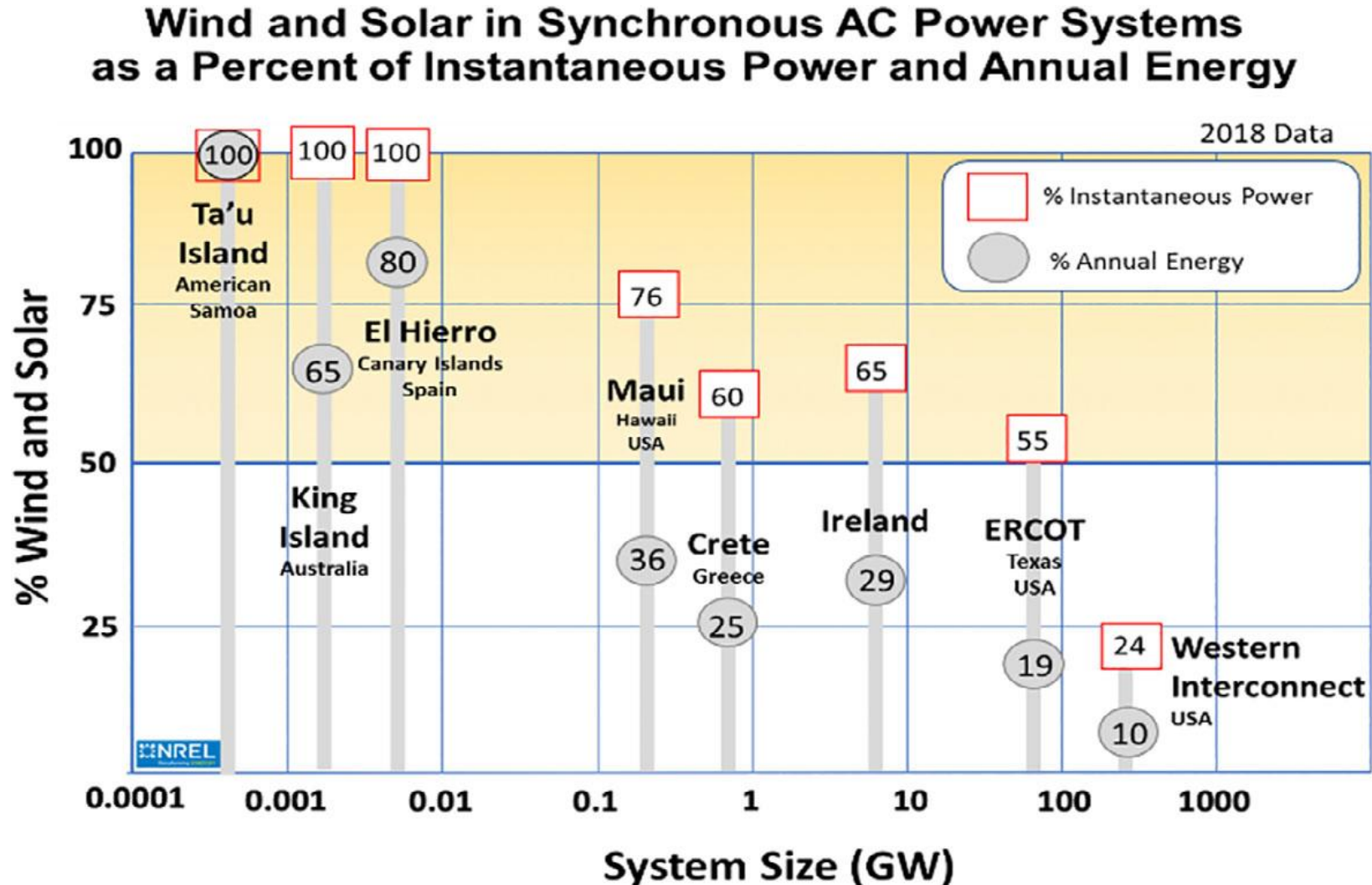
Solar PV and Wind Installations

Global wind and solar installations, cumulative to June 30, 2018



Source: Bloomberg NEF. Note: 1H 2018 figures for onshore wind are based on a conservative estimate; the true figure will be higher. BNEF typically does not publish mid-year installation numbers.

