International Solar Alliance Expert Training Course

Planning - Transmission network with large scale PV power plants

In partnership with the Clean Energy Solutions Center (CESC)

Professor Oriol Gomis-Bellmunt

September 2019

Supporters of this Expert Training Series

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CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY
An Initiative of the Clean Energy Ministerial

CARBON TRUST

Expert Trainer: Prof Oriol Gomis-Bellmunt

- Professor in the Electrical Power Department of Technical University of Catalonia (UPC)
- Directive board member of the research group CITCEA-UPC, where he leads the group of power systems dominated by power electronics, including renewable energy (PV and wind), HVDC transmission systems and other power converter based systems (energy storage, EV chargers)
- 20+ years of experience in the fields of renewable energy, power electronics and power systems. Involved in a number of research projects and contracts of technology transfer to industry.
- Coauthor of 3 books, 7 patents and > 100 journal publications, mainly in the field of power electronics in power systems and grid integration of renewables.
- Supervision of 18 doctoral theses and >60 Bachelor and Master theses.

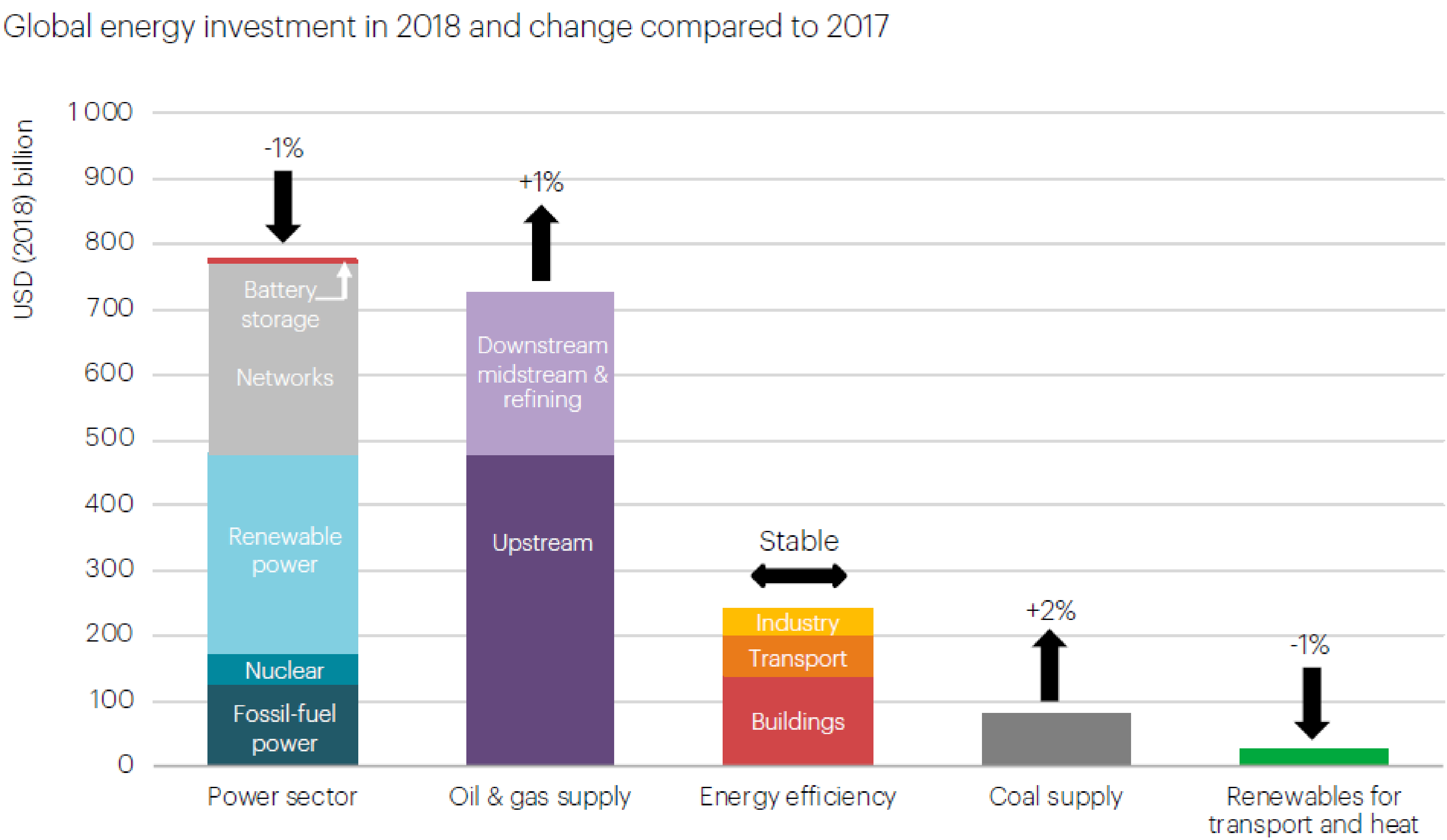
Overview of Training Course Modules

This Training is part of Module 4, and focuses on the issue of planning of transmission systems with PV.

Outline

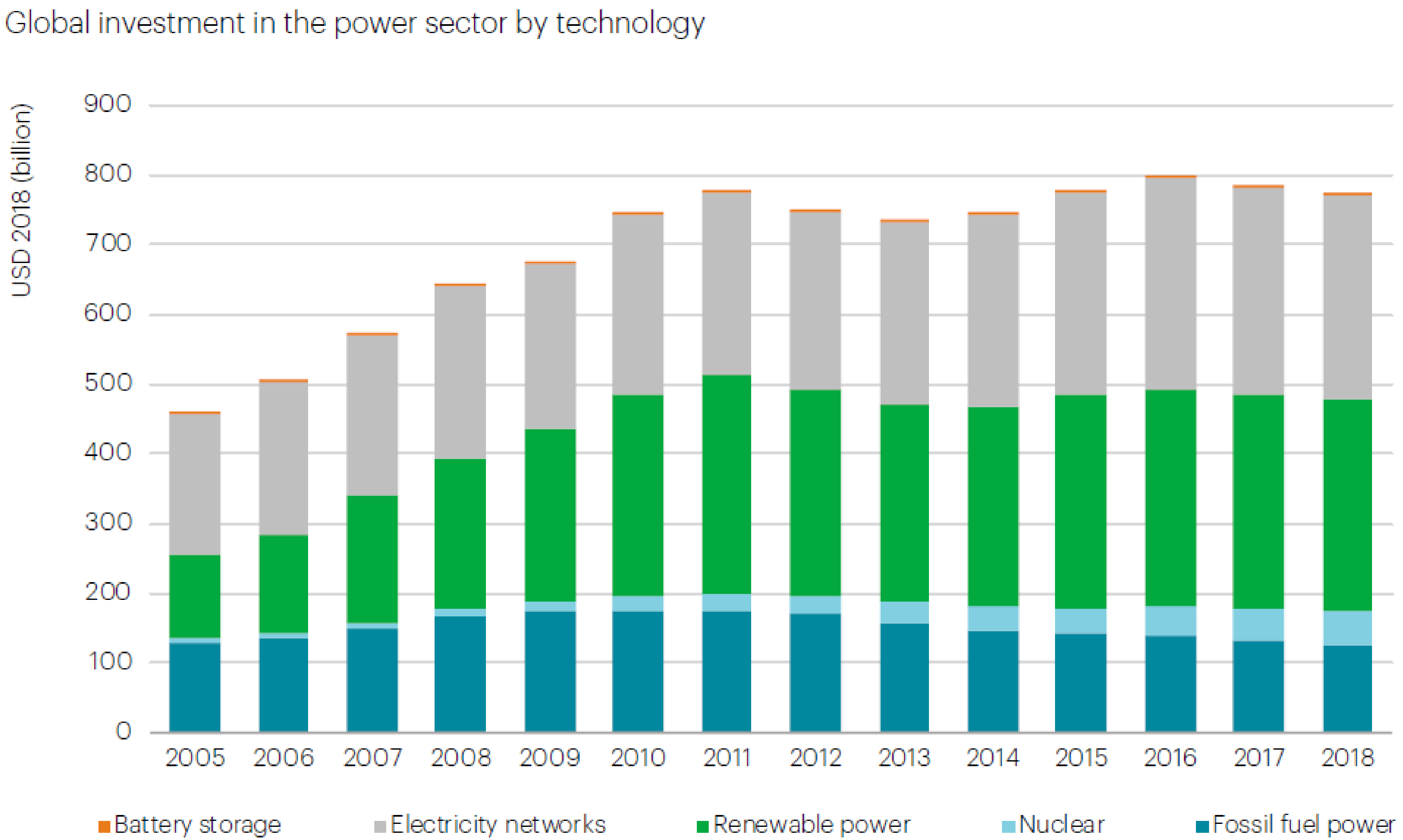
- Introduction
- Challenges for the transmission systems and the system operation
- Transmission system planning
- Example studies

