Presentation by Peter Rae

9 July 2024

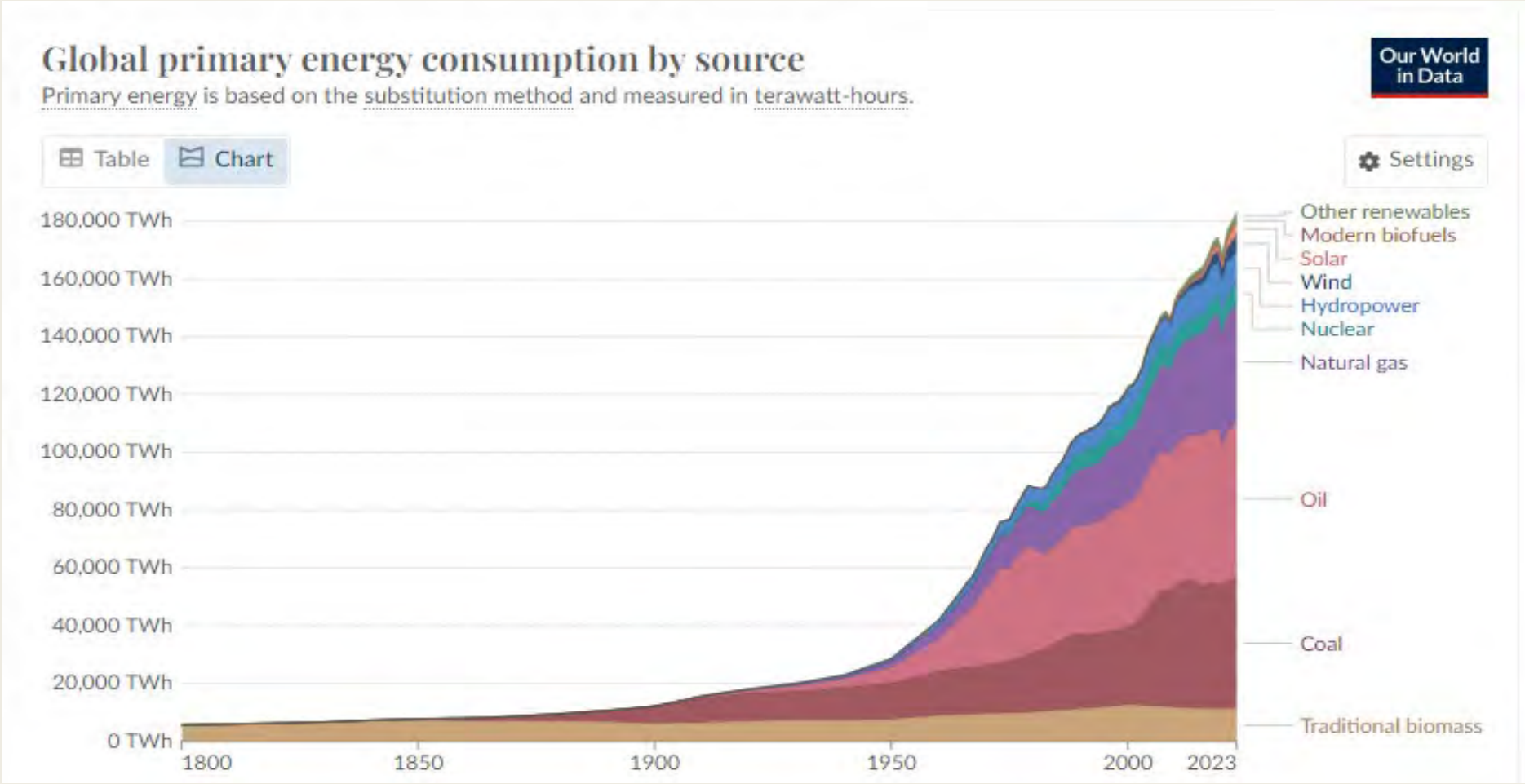
Incorporating a Run-of-River HEP in an Integrated Power System

Presentation Outline

- Power System Overview
- Generation Expansion Planning
- Hydropower Operation
- Operation with Other Renewable Energy