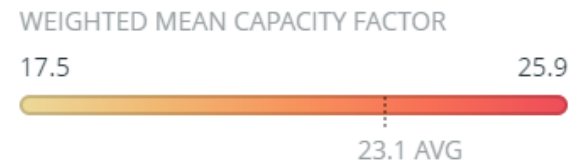
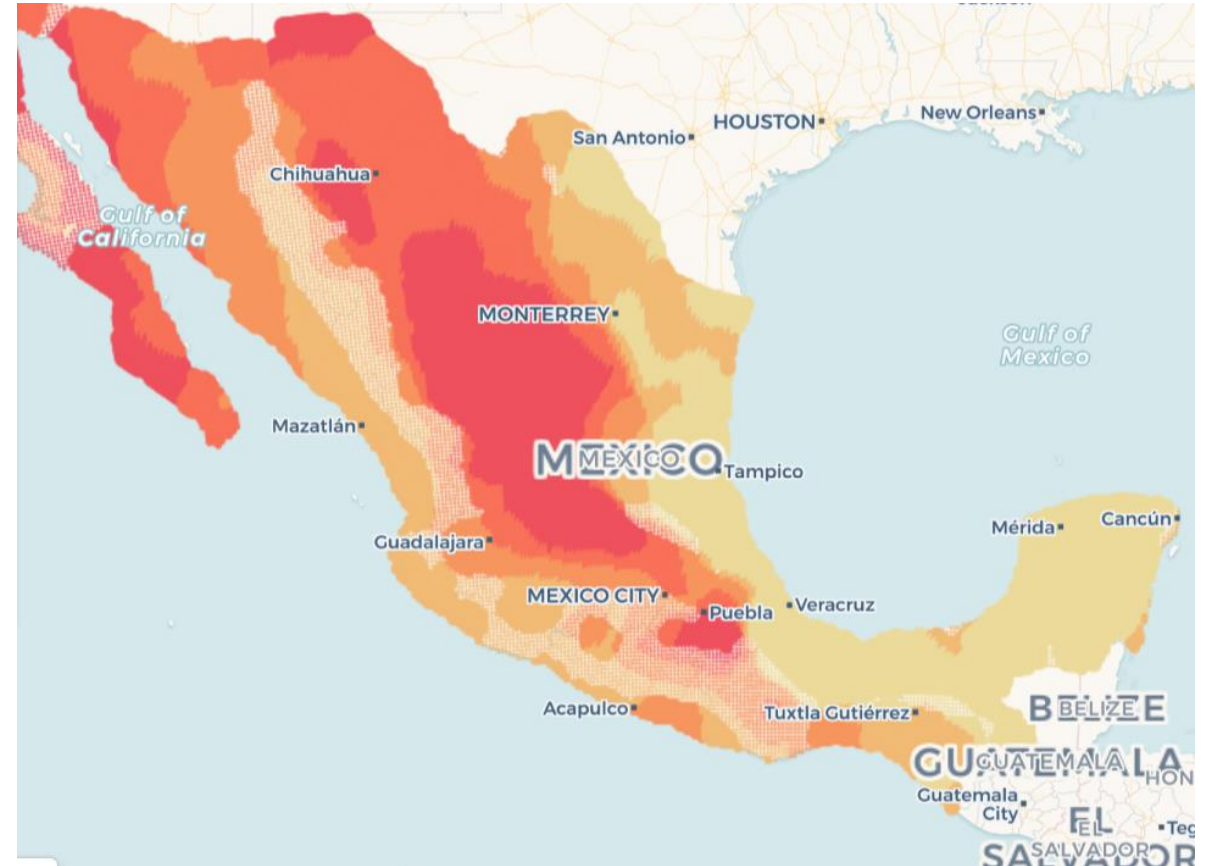
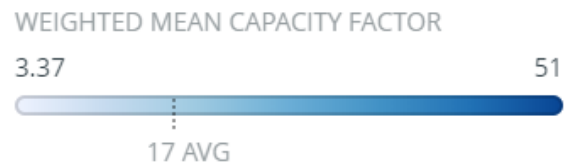
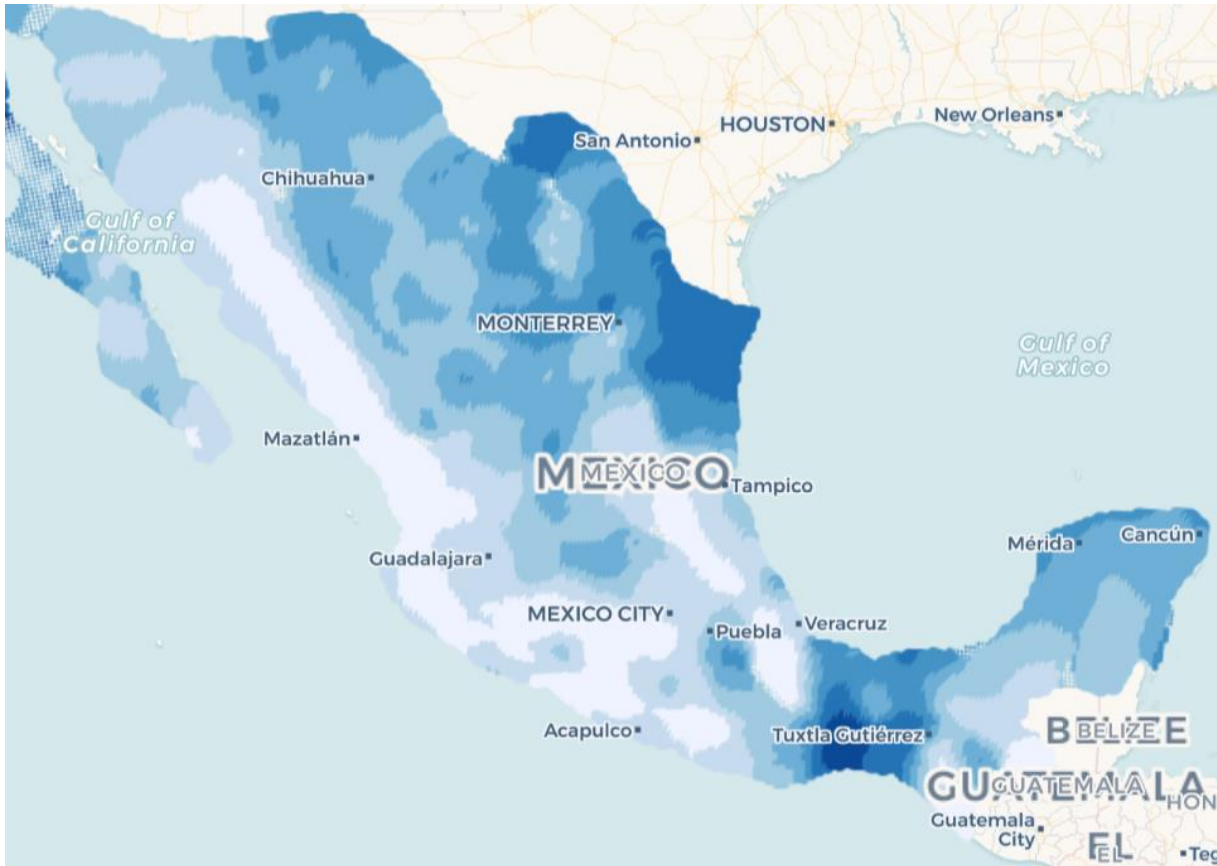
Solar PV and Wind Penetrations