Global investments worldwide



World Energy Investment 2019, IEA

Global investments worldwide – electrical power sector



World Energy Investment 2019, IEA

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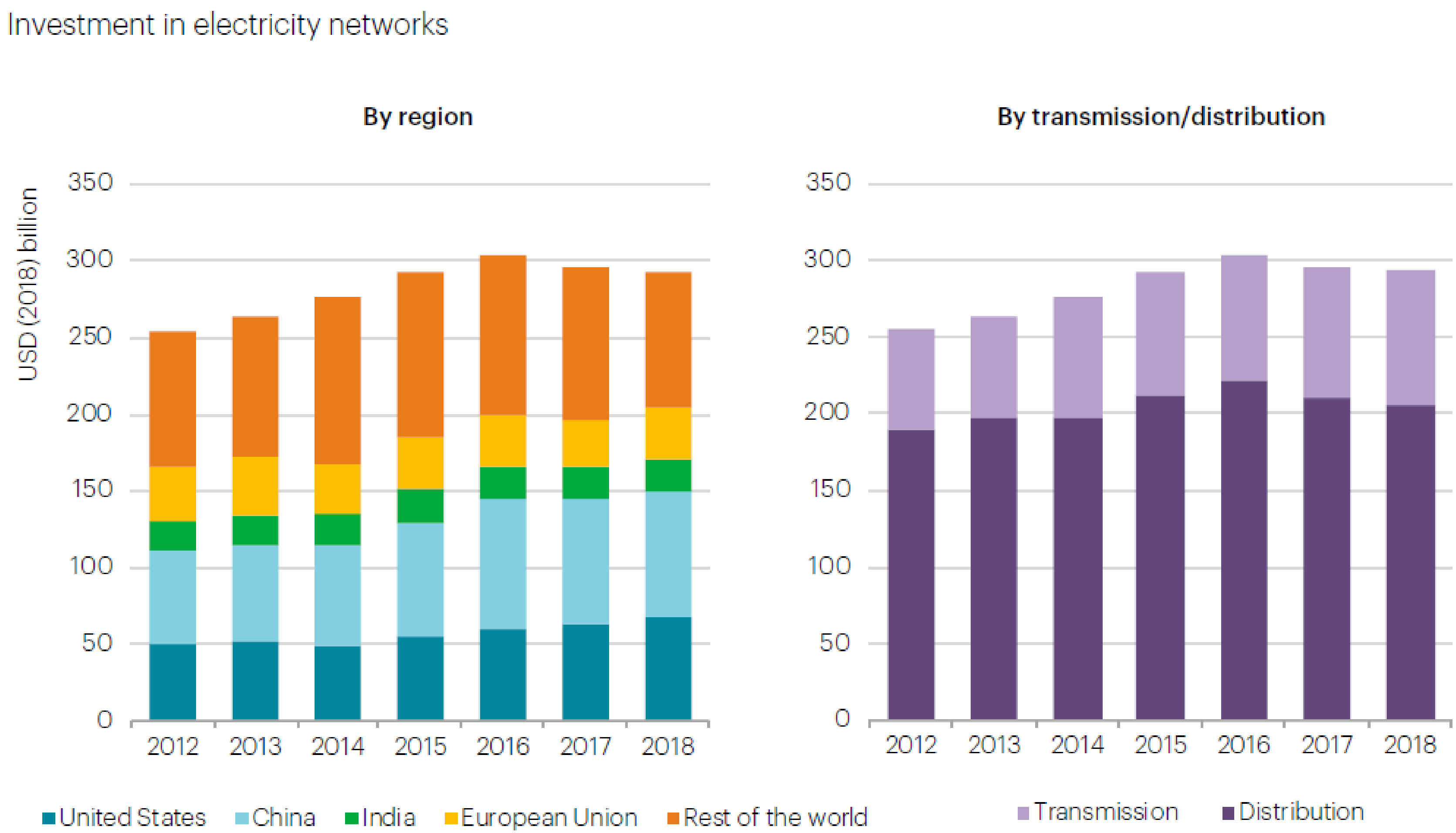
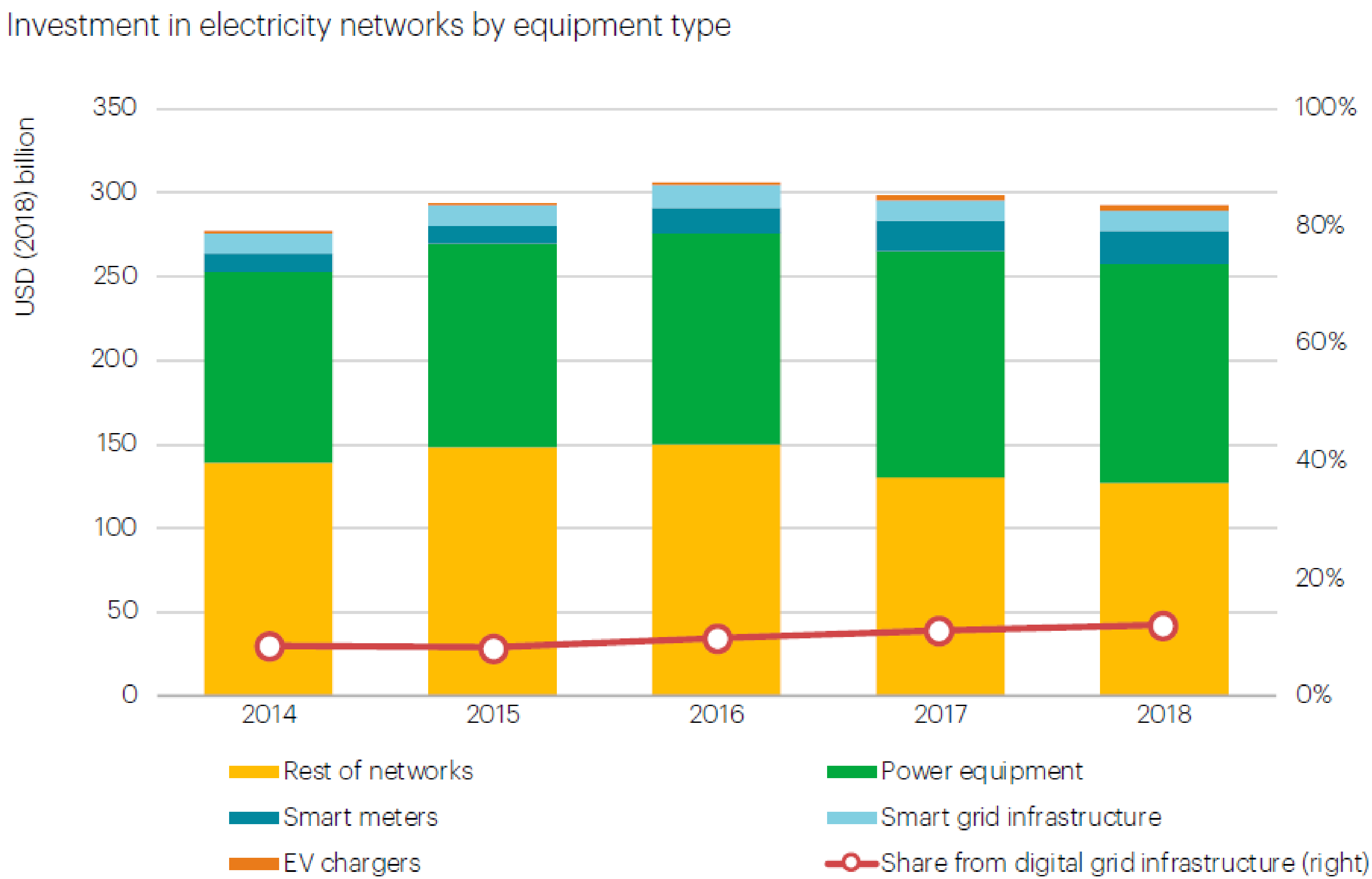
Global investments worldwide – electrical power sector - networks



