Status of Power System Transformation:
Towards growing share of wind and solar

Dr. Peerapat Vithayasrichareon, *Energy Analyst – System Integration of Renewables*

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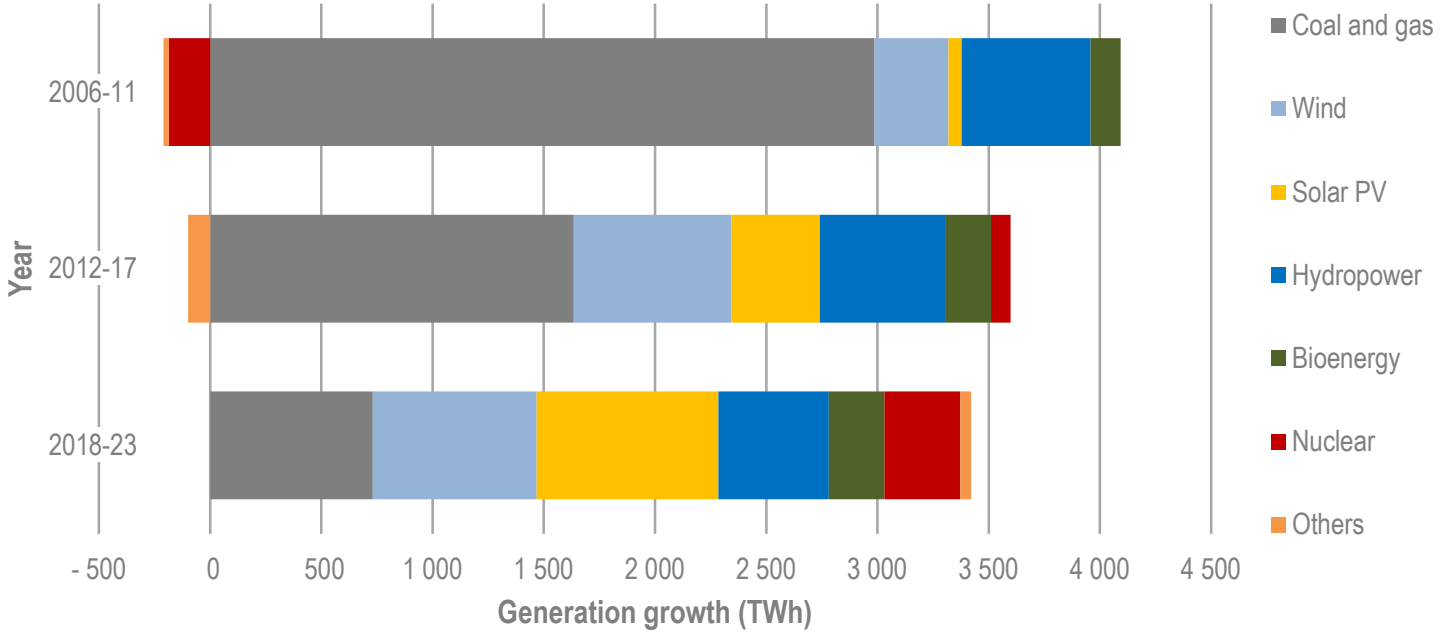
IEA