Source: Hodge et al., [Addressing technical challenges in 100% variable inverter-based renewable energy power systems](#), WIRES Energy and Environment, 2020.

Which are the major **challenges** of integrating higher penetrations of wind and solar energy in a power system?

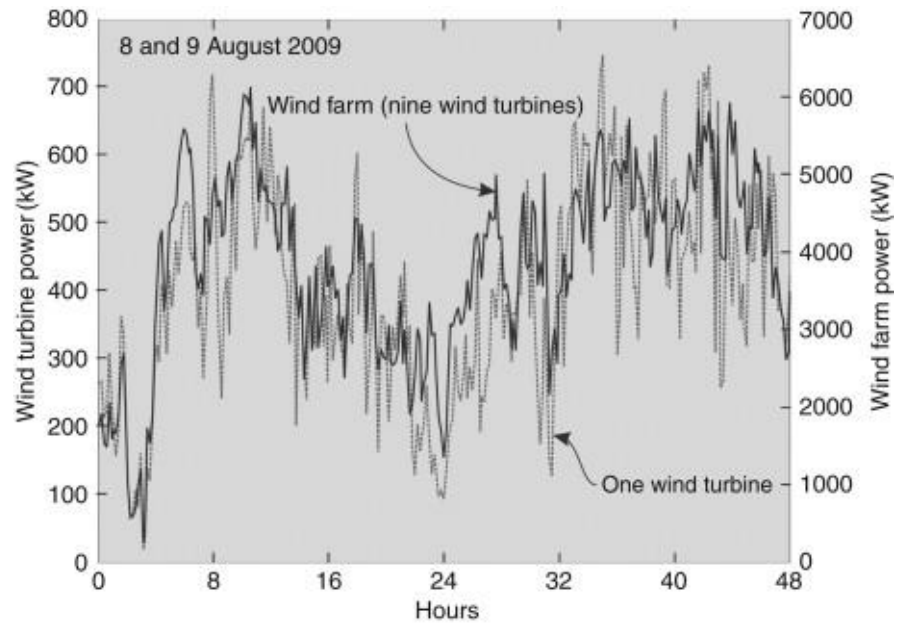
Spatial Variability



Source: NREL, <https://tinyurl.com/y86eeh3t>

Temporal Variability

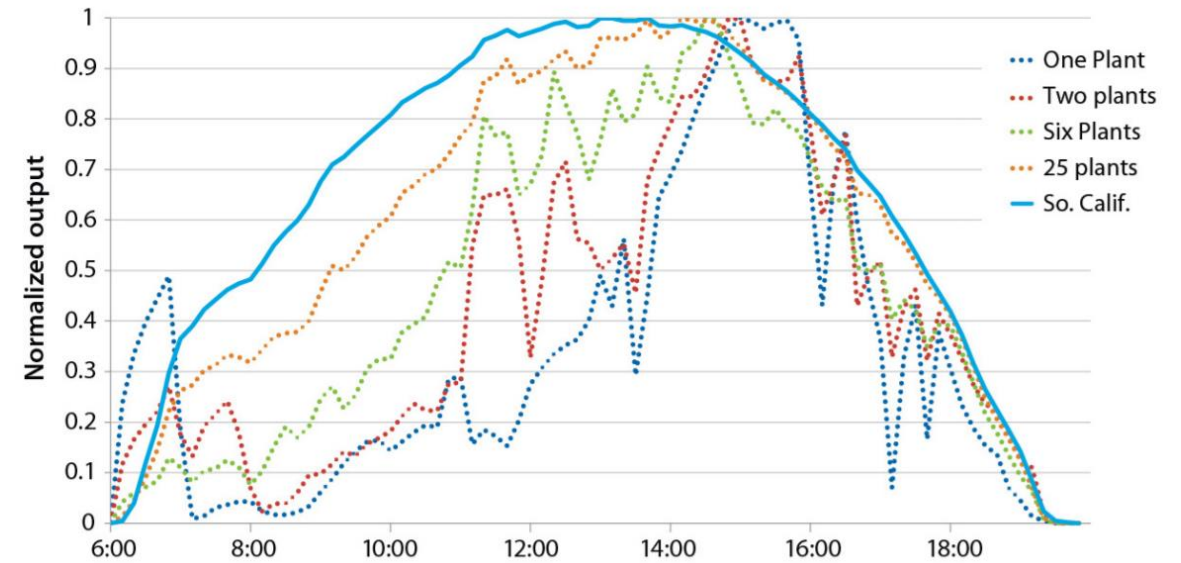
Wind



Source:

<https://www.sciencedirect.com/book/9780128045671/renewable-energy>

Solar

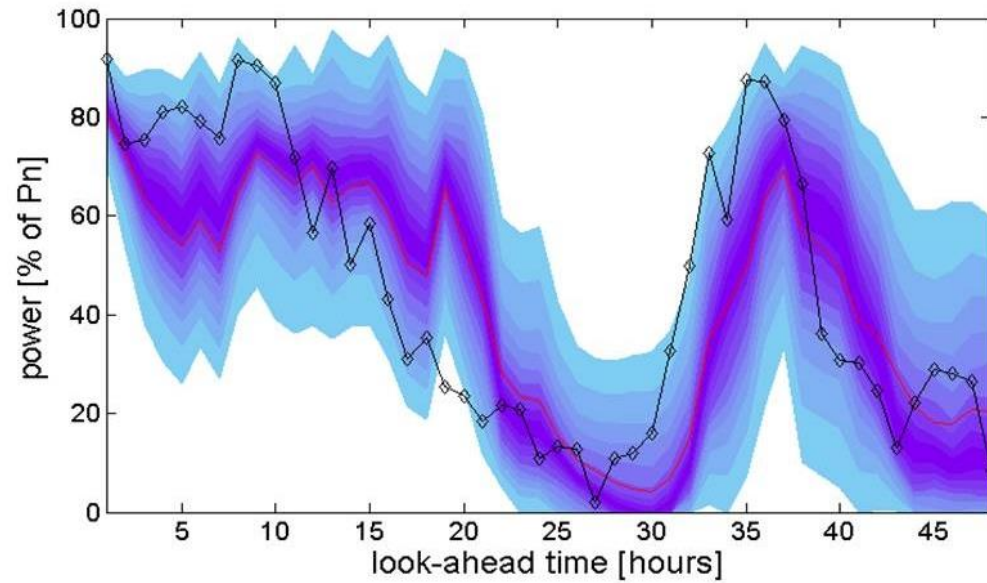


Source:

<https://www.nrel.gov/docs/fy13osti/60451.pdf>

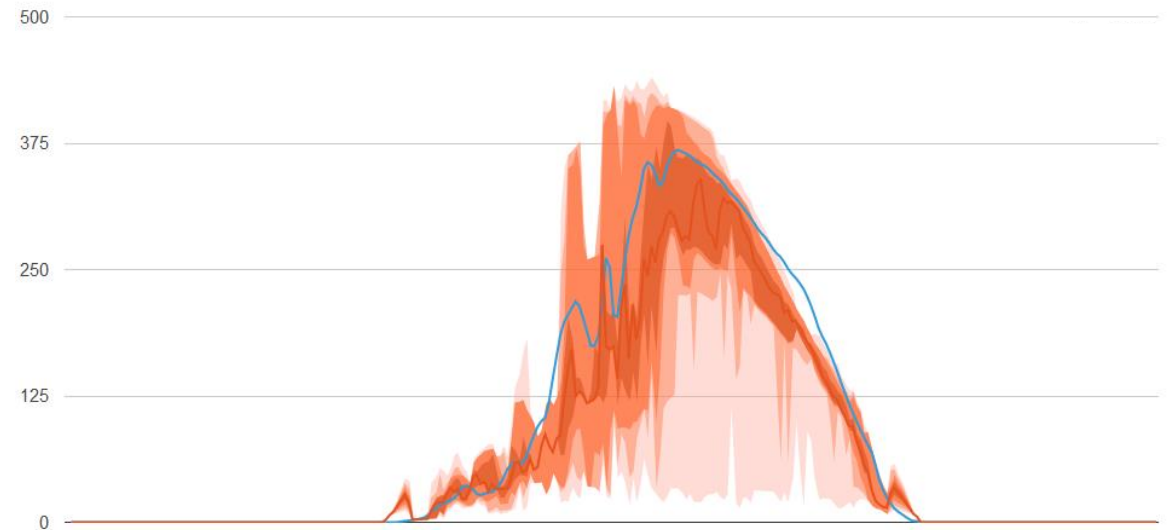
Uncertainty

Wind



Source: <https://www.ewea.org/>

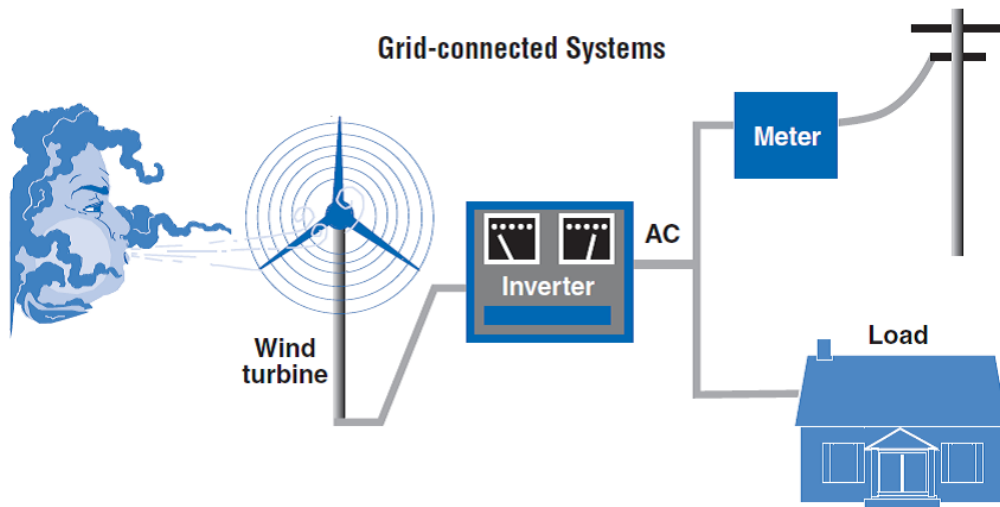
Solar



Source: <https://steady-sun.com>

Asynchronous Generation

Wind



Source: <https://windexchange.energy.gov/>

Solar



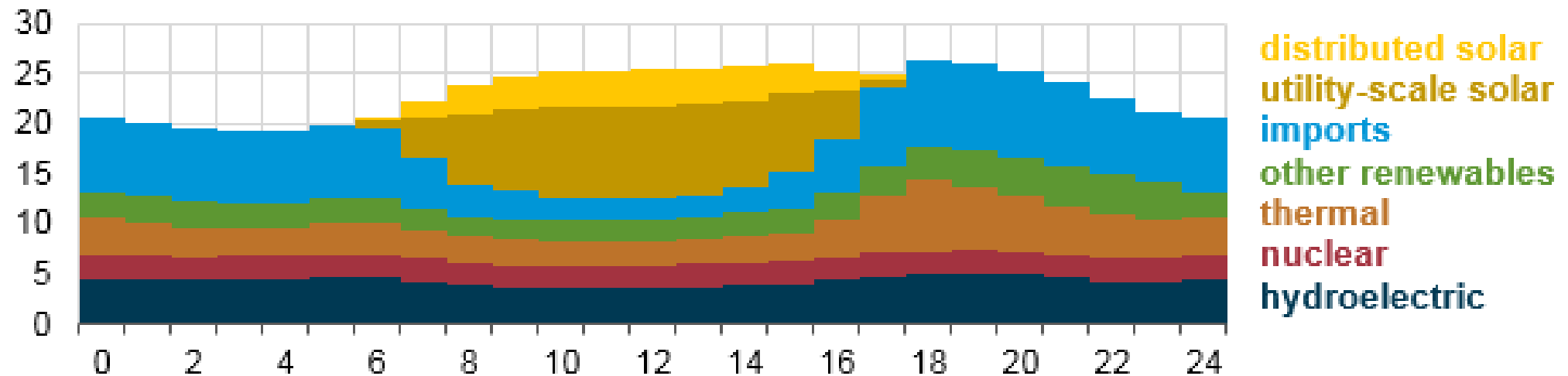
Source: <https://www.cleanenergyreviews.info>

Impact on Electricity Prices

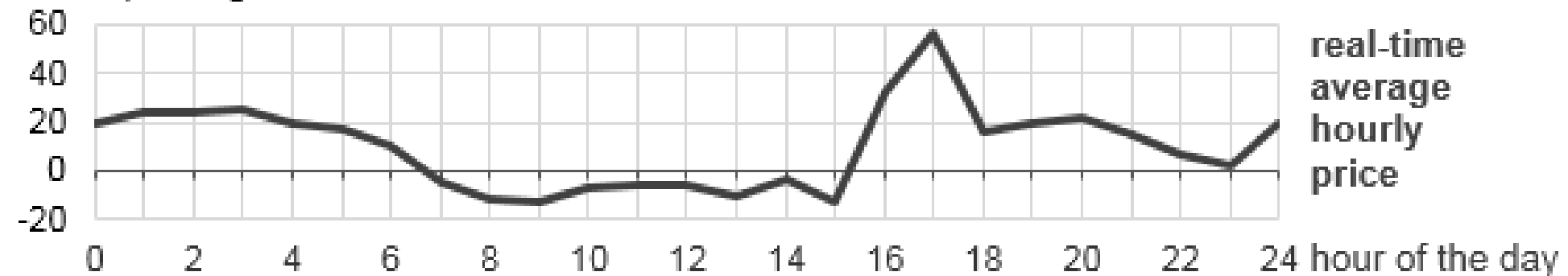
California Independent System Operator net generation, March 11, 2017