World Energy Investment 2019, IEA

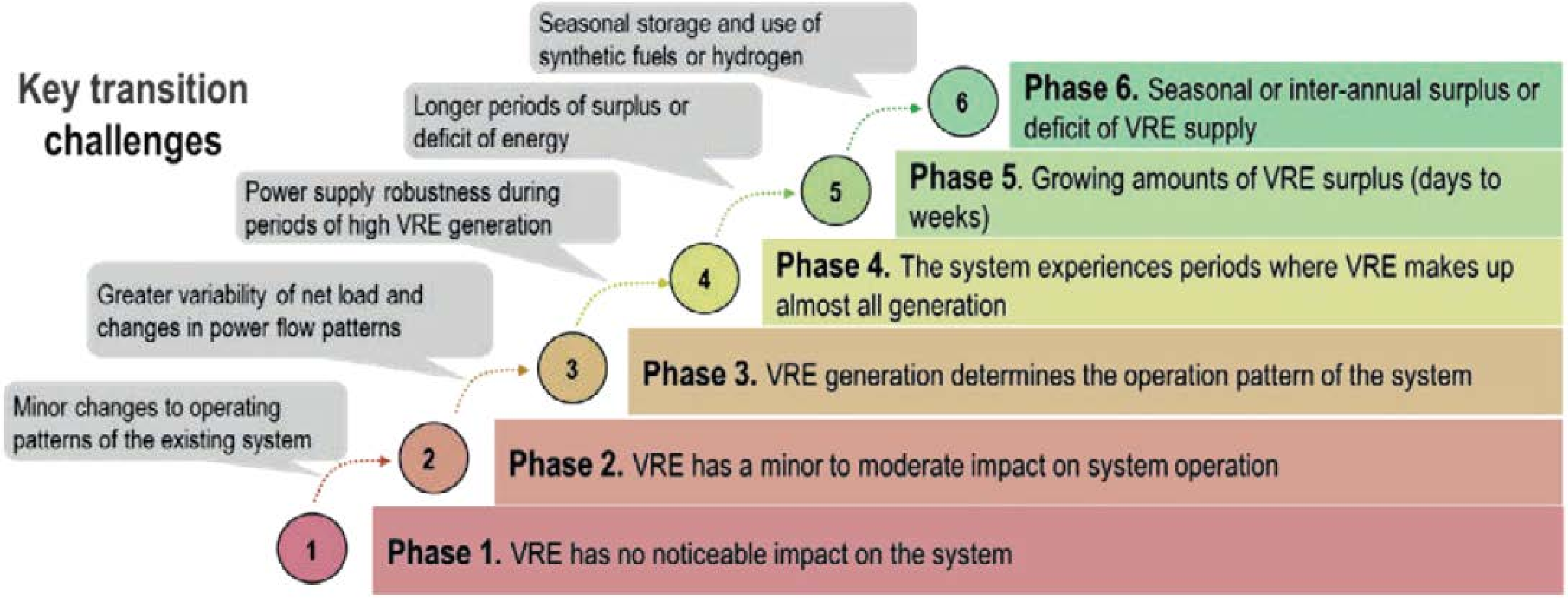
Global investments worldwide – electrical power sector - networks



World Energy Investment 2019, IEA

System integration

Figure 1. Key characteristics and challenges in the different phases of system integration