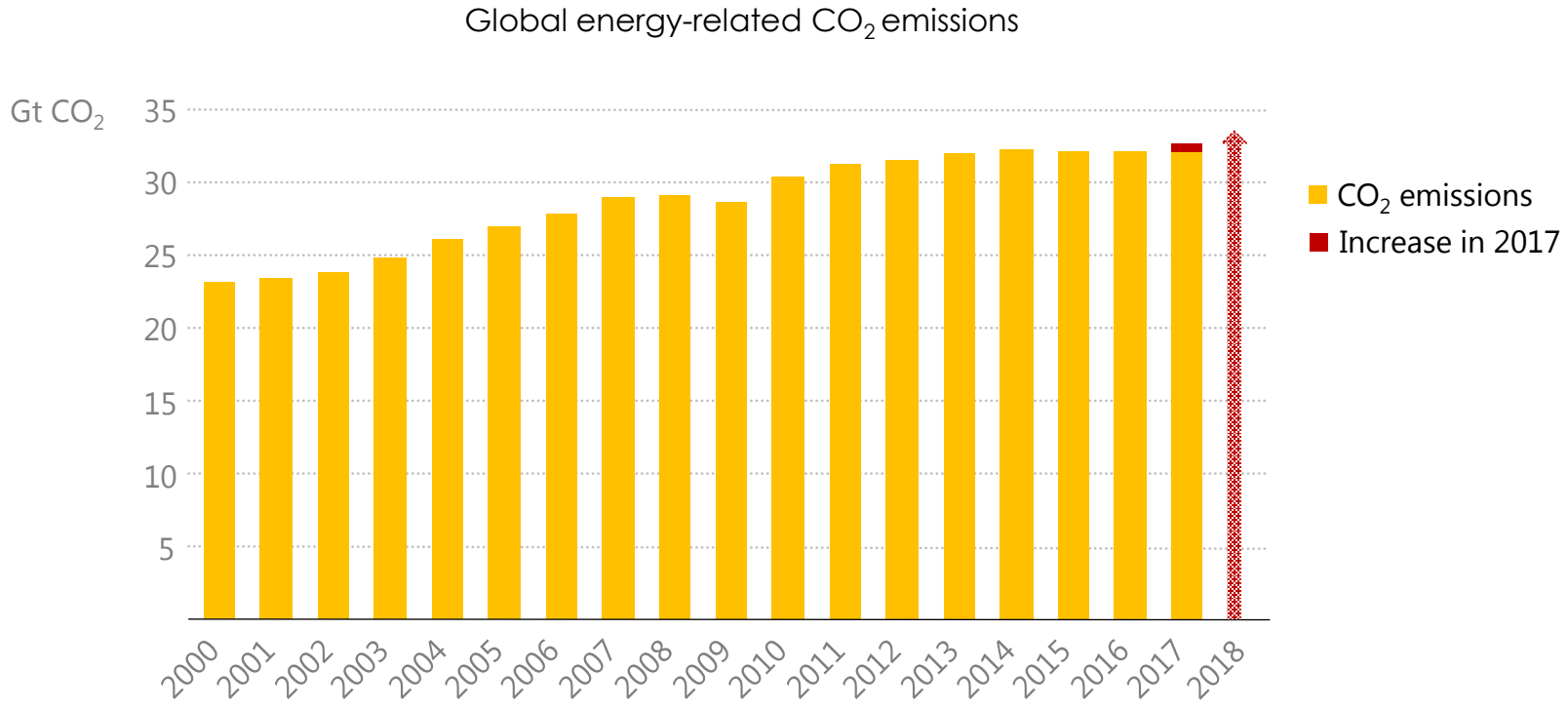
Electricity generation growth by fuel



Renewable generation leads the growth of electricity among different technologies. Expansion of fossil fuel is expected to decline considerably.