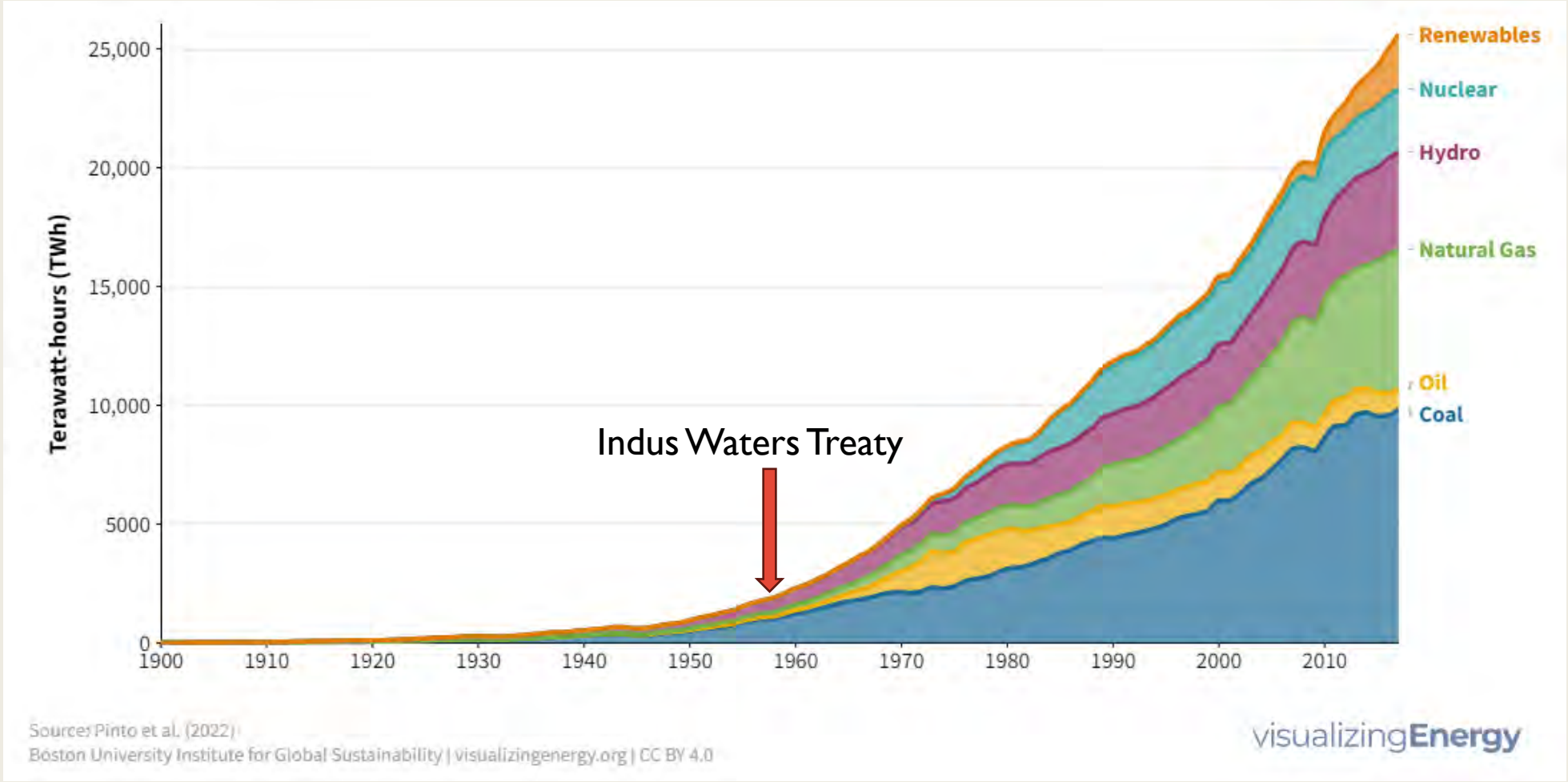
Power System Overview

Global Primary Energy Demand



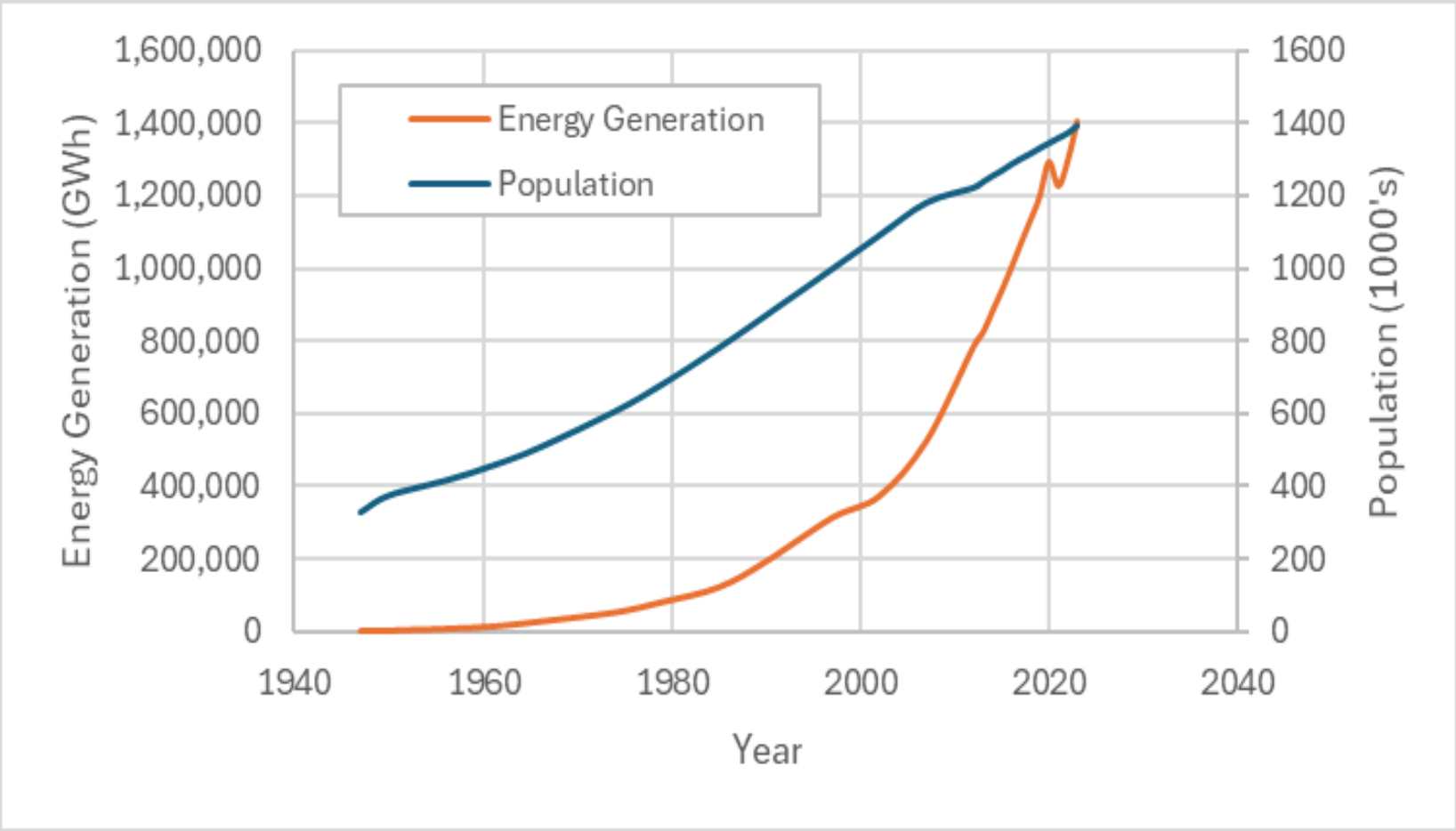
H. Ritchie, "How have the world's energy sources changed over the last two centuries", *Our World in Data*, **P-0588**

Global Electrical Energy Demand



Pinto et al. (2022), 'World electricity generation since 1900', *Boston University Institute for Global Sustainability*, **P-0589**

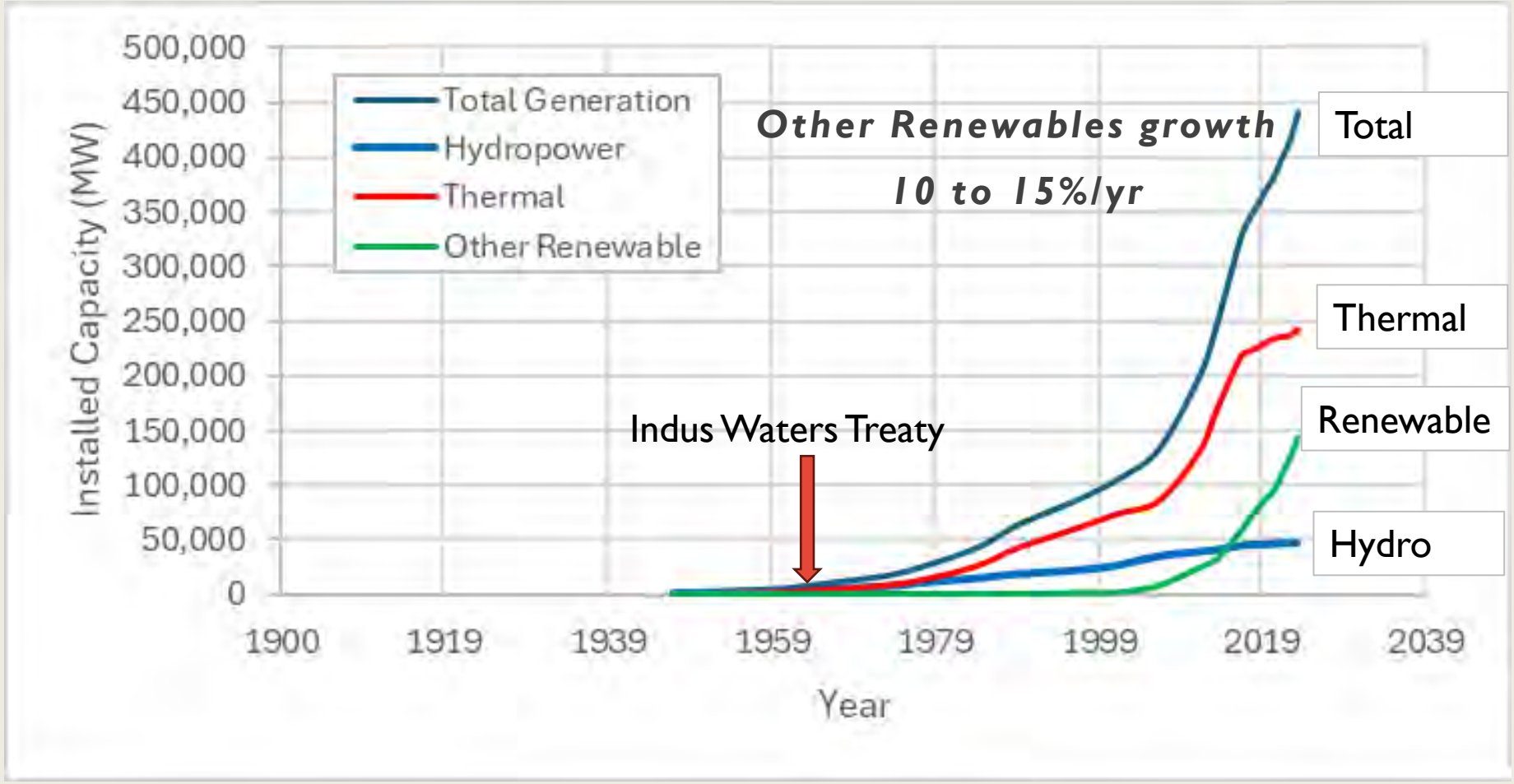
Historical Electricity Generation in India



- Increasing population
- Increasing per capita demand

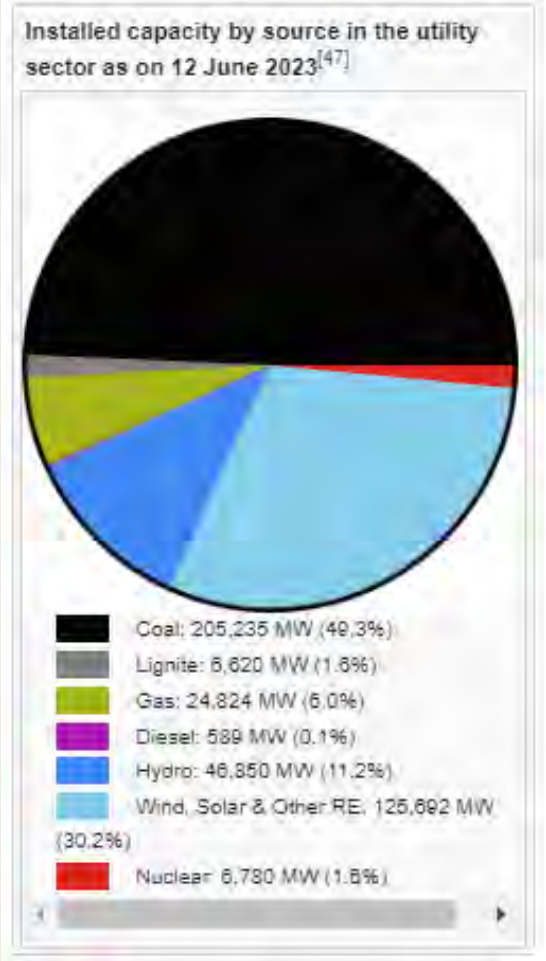
Data Source: "Growth of Electricity Sector in India from 1947 – 2020", Central Electrical Authority, Government of India, P-0590

Historic Installed Capacity in India

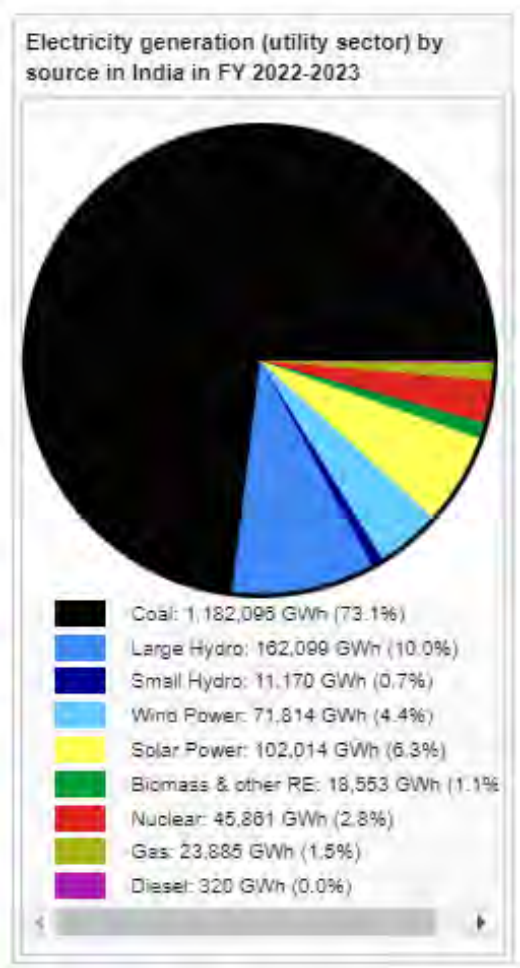


Data Source: "Overview of renewable power generation", Central Electrical Authority, Government of India, **P-0591**