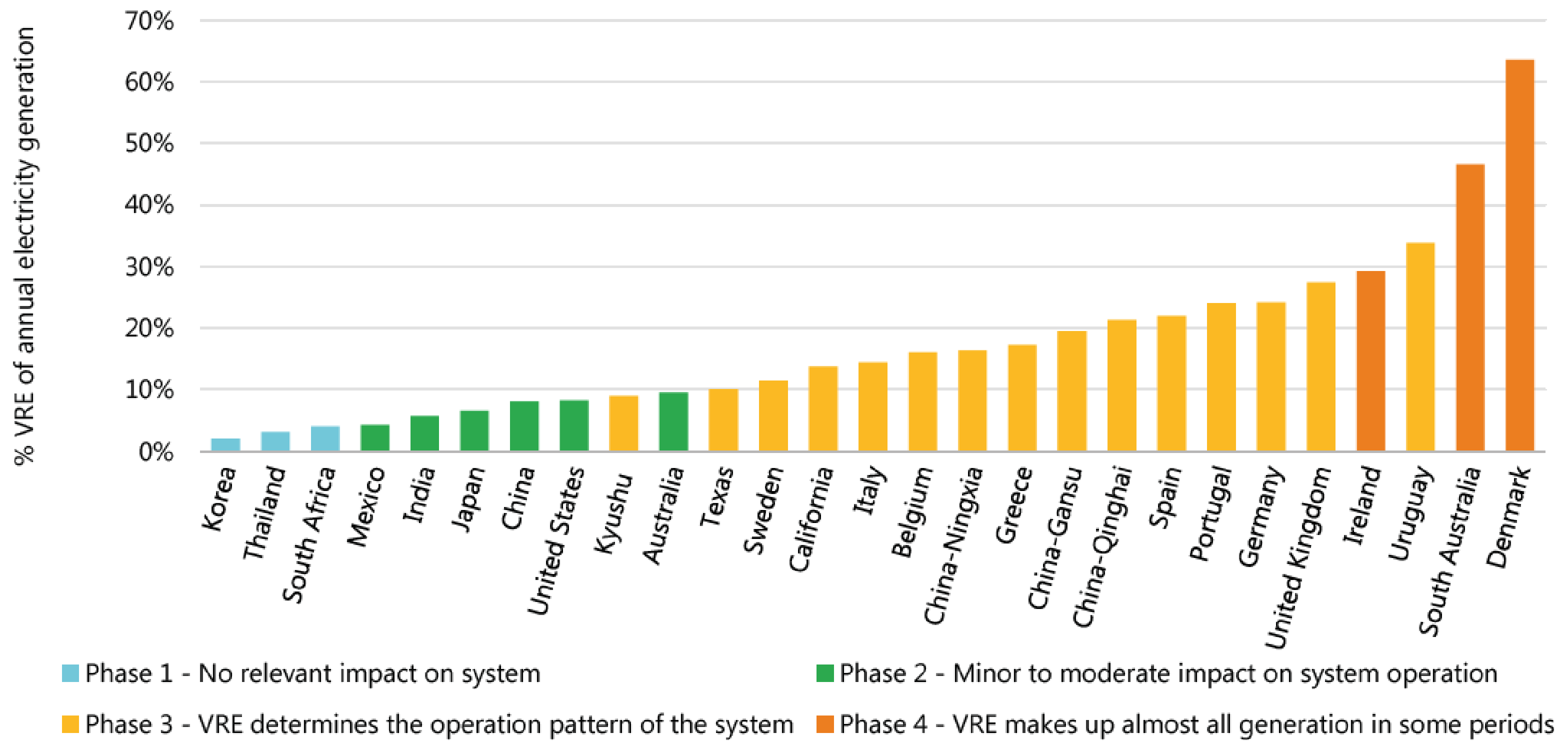


Source: Adapted from IEA (2018a), *World Energy Outlook 2018.*

IEA (2019), "Status of Power System Transformation 2019"

System integration in different countries

Figure 2. Annual VRE share and corresponding system integration phase in selected countries/regions, 2018



Note: China = the People's Republic of China.

Source: IEA (forthcoming), *Renewables 2019: Analysis and Forecasts to 2024*.

IEA (2019), "Status of Power System Transformation 2019"

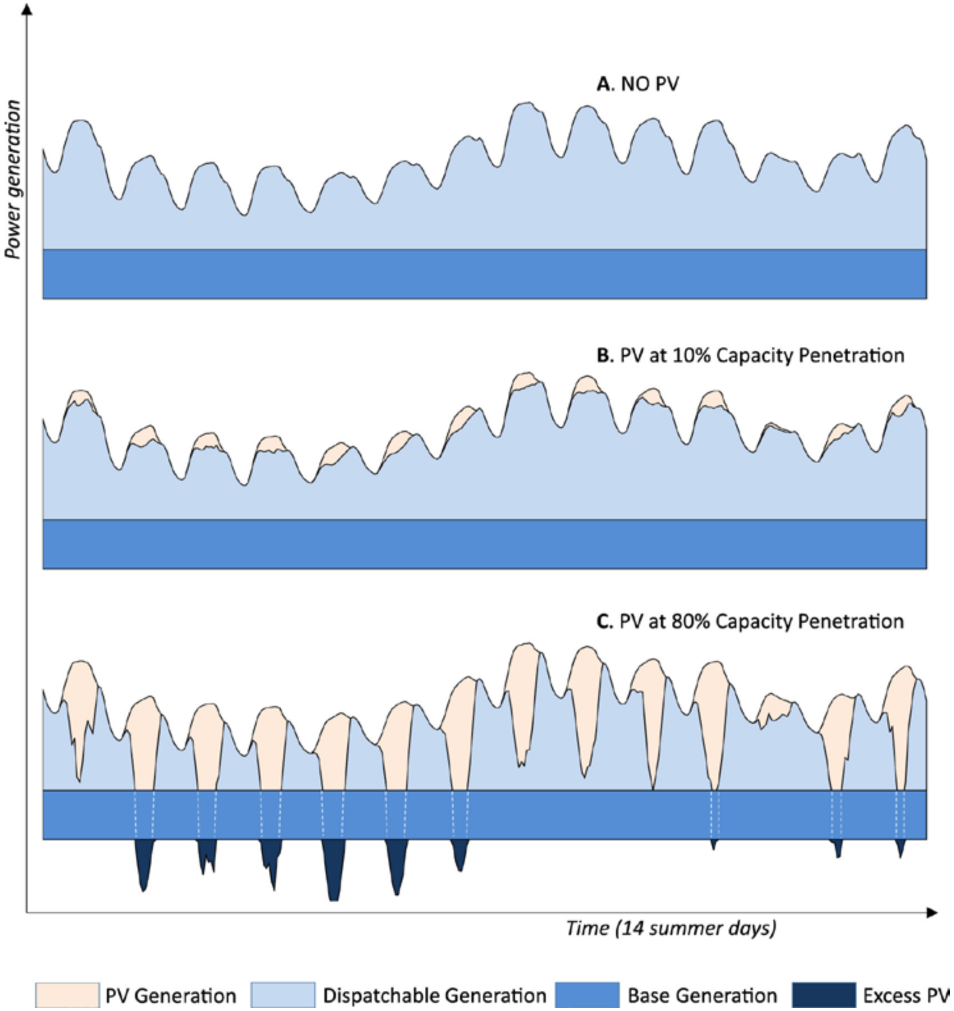
Challenging the transmission system

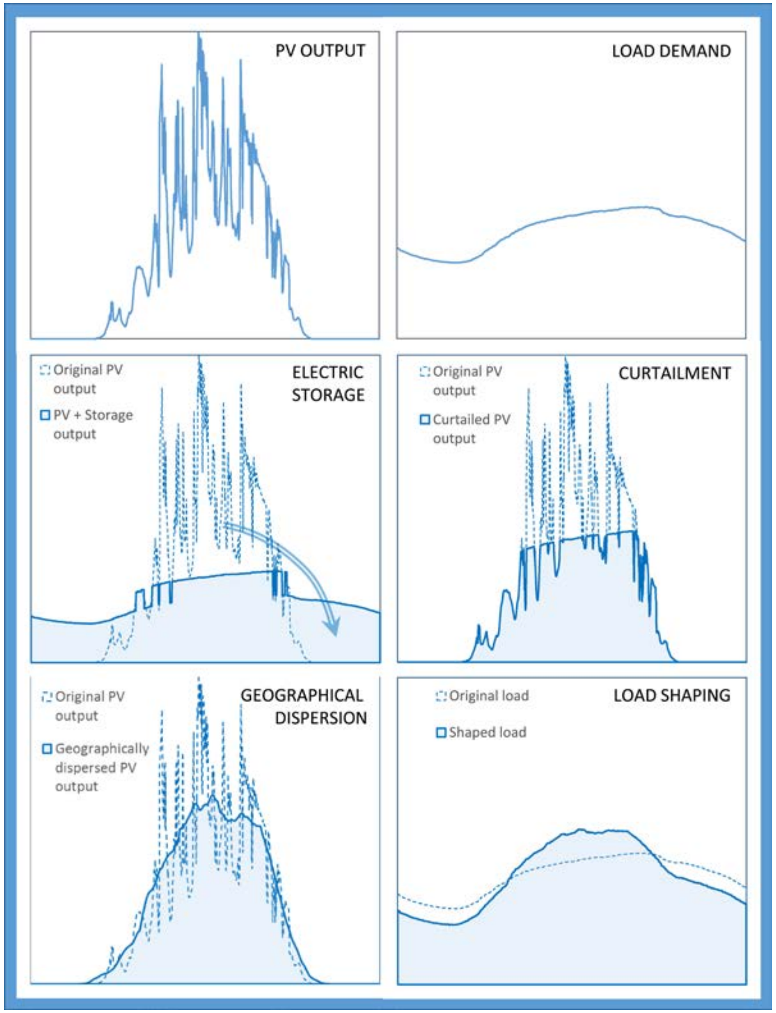
- PV generation has strong variability and limited predictability. This is an important difference with conventional thermal and hydro power generation with controllable output.
- PV power plant output varies periodically in different time scales (years, seasons, days)
- High penetration of PV generation is a challenge for the transmission system:
  – Demand-generation balancing
  – Frequency fluctuations
  – Voltage and power flow issues