gigawatthours



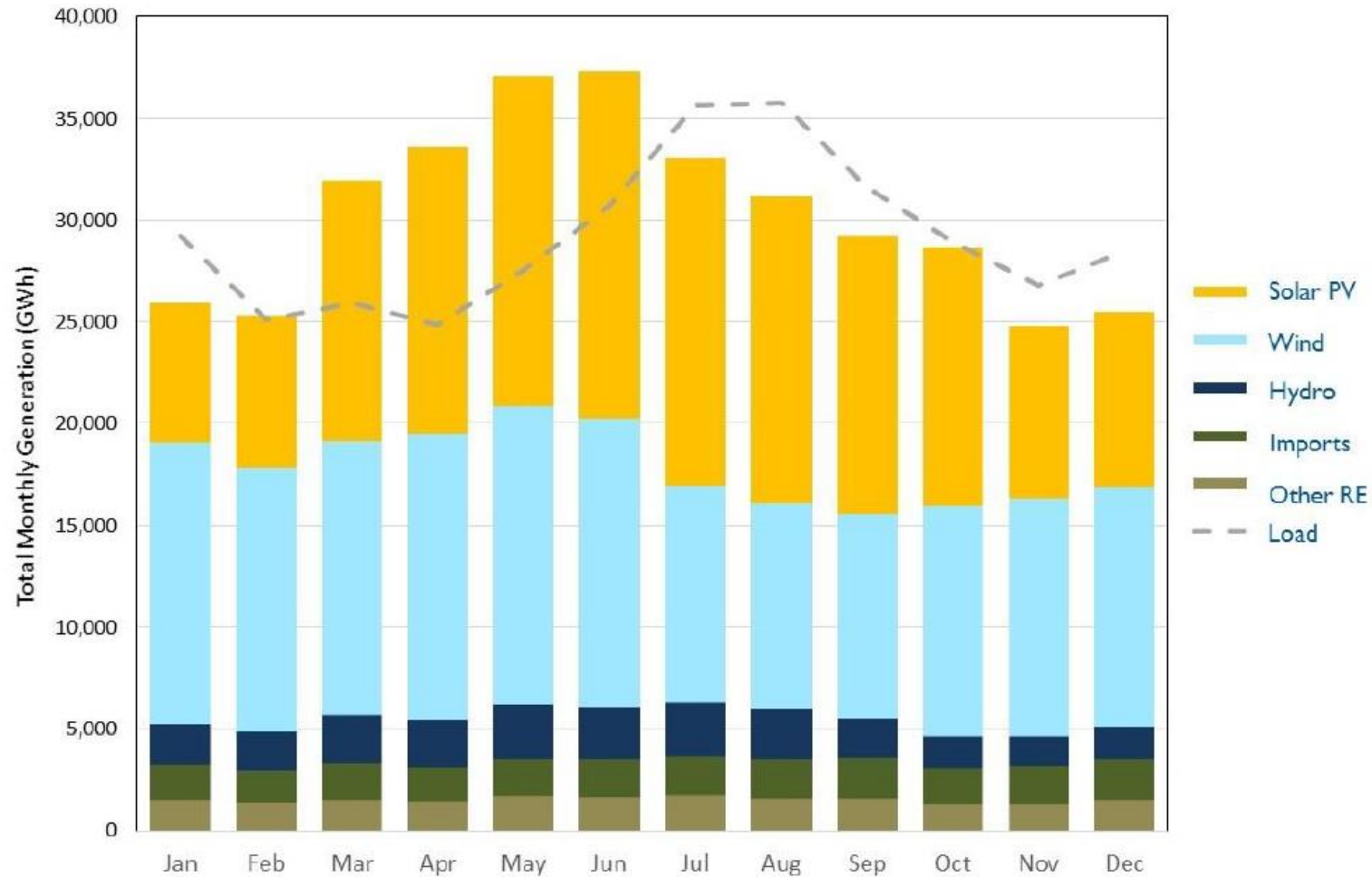
dollars per megawatthour



Source: U.S. Energy Information Administration

Seasonality

Projected Renewable Generation vs. Electric Load in California

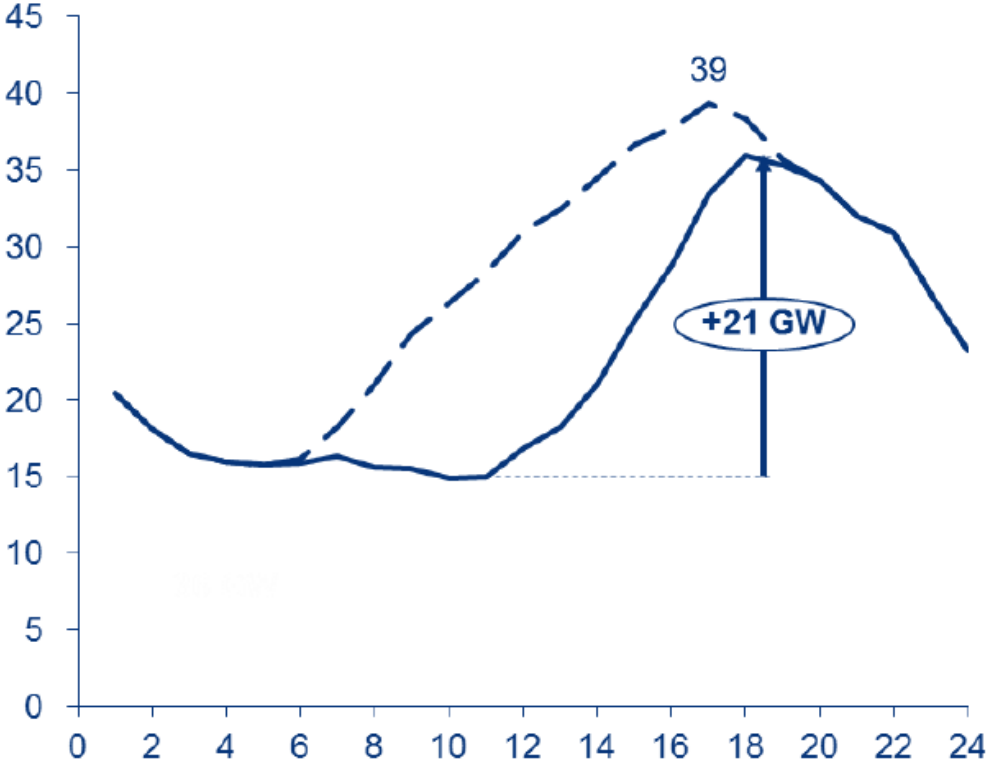


Source: The INGAA Foundation, Inc., The Role of Natural Gas in the Transition to a Lower-Carbon Economy