India Power Generation



"Power Sector at a Glance, All India", Central Electrical Authority, Government of India, **P-0593**

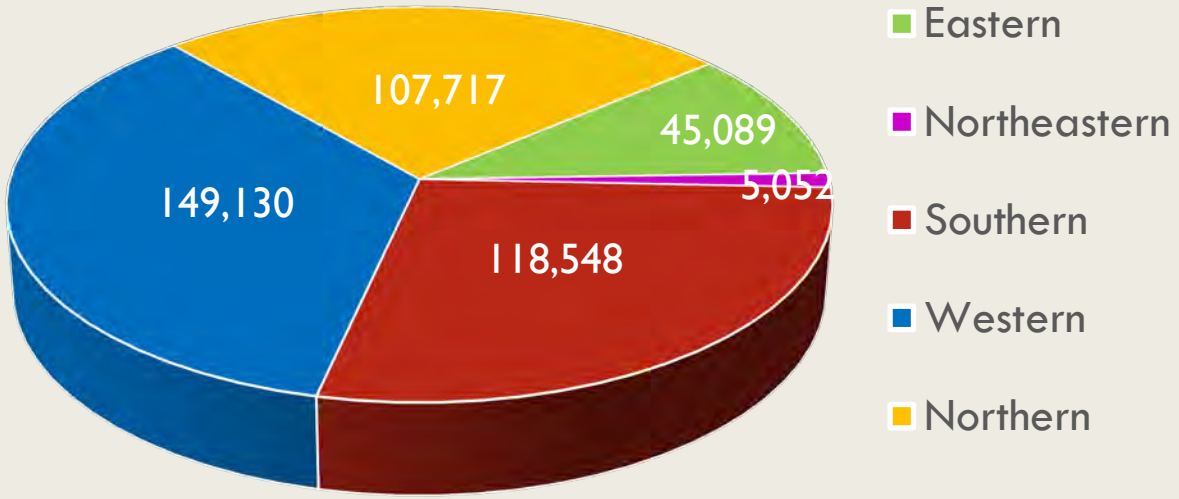


"Status of Pumped Storage Development in India", Central Electrical Authority, Government of India, **P-0592**

- World's 3rd largest power system
- Rapid growth of solar and wind capacity
- Significant plans for new pumped storage development (57 GW listed by CEA as of 2023)

System Interconnection

- Five interconnected Regional Power Grids
- Indus River basin in Northern Region



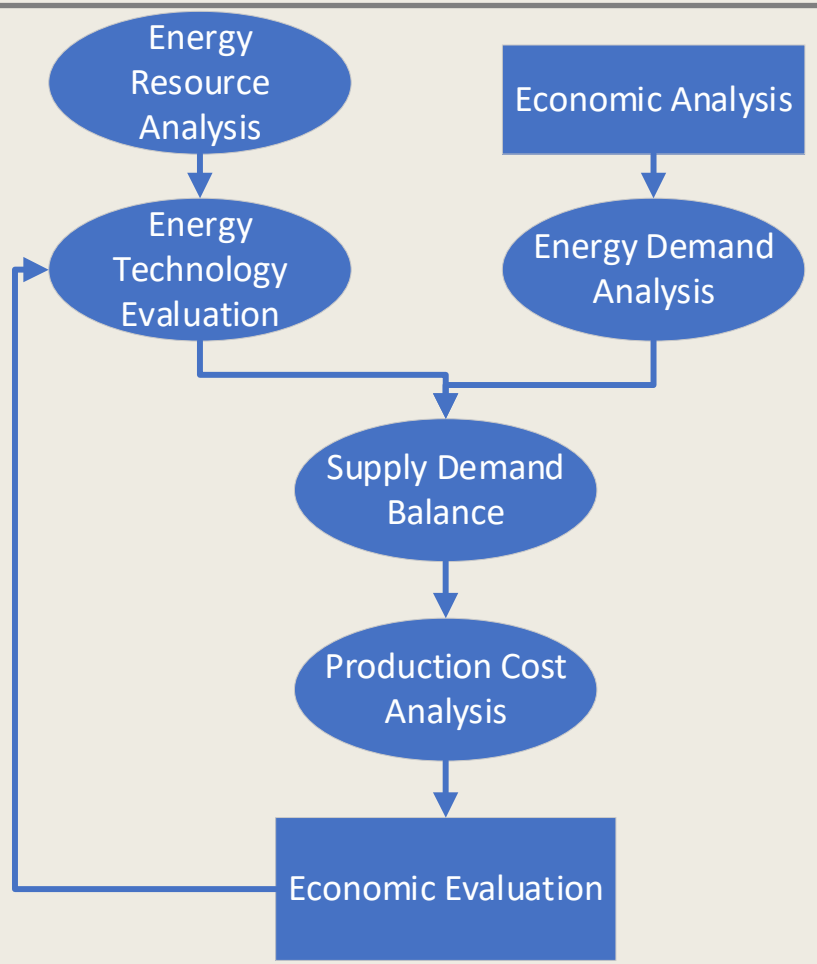
Installed Capacity by Region (MW)

"Growth of Electricity Sector in India from 1947 – 2020", Central Electrical Authority, Government of India, **P-0590**

Generation Expansion Planning

Generation Expansion Planning

- ❑ Optimal new generation
- ❑ Key Outputs
  - ➢ Generation technology
  - ➢ Installed power capacity
  - ➢ Firm Power Capacity
  - ➢ Firm Energy
  - ➢ Energy production cost



Define Options

Define Demand

Select expansion plan

Determine Energy Cost

Evaluate & Optimize

Adapted from International Atomic Energy Agency, "Expansion Planning for Electrical Generating Systems, A Guidebook", Technical Reports Series No 241, 1984, Figure 2.1, **P-0601**

Firm Power and Firm Energy

- ❑ Firm Energy: Energy with assured availability.
  - ➢ 95 to 98% reliability.
  - ➢ Determined by Hydrology
- ❑ Firm Power: Power with assured availability.
  - ➢ Power is the rate of energy transfer
  - ➢ Determined by plant characteristics
- ❑ System Requirement
  - ➢ Demand = Systemwide Firm Power
  - ➢ Surplus Firm Power for reserve capacity

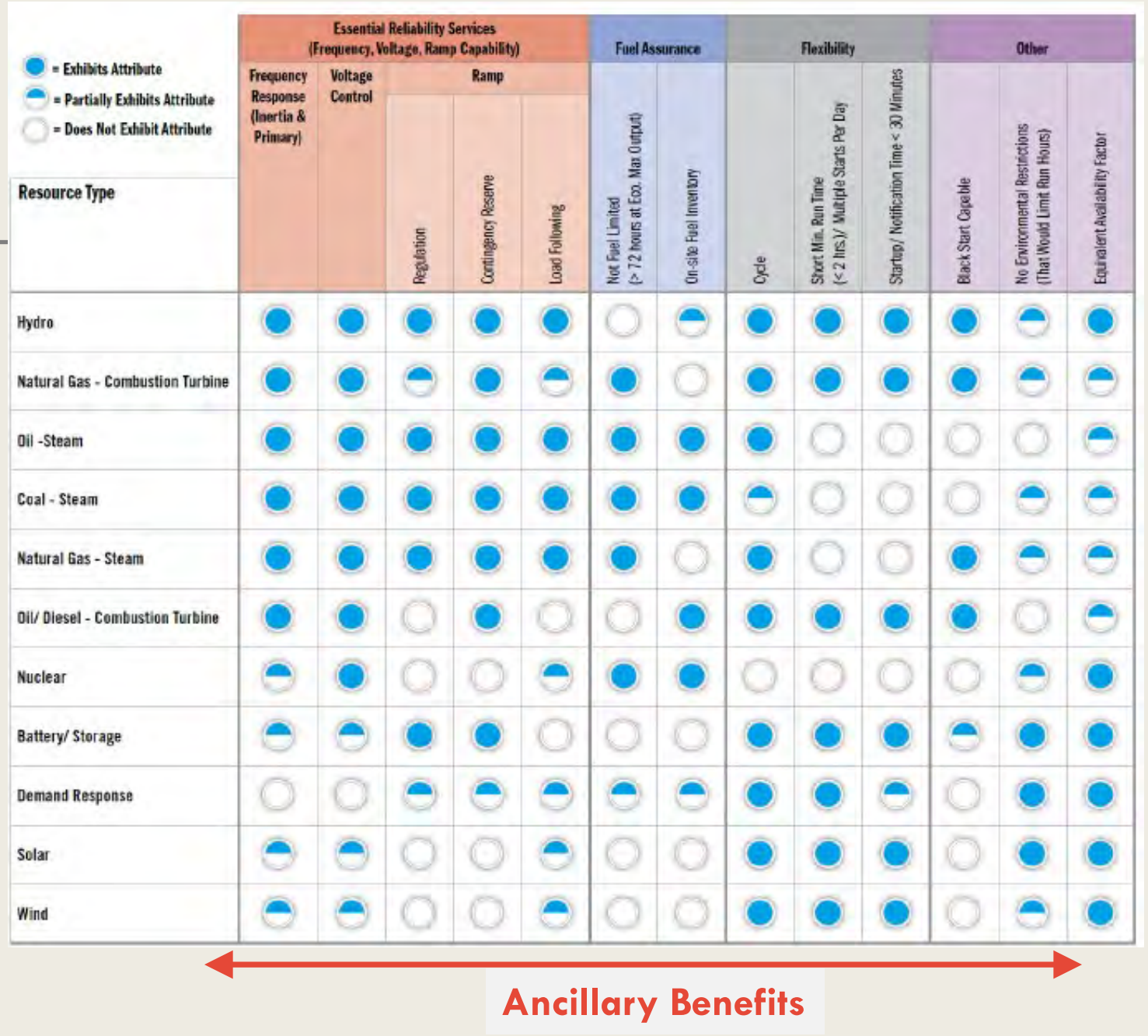
Key Issues:

- ❑ *Duration of Firm Power is limited by the available energy*
- ❑ *Pondage is computed for the duration of operation*
- ❑ *Energy determined by hydrology*

Indus Waters Treaty has a specific definition of Firm Power

System Benefits

- ❑ Key Requirements
  - ➢ Constant Voltage
  - ➢ Constant Frequency
  - ➢ System Inertia
  - ➢ Load following capacity
  - ➢ Black start capability
- ❑ Reserves
  - ➢ Spinning Reserve capacity
  - ➢ Standby Reserve capacity
  - ➢ Maintenance capacity

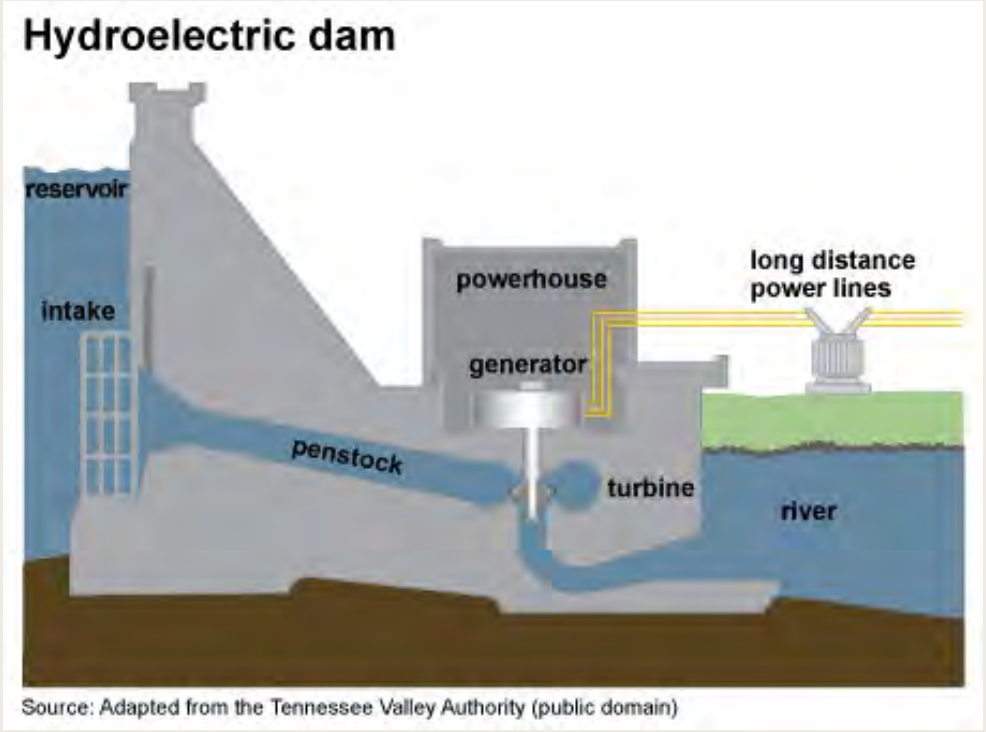


"PJM's Evolving Resource Mix and System Reliability", PJM Interconnection, **P-0603**

Hydropower Operation

HEP Operation

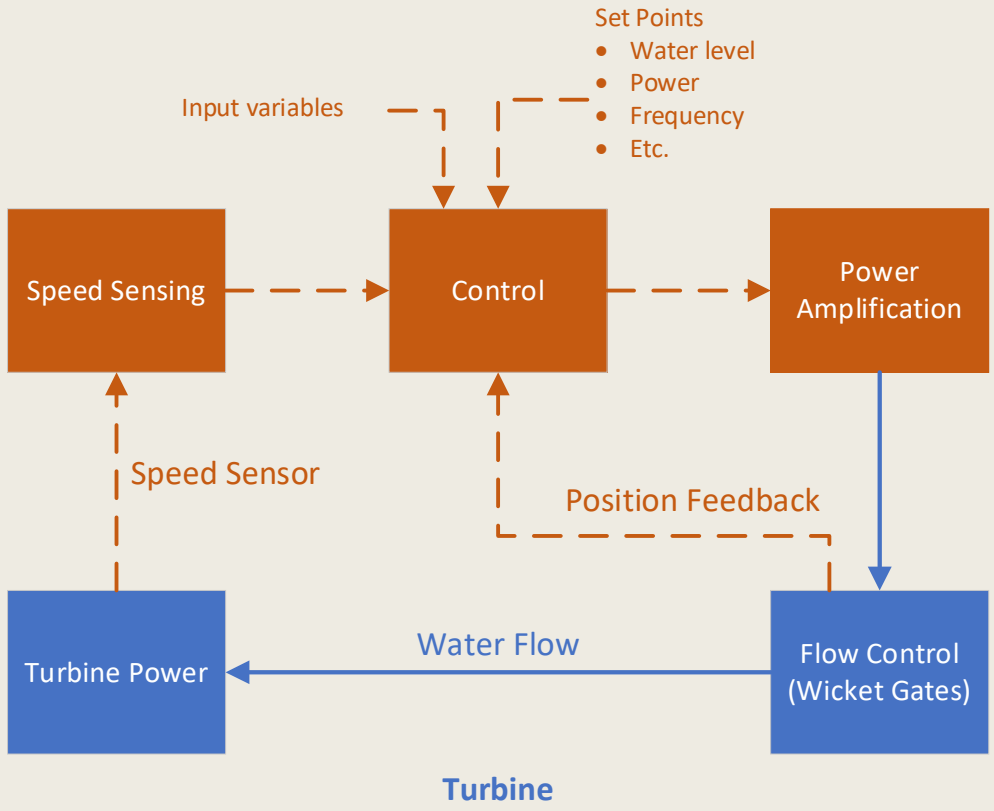
- ❑ Turbine - hydraulic to mechanical energy
- ❑ Generator - mechanical to electrical energy
- ❑ Turbine-Generator constant unit speed determines Frequency
- ❑ Plant outputs
  - ➢ Power (MW) varying with flowrate and head
  - ➢ Energy (GWh)
  - ➢ Ancillary Services



Source: Adapted from the Tennessee Valley Authority (public domain)

Turbine Governor

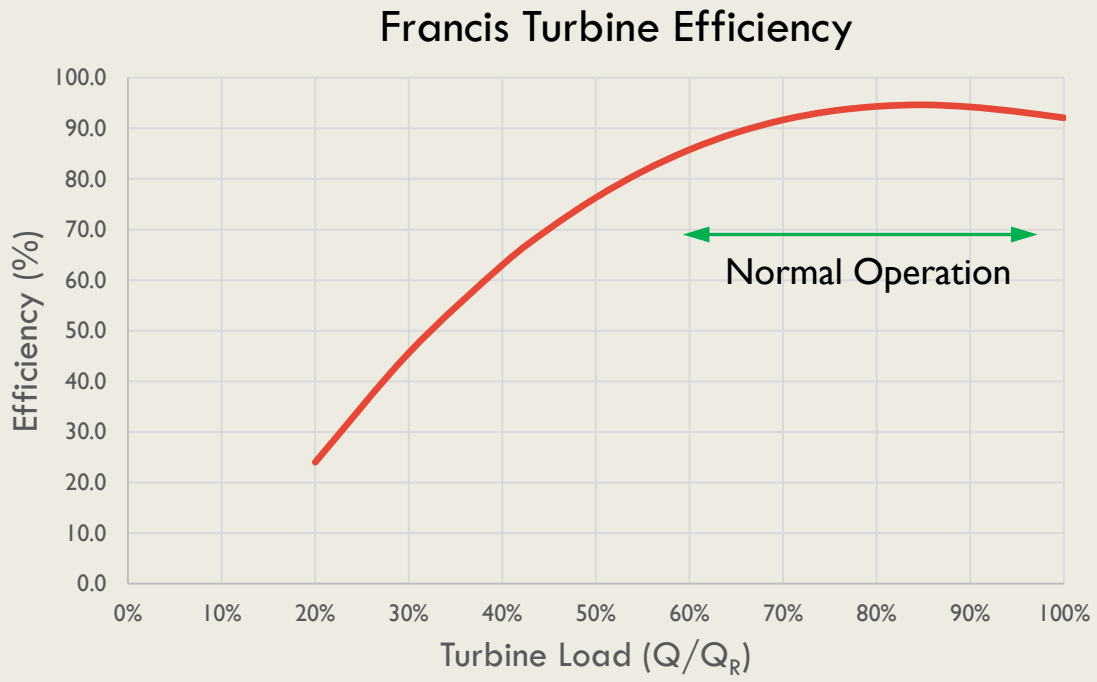
- ❑ Turbine Governor
  - ➢ Adjust flow to maintain speed and frequency
  - ➢ Share load changes with other units
  - ➢ Adjusts unit output & protects plant
- ❑ Operating Modes
  - ➢ Speed Control
  - ➢ Power Control
  - ➢ Gate position/flow control
  - ➢ Water level control