Transmission system planning

- In conventional systems, the planning is oriented to ensure the correct performance of the system to meet the peak load.
- In systems with significant penetration of renewables, the system energy and power needs has to be satisfied continuously. Non-dispatchable renewables (wind and PV) are generation sources which cannot be considered (power) capacity sources. The power capacity we expect from them has to be much lower than the nominal power and changes during the time depending on the resource availability.
- This implies that the system needs to take into account the so-called net-load (considering non-dispatchable generation)

PV variability and conceptual solutions



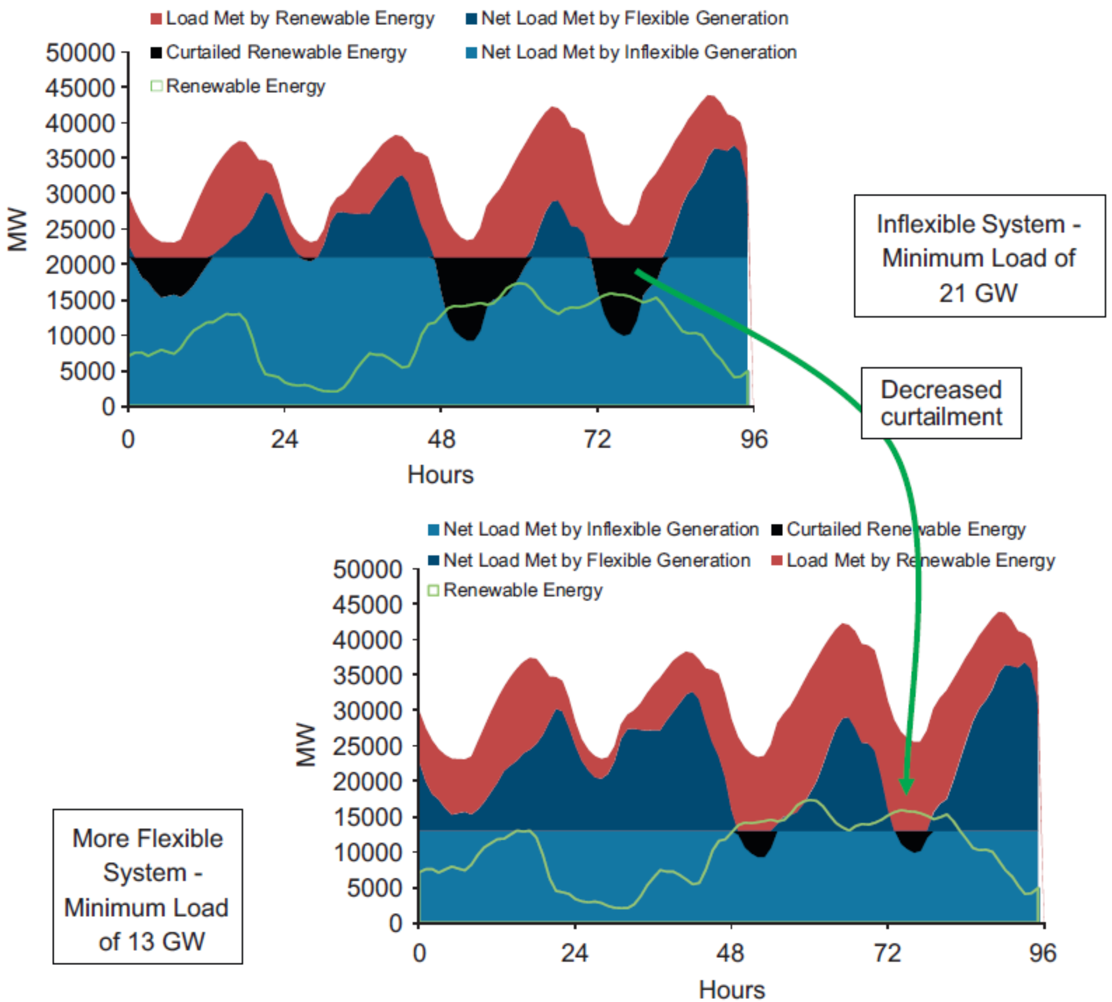


Perez et al "Achieving very high PV penetration – The need for an effective electricity remuneration framework and a central role for grid operators" Energy Policy 2016

Transmission system planning

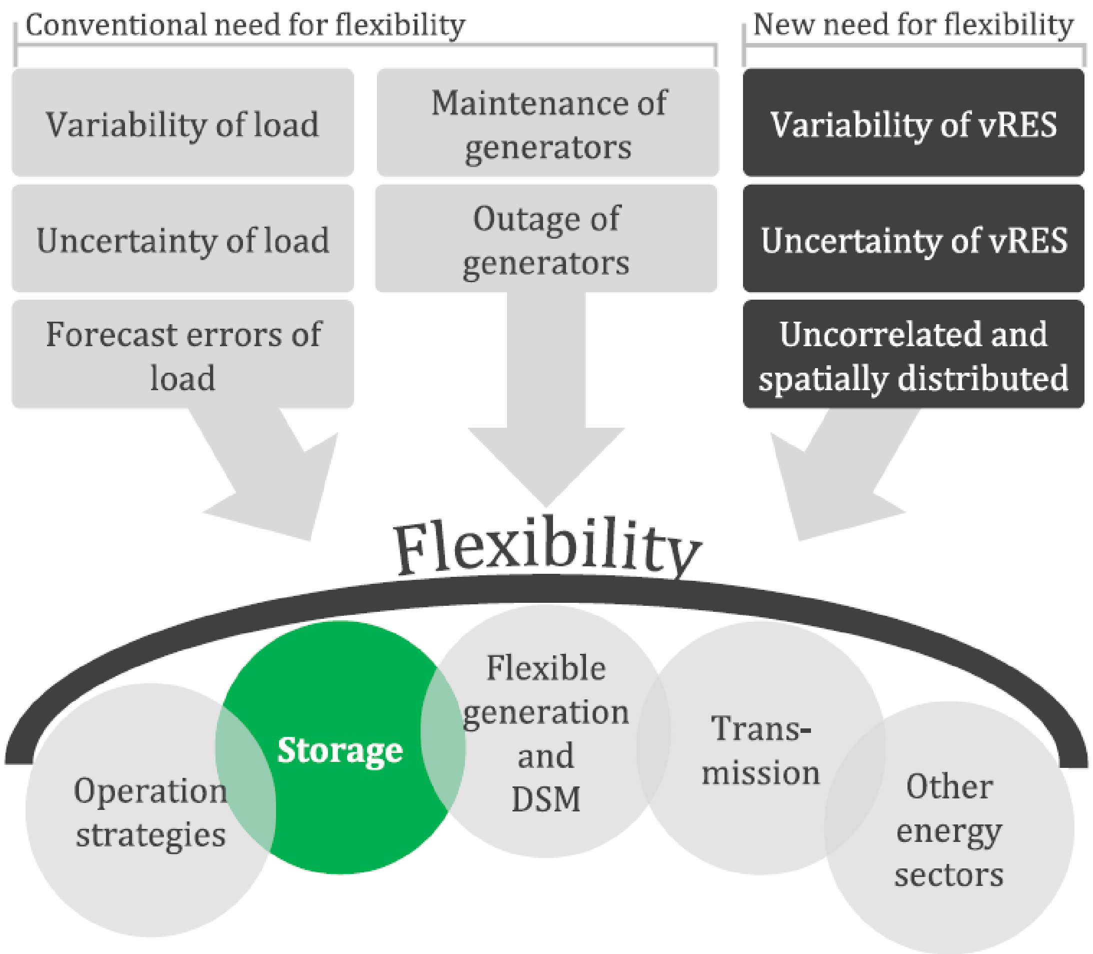
- Transmission system planning needs to study the system impact of variable generation, considering how the load and variable generation changes. Studies need to take into account the potential accuracy of forecast systems which will be employed. This is important for the transmission system planning, because the deviations will need to be balanced by the rest of the network using the transmission network.
- It needs to be ensured that the system include sufficient flexibility

Impact of system flexibility on curtailed energy



Denholm and Hand, "Grid flexibility and storage required to achieve very high penetration of variable renewable electricity" Energy Policy

How is the flexibility achieved?