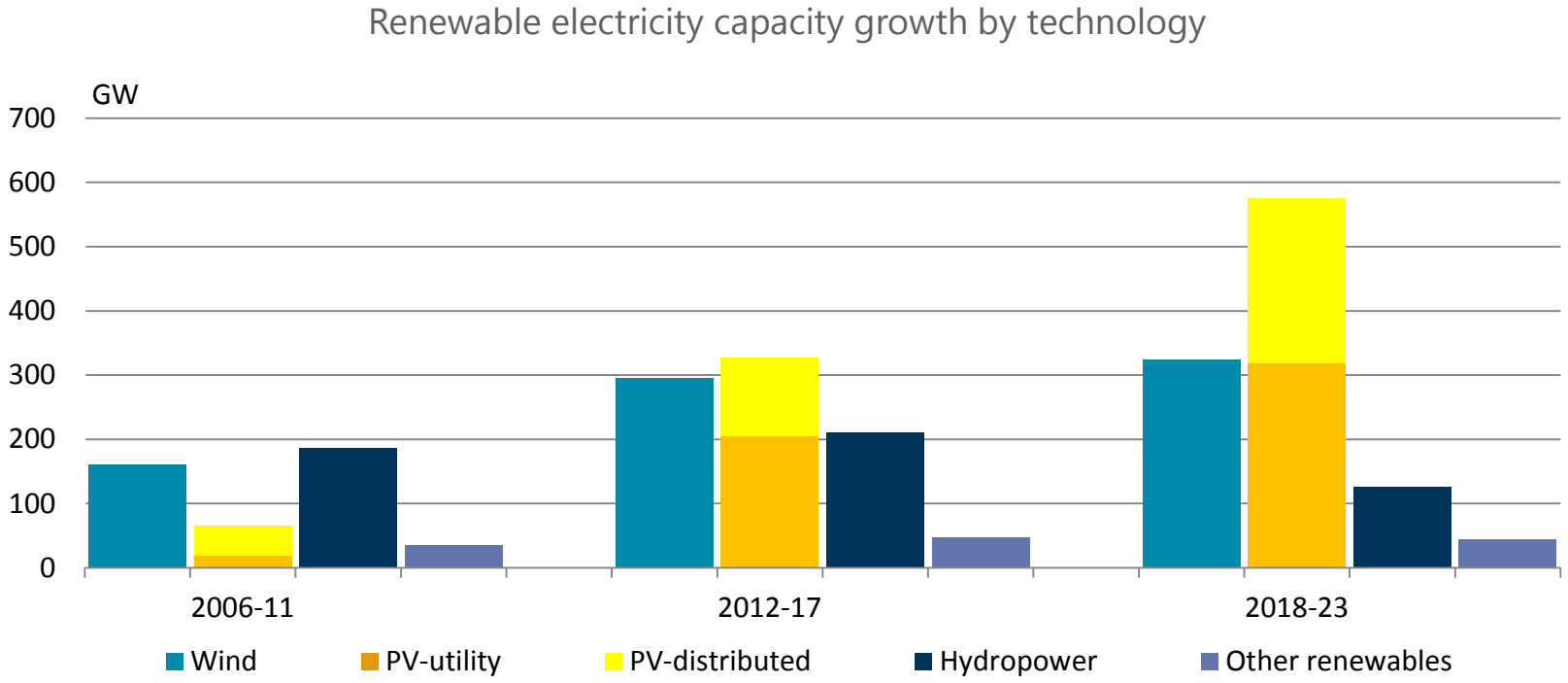
Source: Renewable 2018: Analysis and Forecasts to 2023

Global emissions are set to increase in 2018 - again



Despite need for early emission reduction, the world is not moving towards the Paris goals but rather away from them

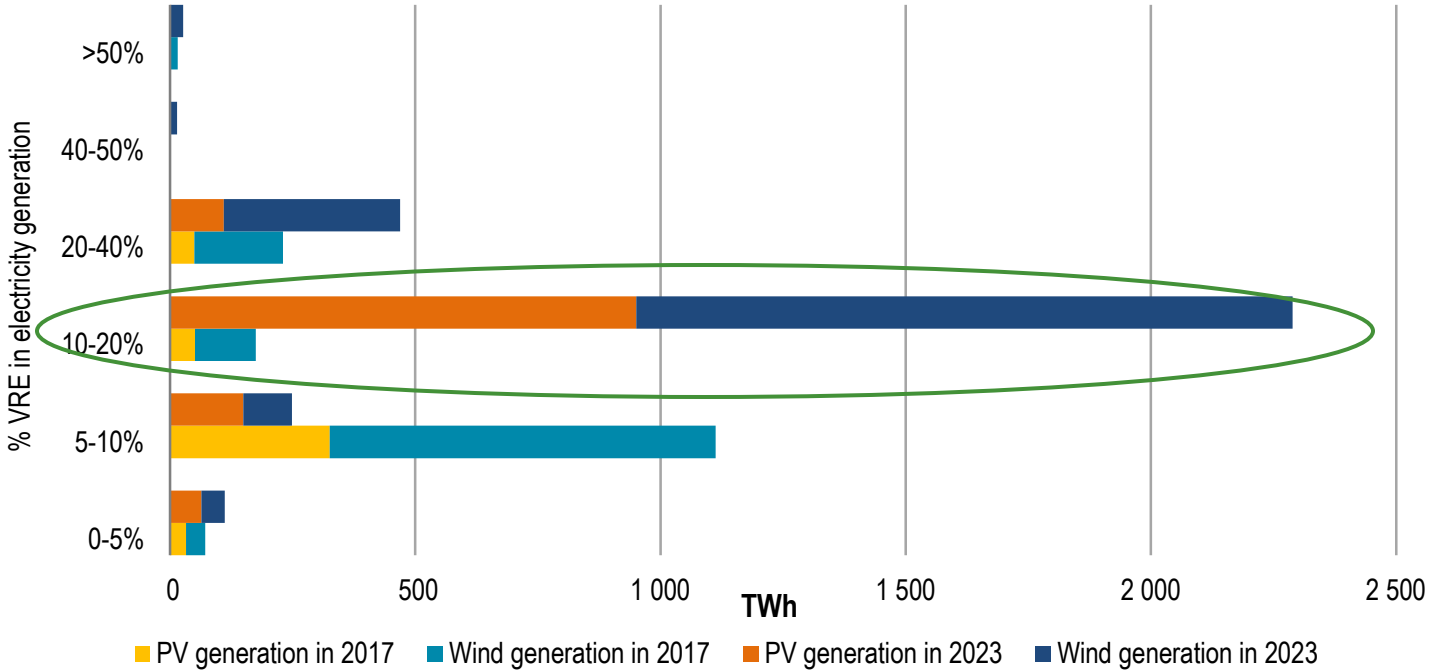
Solar PV expansion in electricity larger than all renewables combined