ASME, "The Guide to Hydropower Mechanical Design", Prepared by the ASME Hydro Power Technical Committee, HCI Publications, 1996, (Extract, Figure 3-19 and Figure 4-1), **P-0604**

ROR HEP Operation

- ❑ Daily schedule based on flow available
- ❑ Normally operates at part load
  - ➢ Creates "spinning" reserve
  - ➢ Maximizes efficiency
- ❑ Governor varies turbine flow to follow frequency and control water level with fluctuating inflow
- ❑ Pondage stores "energy"
  - ➢ Varies with inflow and power
  - ➢ Limited daily peaking

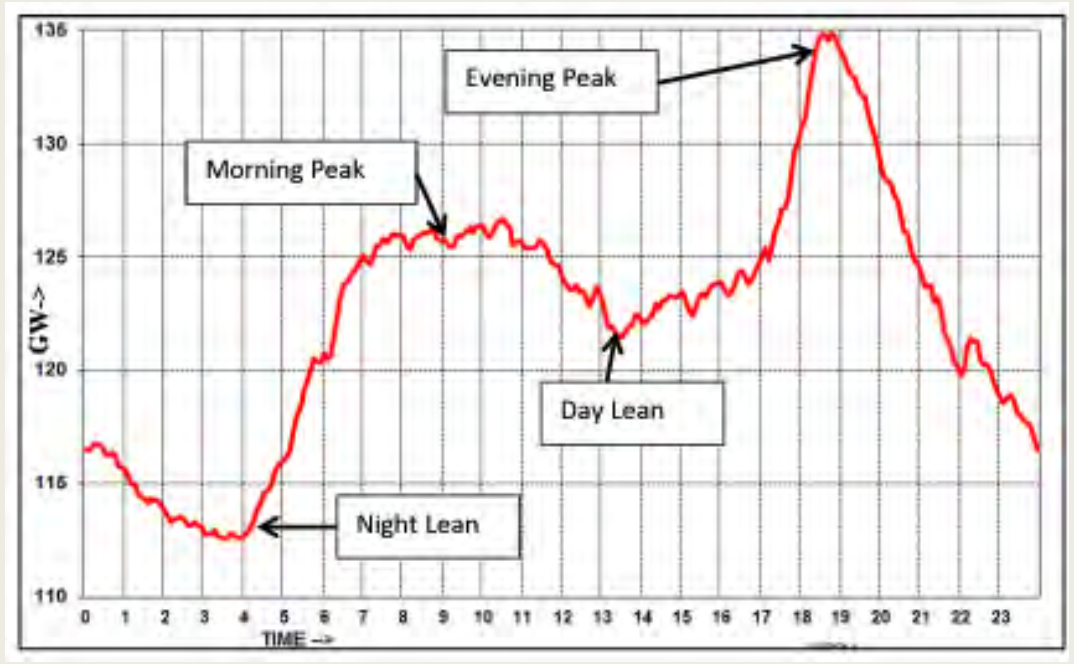


ASME, "The Guide to Hydropower Mechanical Design", Prepared by the ASME Hydro Power Technical Committee, HCI Publications, 1996, (Extract, Figure 3-19 and Figure 4-1), **P-0604**

Power System Operation

- Varies seasonally, daily and regionally
- Daily availability declaration
- Most plants follow load
- Frequency and Voltage maintained by generators
- Dispatch Operator defines daily peaking or ancillary service (spinning reserve, frequency control, etc.)

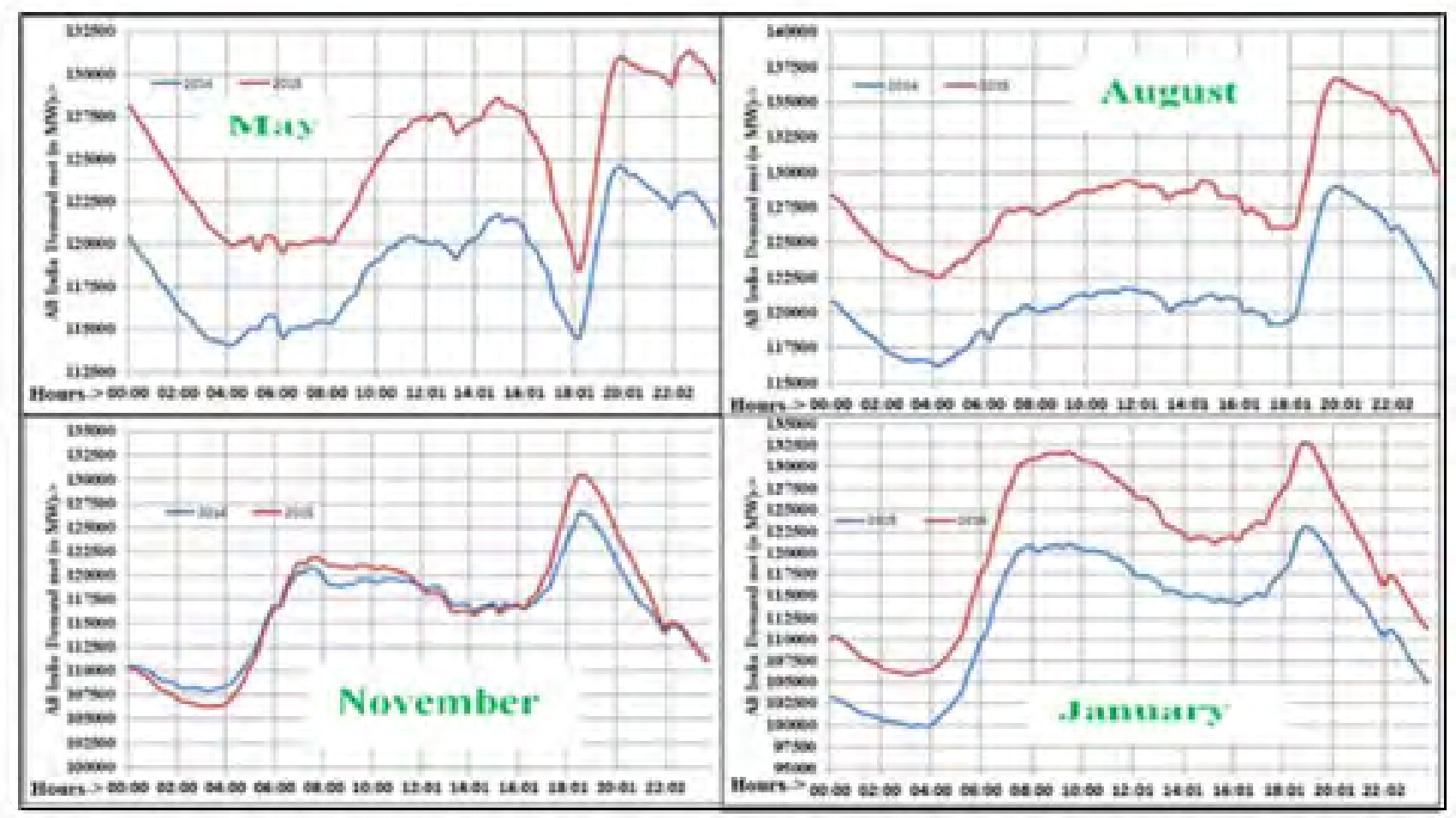
Typical Daily Demand



Power System Operation Corporation Ltd, "Electricity Demand Pattern Analysis", POSOCO 2016. (Extract, Figures 1, 7 and Section 16.3.3), **P-0605**