Haas et al "Challenges and trends of energy storage expansion planning for flexibility provision in low-carbon power systems – a review" Renewable and Sustainable Energy Reviews

Renewable energy zone (REZ) transmission planning process

STEP 1. PROCESS DESIGN & VISION STATEMENT

STEP 2. RENEWABLE ENERGY RESOURCE ASSESSMENT

Summary: Select areas with highest potential

Output: Study areas map and supply curves

- Assess resource
- Screen exclusion areas
- Identify the areas with the highest quality, developable resource

STEP 3. CANDIDATE ZONES SELECTION

Summary: Identify zones with highest probability of development

Output: Candidate zone map and supply curves (one per area)

- Gauge commercial interest
- Identify areas where high quality resources intersect with commercial interest

STEP 4. TRANSMISSION OPTIONS DEVELOPMENT

Summary: Bundle candidate zones and conduct analyses of the options

Output: Cost, benefit, and reliability impacts for each transmission alternative

- Select scenario creation (bundling) methodology
- Conduct cost-benefit analysis of options
- Steady-state, dynamic stability, production cost, and reliability analysis

STEP 5. FINAL TRANSMISSION PLAN DESIGNATION

Summary: Select transmission option according to pre-set criteria

Output: Final transmission order

- Select transmission option that best complies with predetermined criteria, including reliability standards, economic benefits, and environmental goals

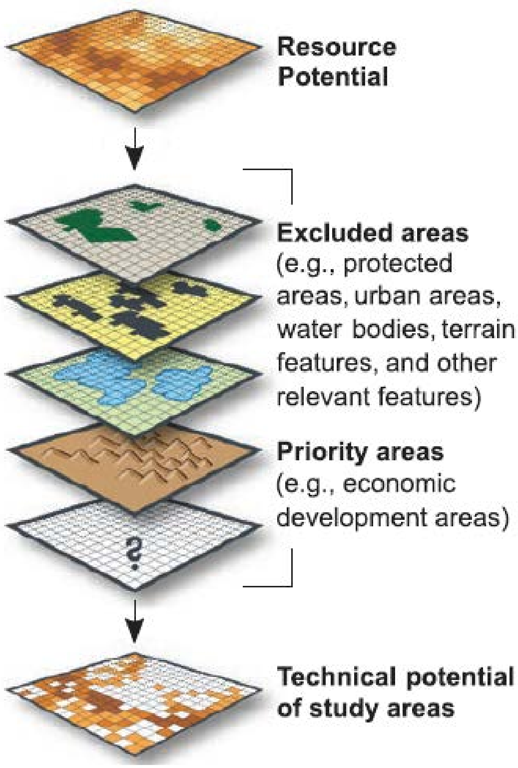
STEP 6. TRANSMISSION SYSTEM UPGRADE

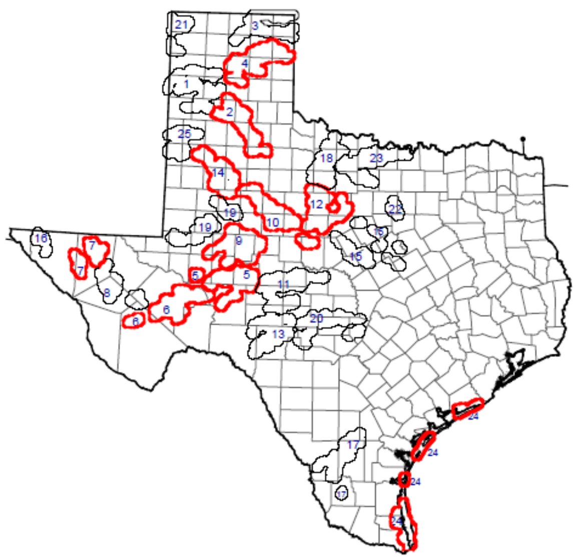
- Transmission planning decisions need to be made well in advance of renewable generation development decisions. Wind and solar power pants are located where the resource is, typically far away from load centers.
- Transmission system access to these areas may require 5–10 years to plan and construct; wind and solar generation projects only require 1–3 years to construct.
- Financing for these remote generation projects is not available without transmission access, but transmission lines cannot be built without a demonstrated need for service.
- Renewable energy planning that does not consider transmission expansion may limit countries to less economical renewable energy development.

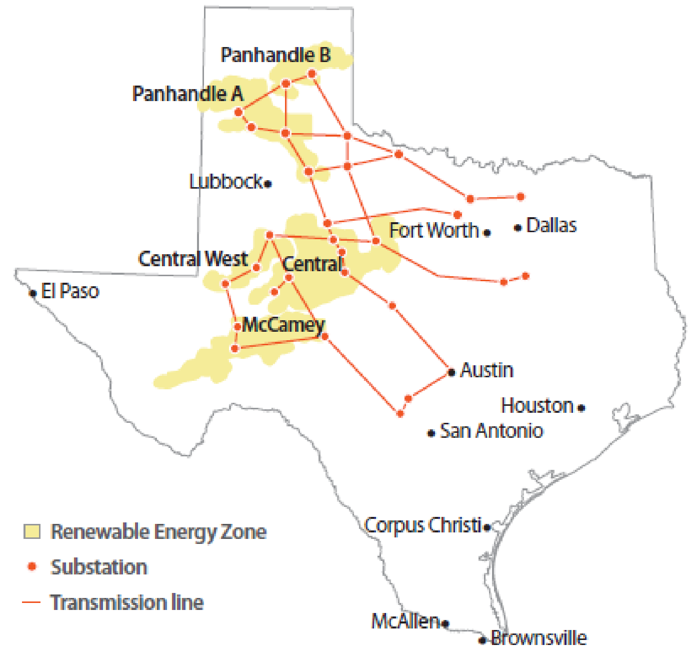
Lee et al. NREL, Renewable energy zone transmission planning process: A guidebook for practitioners

Renewable energy zone (REZ) transmission planning process

Resource assessment → Candidate zones selection → Transmission planning







Lee et al. NREL, Renewable energy zone transmission planning process: A guidebook for practitioners

Transmission system planning

- Adaptation or expansion of the transmission system can be needed, as the integration of massive amount of renewables can changes significantly the power flows. This can be achieved with
  - Conventional solutions: Building new lines and substations.
  - Flexible power system solutions:
    - Using power electronics (FACTS, HVDC) to better control the system.
    - Using energy storage systems or demand side management.
- Studies need to consider also outages in the systems and ensure safe system operation in these conditions: security constrained power flow analysis.
- These studies can take into account that modern power systems offer more controllability and flexibility and therefore corrective actions can be rapidly provided from several system units (like power electronics based converters)