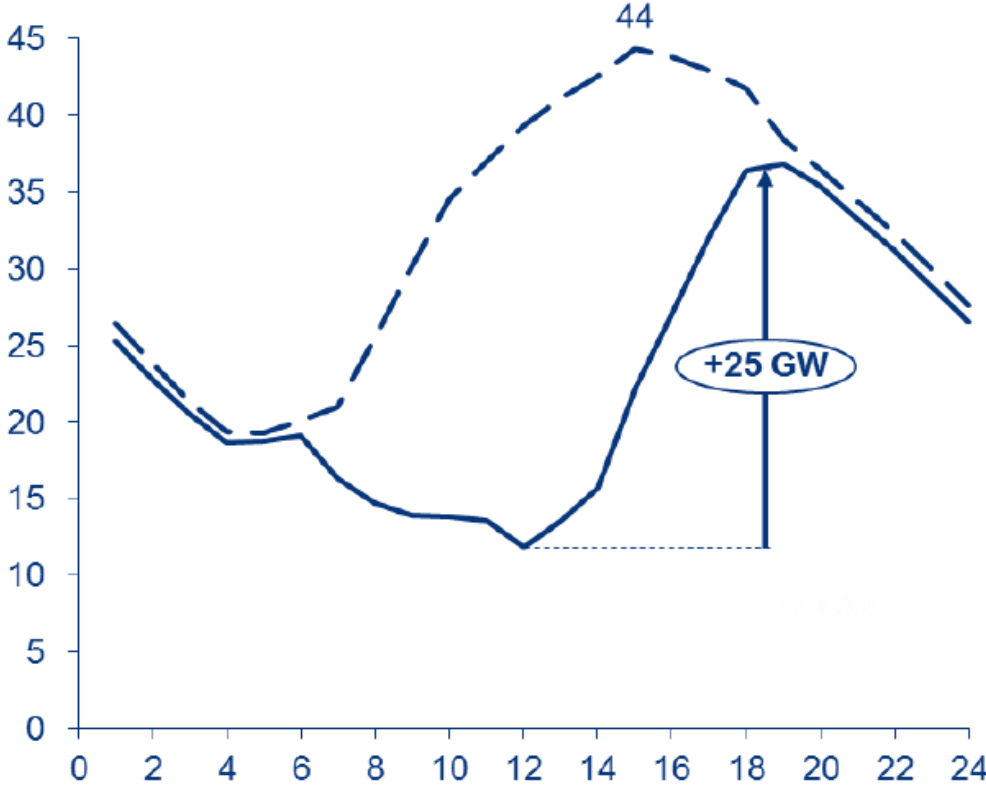
Diurnal Pattern

Hourly Electric Load in California

2017 hourly electric load – Aug 21 (GW)



2026 hourly electric load - Aug 21 (GW)



— — Load — Net load

Source: Wood Mackenzie, Western Interconnection Gas – Electric Interface Study

How can we study the potential impacts of higher penetrations of wind and solar energy on power system planning and operations?

Power System Models

Capacity Expansion Model

Optimization of the expansion of the power system generation and transmission to meet future goals and forecasts, while considering system constraints.

Production Cost Model

Optimization of the variable electricity generation costs, while considering system constraints.

Reliability Model

Power flow simulations and dynamic simulations of the power system to evaluate its stability and response to a contingency.

What is a Production Cost Model

It is an **optimization** mathematical model that simulates the operation of a power system by defining the **commitment** and **dispatch** of generators, storage, and flexible demand, while considering system constraints and minimizing variable operational costs

$$\min \sum_{t=1}^{t=T} \sum_{g=1}^{g=G} (P_{g,t} * C_g)$$

subject to:

$$\sum_{g=1}^{g=G} P_{g,t} = D_t \quad \forall t \in T$$

t : time period

g : generator

$P_{g,t}$: electricity generation of generator g during period t (MWh)

C_g : variable generation costs of generator g (\$/MWh), these include variable operation & maintenance costs, fuel costs, as well as startup and shutdown costs

D_t : electricity demand during period t (MWh)

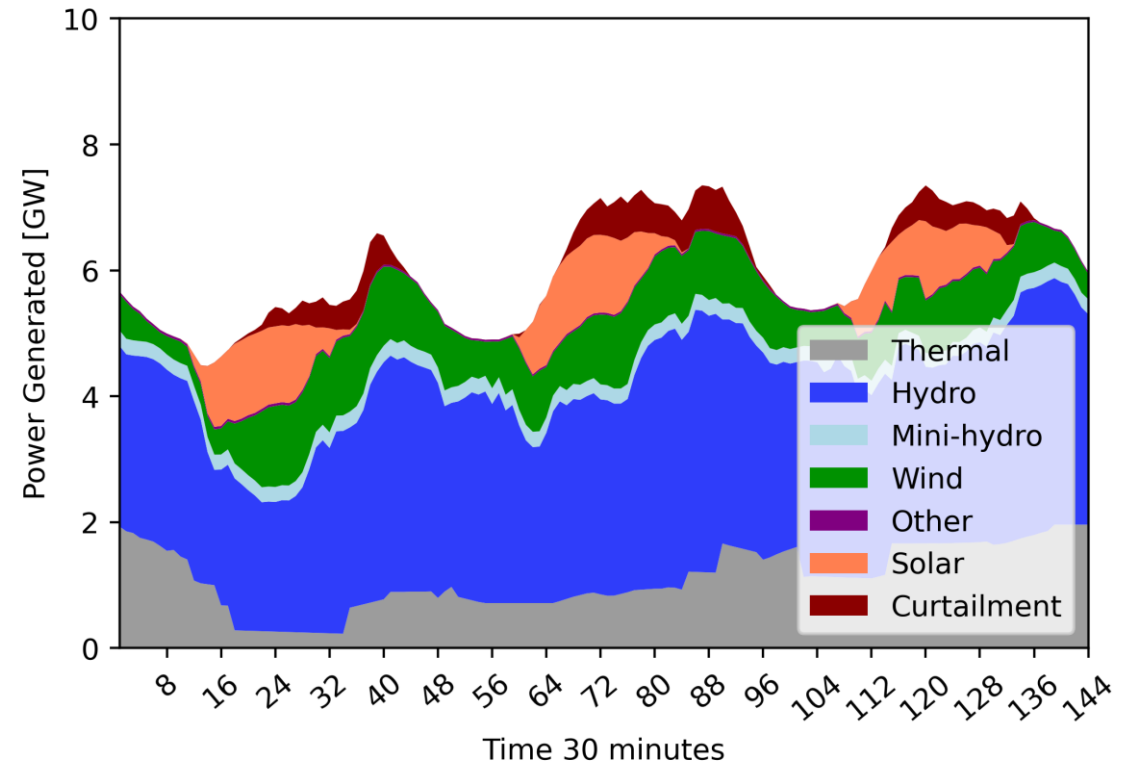
and many other generation, transmission, storage, demand, and operational reserve constraints