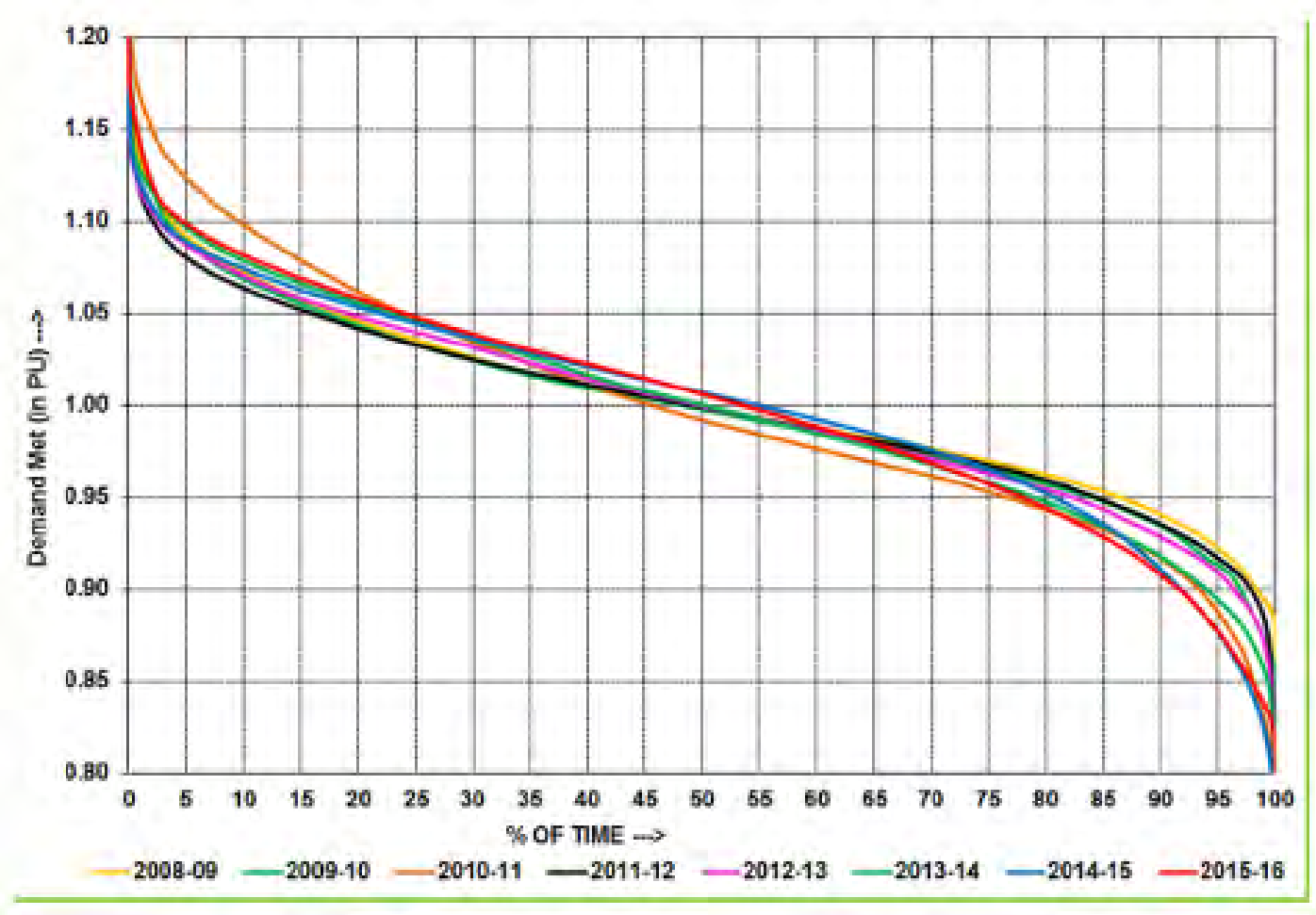
Daily Demand by Season

- Significant seasonal variation in load curves
- No unique "Load Curve"



Power System Operation Corporation Ltd, "Electricity Demand Pattern Analysis", POSOCO 2016. (Extract, Figures 1, 7 and Section 16.3.3), **P-0605**

Average Load Duration Curve by Year



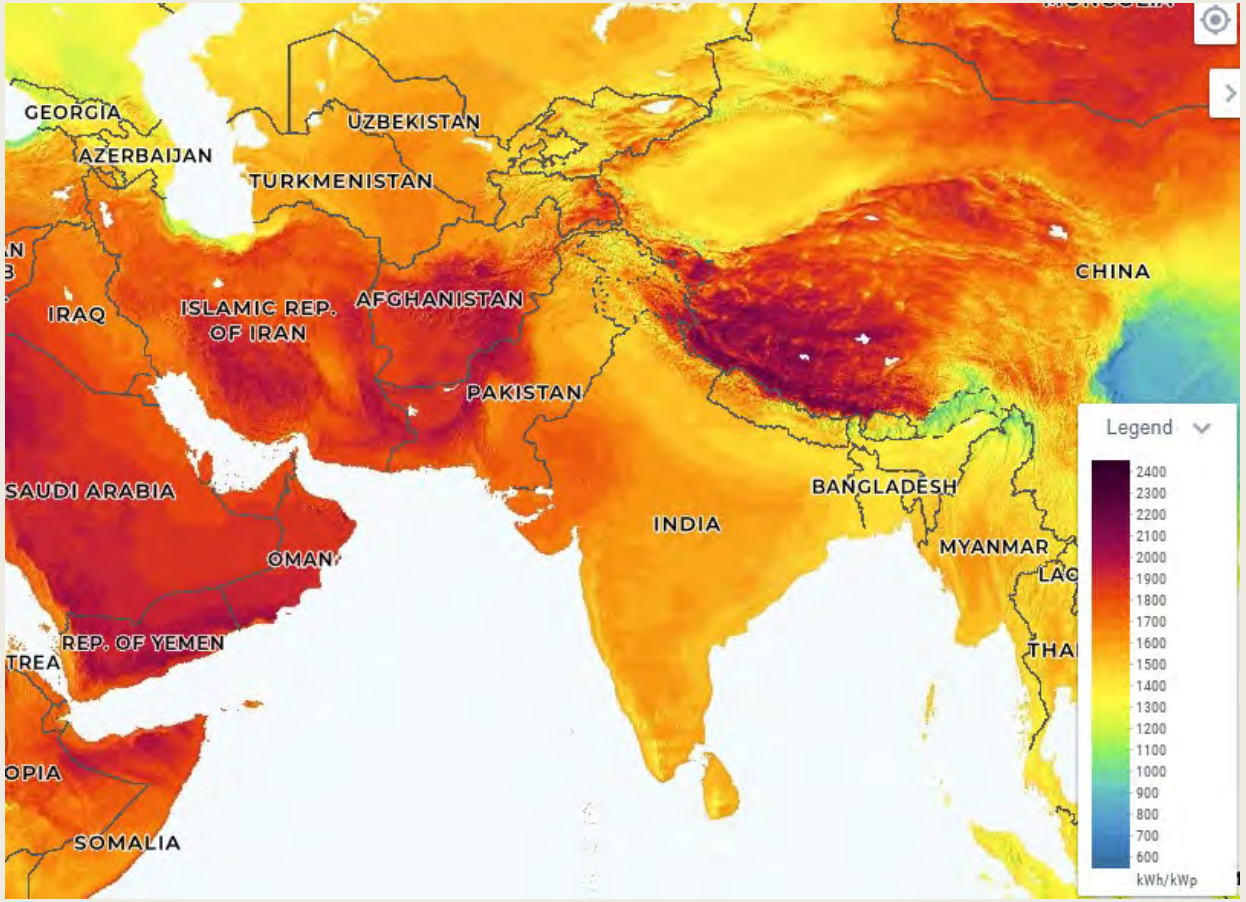
Daily load variation about ±20 of Average Load

Power System Operation Corporation Ltd, "Electricity Demand Pattern Analysis", POSOCO 2016. (Extract, Figures 1, 7 and Section 16.3.3), **P-0605**

Operation with Other Renewable Energy Sources

Other Renewable Generation

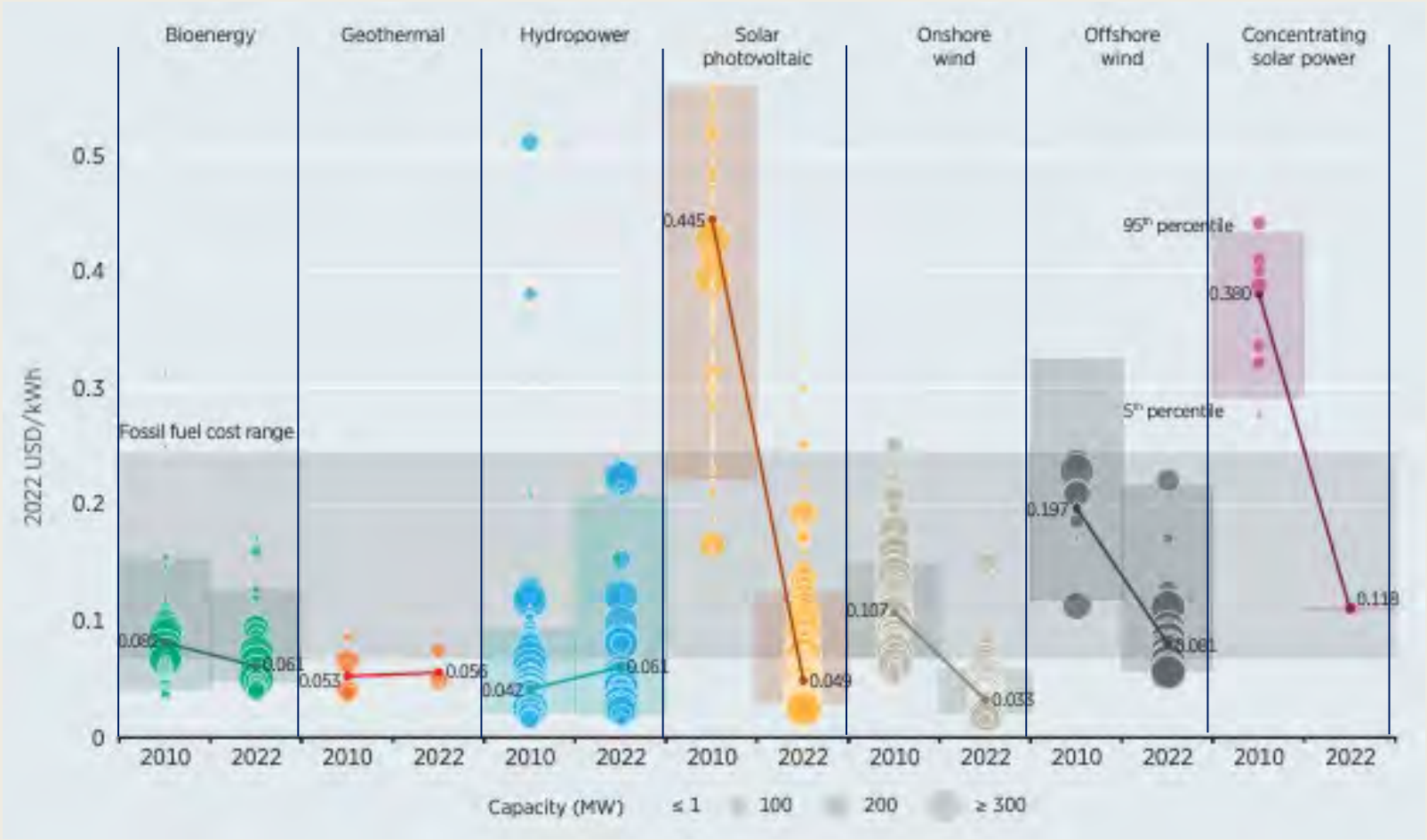
- ❑ Predominantly Wind and Solar sources
- ❑ Energy generated when available
- ❑ Not available on-demand
- ❑ Energy is used immediately
- ❑ Energy Storage
- ➢ Conventional – pre-transformation
- ➢ Renewable storage - after transformation (e.g., batteries, Pumped Storage Hydro, compressed air, etc.)