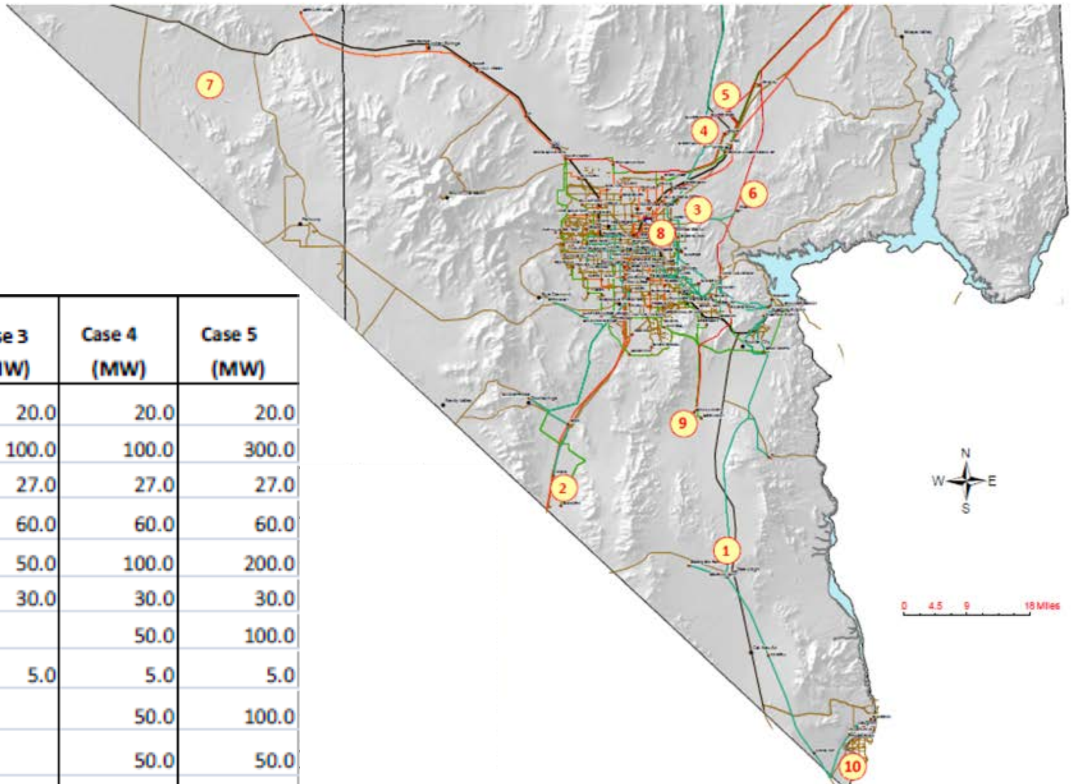
Analysis needed

	Production Cost Analysis	Load Flow Analysis	Stability Analysis
Purpose	Estimate operational cost and performance impacts on the power system that result from transmission expansion options	Identify limitations of system operational feasibility and reliability given scheduled and reasonably expected, unscheduled outages; refine cost estimates	Identify reliability limitations and contingency needs of the transmission system to withstand unexpected disturbances and recover to steady state; refine cost estimates
Inputs	Detailed data on: • Generator parameters • Storage parameters • Load (profile and forecast) • Transmission parameters • Substation bus parameters • Electricity market details • Energy or fuel resources • Time-synchronous generation and load data	Detailed data on: • Generator and storage commitment and dispatch for periods of interest • Contingency events • Load • Transmission parameters • Substation bus parameters	Detailed data on: • Generator dynamic models • Inverter control models • Contingency event list • Load • Transmission parameters • Substation bus parameters
Outputs	Detailed data on: • Generation • Operational costs • Electricity prices • Transmission system congestion • Expected renewable energy curtailment • Reserve holding • Lost load probability • Emissions	Detailed data on: • Voltage levels and phase angles at buses • Active and reactive power flows in transmission lines • System losses	Detailed data on the dynamic performance of the system in the seconds after simulated faults: • Rotor angle stability • Frequency stability • Voltage stability
Key institutions that may perform or contribute to the analysis	• Ministries of energy • Regulators • System operators or planners • Utilities • Research institutes or consultants	• Regulators • System operators or planners • Utilities • Research institutes or consultants	• Regulators • System operators or planners • Utilities • Research institutes or consultants

Transmission Planning Studies for the Renewable Energy Zone (REZ) Process, N Lee, C Barrows, NREL, USA

An example large scale PV Integration study -> impact on reserves

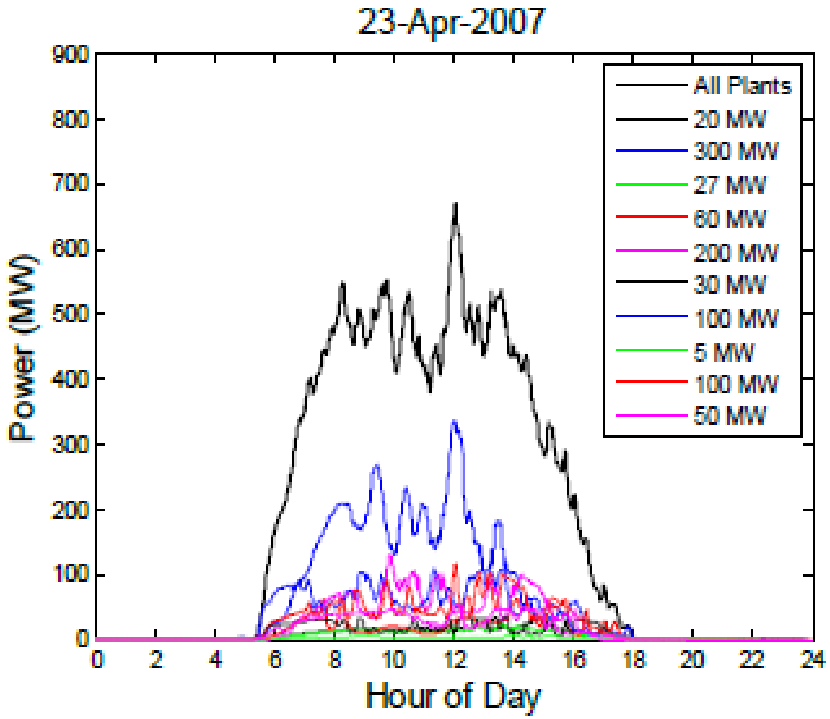
- The study considers almost 900 MW of PV in Nevada (USA).
- PV plants range in size from 5 MW to over 300 MW at ten locations.