Inputs of a Production Cost Model

- Transmission network topology (substations, lines, transformers)
- Thermal capacity, resistance, and reactance of transmission elements
- Technical constraints, availability, and efficiency of generators
- Variable operation & maintenance, fuel, and startup & shutdown costs of generators
- Operational reserve requirements & ability of generators to contribute to them
- Electricity demand time series
- Hydro, wind, and solar resource time series
- Generation & transmission operational limits to maintain system reliability & stability

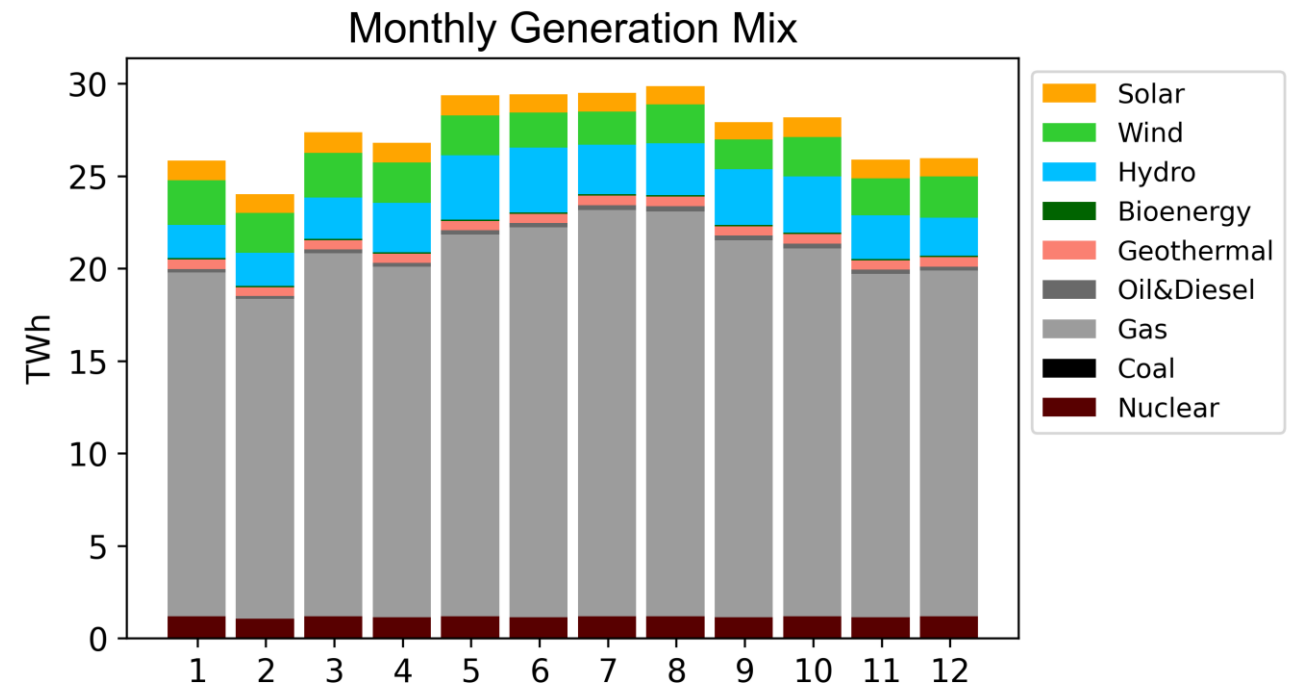
Outputs of a Production Cost Model

- Ability of the system to meet demand and operational reserve requirements
- Commitment and dispatch of generators
- Transmission flows & congestion
- Renewable curtailment
- Energy storage utilization
- Flexible demand behavior
- Fuel consumption
- Greenhouse gas emission
- Electricity Prices



Applications of a Production Cost Model

- Simulation of power system operations under potential future scenarios and conditions
- Analysis of potential power system operational challenges
- Analysis of the impact of different investments:
 - Energy storage
 - Flexible demand
 - Transmission capacity
 - Flexible generation
 - Etc.
- Analysis of electric sector regulations



Thank you for your attention!

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www.encoord.com