Global Solar Atlas Available at: https://globalsolaratlas.info/map?c=11.609193,8.4375,3,

P-0606

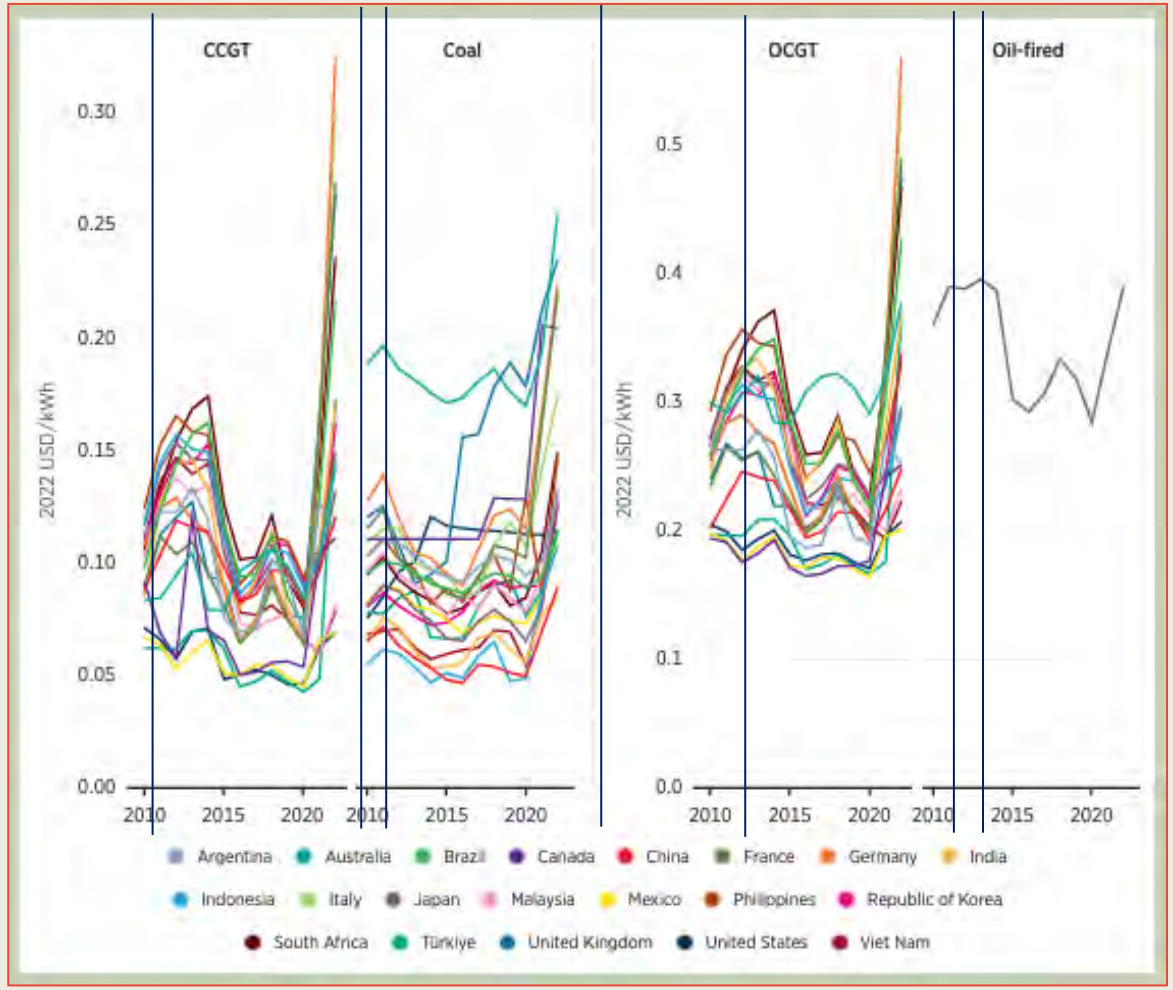
World Renewable Energy Generation Costs



- LCOE 2022
  - Wind $0.033/kWh,
  - Solar $0.049/kWh
  - Hydro $0.061/kWh

International Renewable Energy Agency, "Renewable Power Generation Costs in 2022", IRENA 2023, **P-0611**