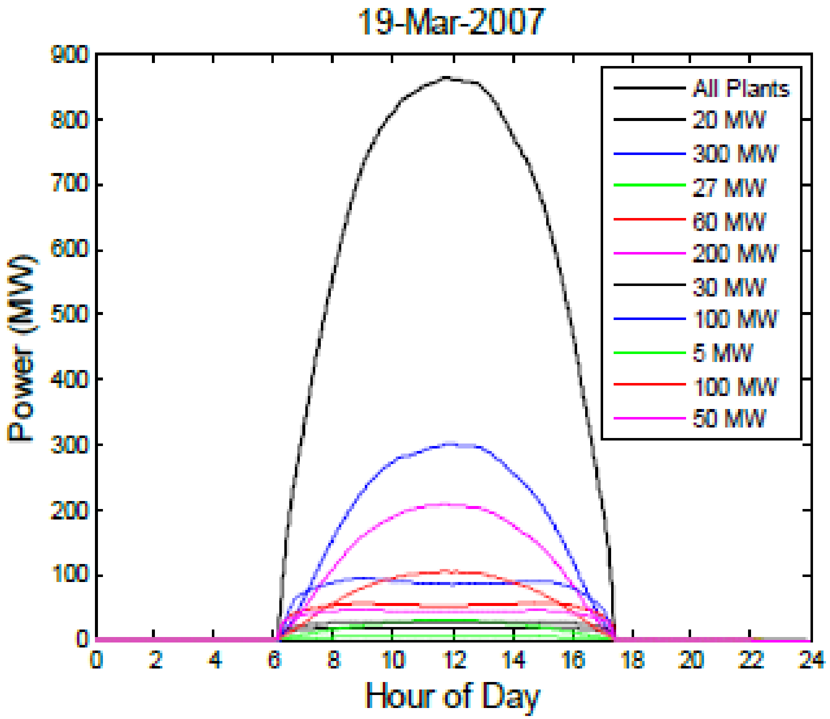


Solar PV Project Map ID	Base Case (MW)	Committed Case 1 (MW)	Case 2 (MW)	Case 3 (MW)	Case 4 (MW)	Case 5 (MW)
Solar PV Project 1	0.0	17.5	20.0	20.0	20.0	20.0
Solar PV Project 2	0.0	50.0	50.0	100.0	100.0	300.0
Solar PV Project 3	0.0	12.0	27.0	27.0	27.0	27.0
Solar PV Project 4	0.0	40.0	40.0	60.0	60.0	60.0
Solar PV Project 5	0.0		50.0	50.0	100.0	200.0
Solar PV Project 6	0.0	30.0	30.0	30.0	30.0	30.0
Solar PV Project 7	0.0				50.0	100.0
Solar PV Project 8	0.0		5.0	5.0	5.0	5.0
Solar PV Project 9	0.0				50.0	100.0
Solar PV Project 10	0.0				50.0	50.0
Total:		149.5	222	292	492	892

PNNL-20677, Large-Scale PV Integration Study, Pacific Northwest National Laboratory

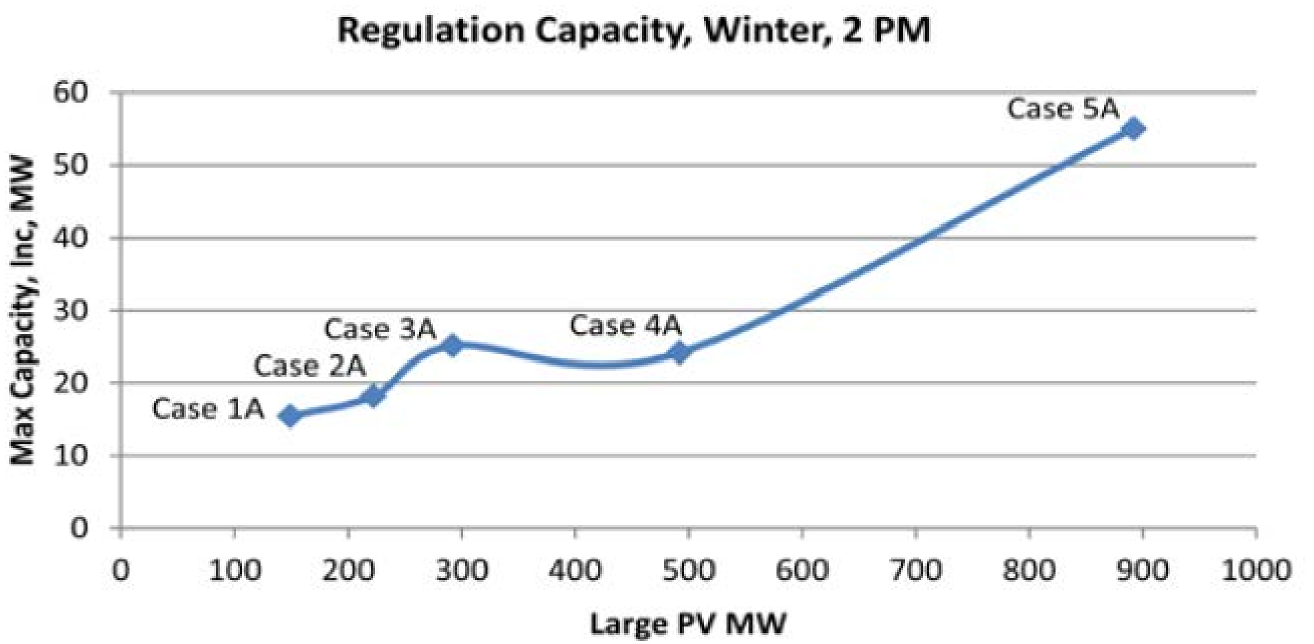
PV production variability





PNNL-20677, Large-Scale PV Integration Study, Pacific Northwest National Laboratory

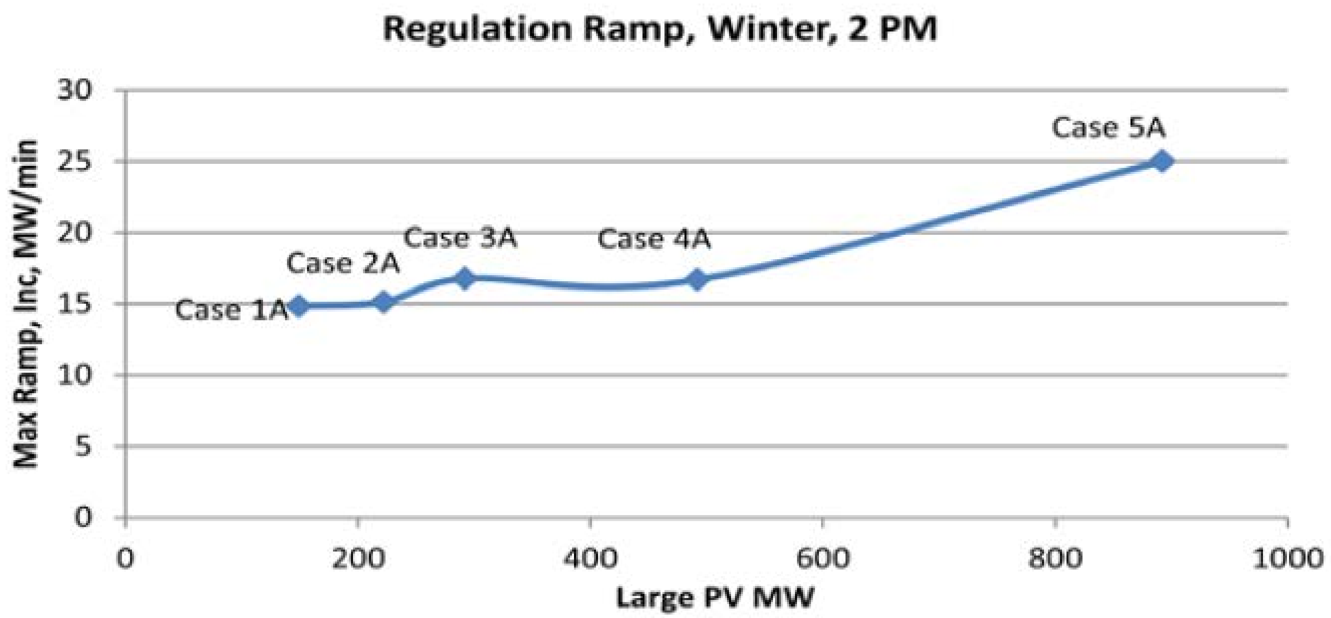
Impact on reserves – regulation capacity



Additional reserve needed for PV installation

PNNL-20677, Large-Scale PV Integration Study, Pacific Northwest National Laboratory

Impact on reserves



Additional ramping capability needed for PV installation

PNNL-20677, Large-Scale PV Integration Study, Pacific Northwest National Laboratory

Summary

- Transmission system planning including large PV power plants is challenging as it has to consider the intermittency and non-dispatch-ability of PV.
- The additional costs related to operation and reserves are relevant and need to be studied for each system.
- Generation cost, power flow and stability studies are needed.

Thanks for your attention!

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