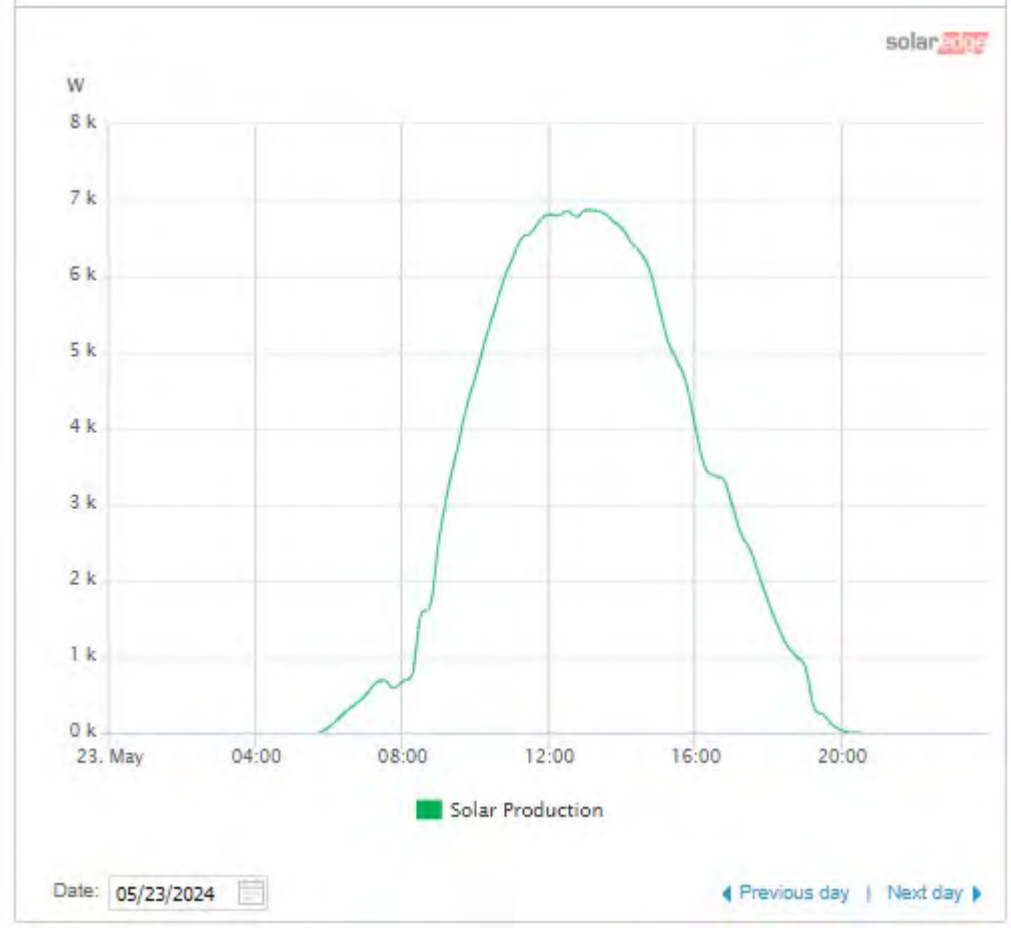
World Thermal Energy Generation Costs

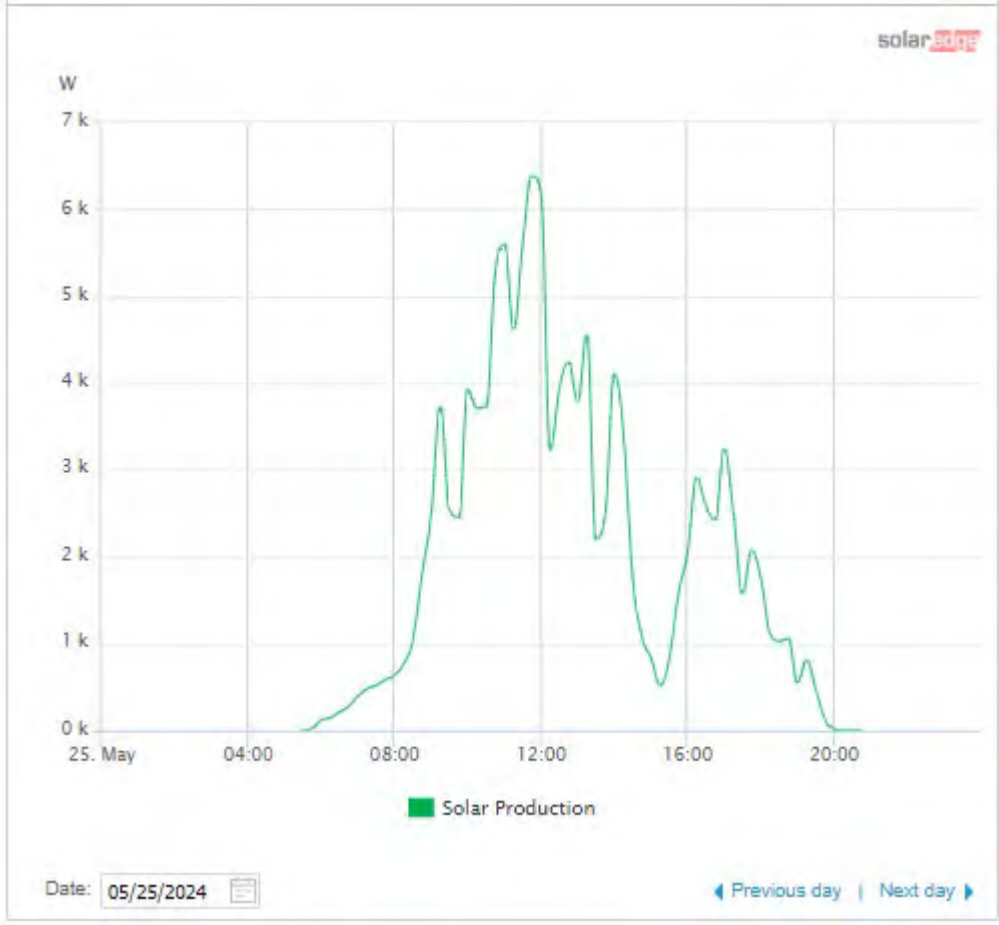


- LCOE 2022
  - Fossil Fuel Plant $0.058/kWh and up
  - Solar & Wind produce energy at lower cost

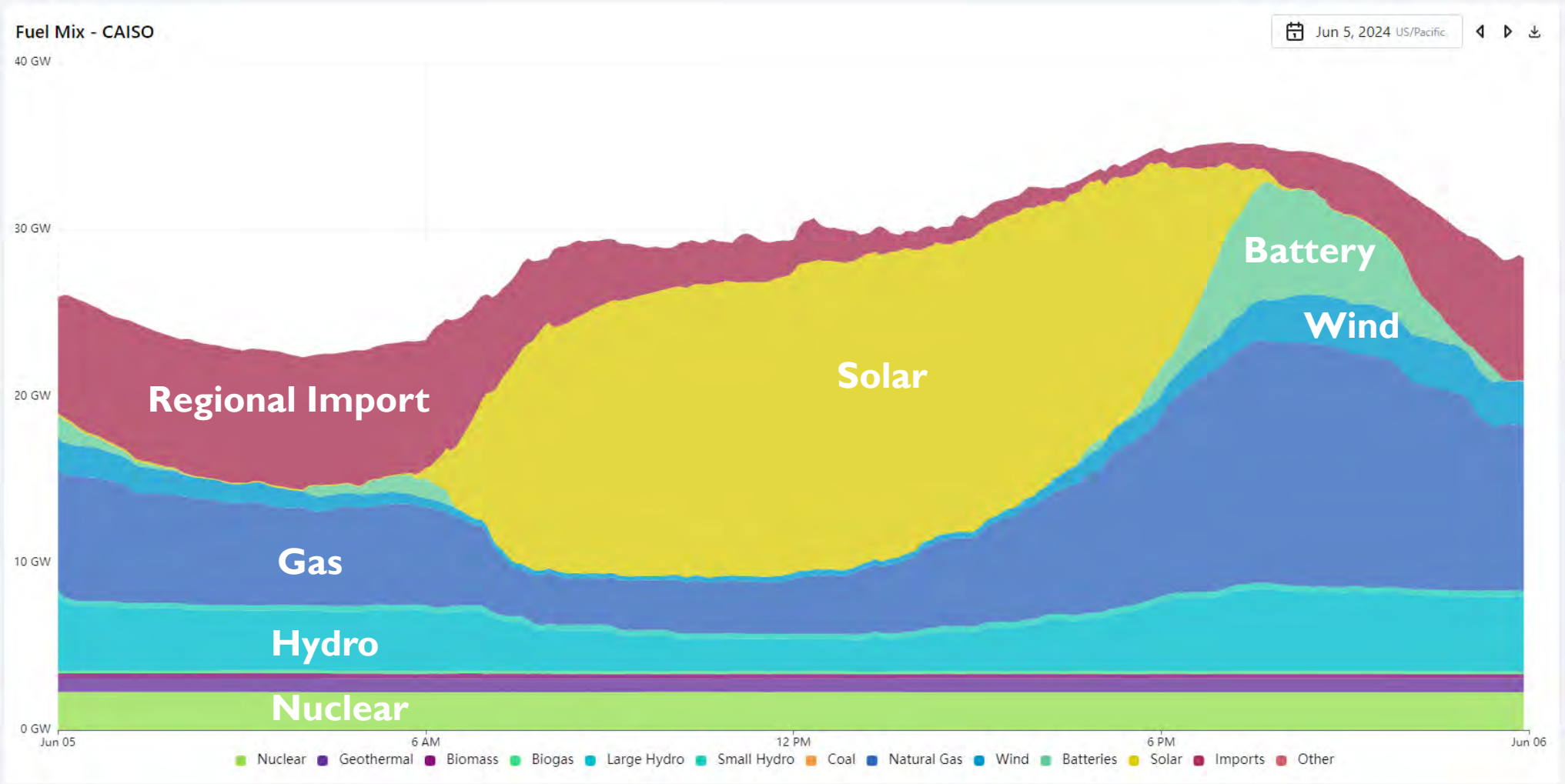
International Renewable Energy Agency, "Renewable Power Generation Costs in 2022", IRENA 2023, **P-0611**

Solar Generation





Generation with Wind and Solar



California Independent System Operator, Grid Status.IO, **P-0607**

Hydro – Solar Hybridization

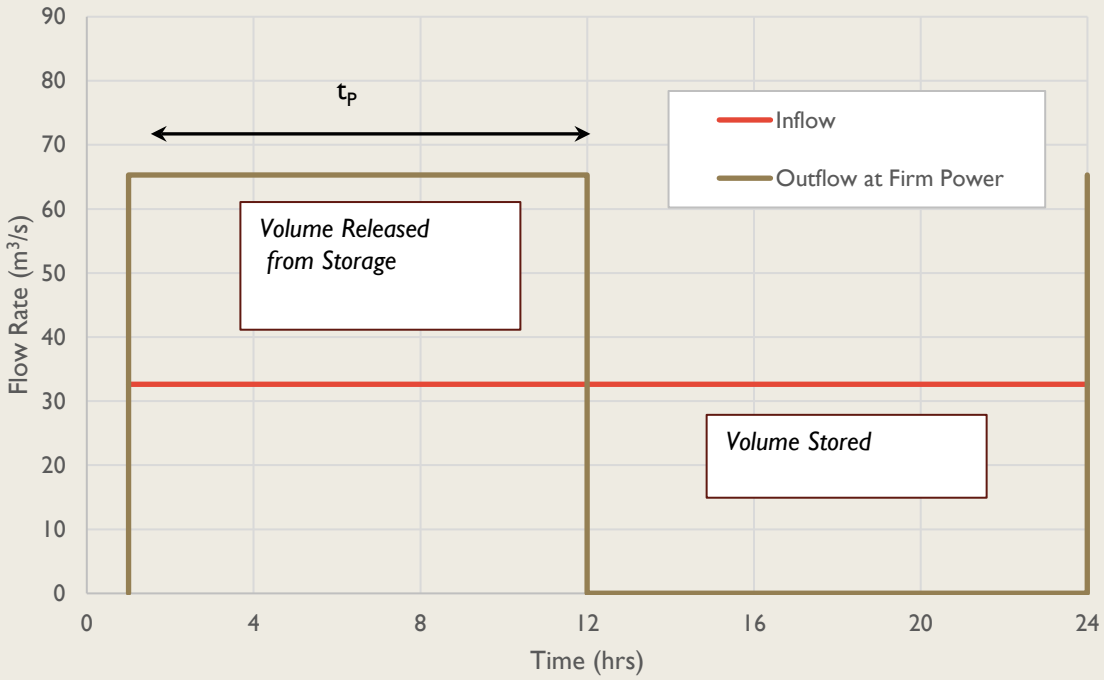
- Key contributions
  - Regulation of solar ramping
  - Spinning & standby reserve
  - Inertia, Reactive Power, etc.
  - Peak period energy storage
- Energy storage - solar energy become dispatchable
- Ancillary services - system quality

- Limitations
  - Energy transfer limited hydrology
  - ROR low flow periods - small energy storage capacity
  - ROR high flow period has no energy storage capacity
  - Ancillary benefits – conflicts with energy transfers

Large solar and wind expansion requires dedicated energy storage

Energy Storage - Pondage

- Pondage:
  - Reservoir storage of limited magnitude that provides only daily or weekly regulation of streamflow (USACE, EM1110-2-1701)
  - Function of (i) inflow and (ii) peak period flow rate
- Pondage can only provide energy storage up to limit of available natural inflow



Pakistan's Memorial, Appendix E2, Figure 1

Summary

Summary Observations - 1

- ❑ Cost trends
  - ➢ Increasing solar and wind generation
  - ➢ Selective Hydro applications
  - ➢ Reducing thermal generation
- ❑ Evolution of power systems to solar and wind with dedicated energy storage (i.e., batteries & pumped storage)

Summary Observations - 2

- ❑ Power system load curves
  - ➢ Vary seasonally and yearly
  - ➢ important for power system planning
  - ➢ Not applicable to individual plant
- ❑ Pondage
  - ➢ Computed from available energy and Firm Power
  - ➢ Daily dispatch for peaking limited to daily flow available
  - ➢ Provision of system ancillary benefits


ایمان اتحاد نظم