China remains the absolute solar PV leader by far, holding almost 40% of global installed PV capacity in 2023
The US remains the second-largest growth market for solar PV, followed by India, whose capacity quadruples

Source: Renewable 2018: Analysis and Forecasts to 2023

Wind and solar is leading power system transformation



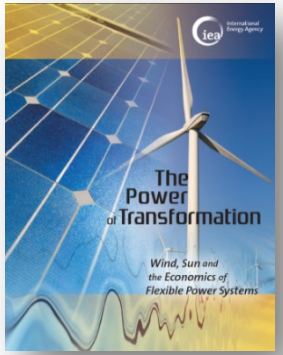
In most power systems the share of VRE is expected to double to over 10% in just five years. The shift from wind to solar capacity addition raises the system integration issues.

Source: Renewable 2018: Analysis and Forecasts to 2023

IEA System Integration of Renewables analysis at a glance

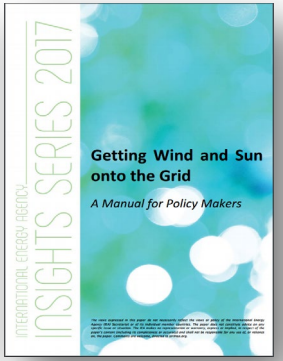
- Over 10 years of grid integration work at the IEA
  - Grid Integration of Variable Renewables (GIVAR) Programme
    - Use of proprietary and external modelling tools for techno-economic grid integration assessment
    - Global expert network via IEA Technology Collaboration Programmes and GIVAR Advisory Group
  - Part of delivering the IEA modernisation strategy

2014 2016 2017 2017 2018 2018

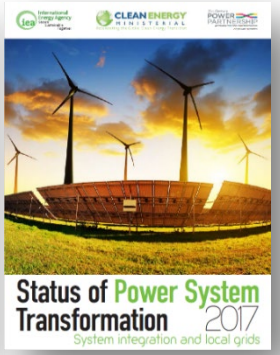


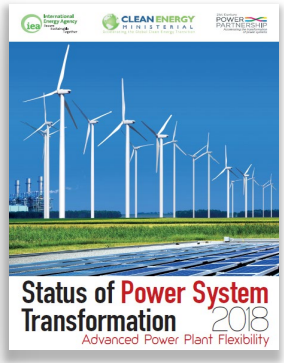
Framework, Technology, Economics

Policy

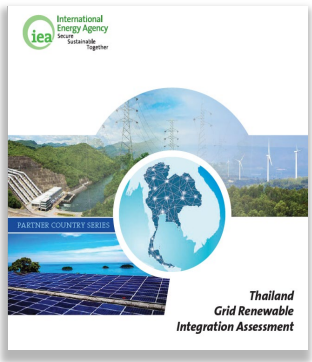


Implementation





Progress & Tracking



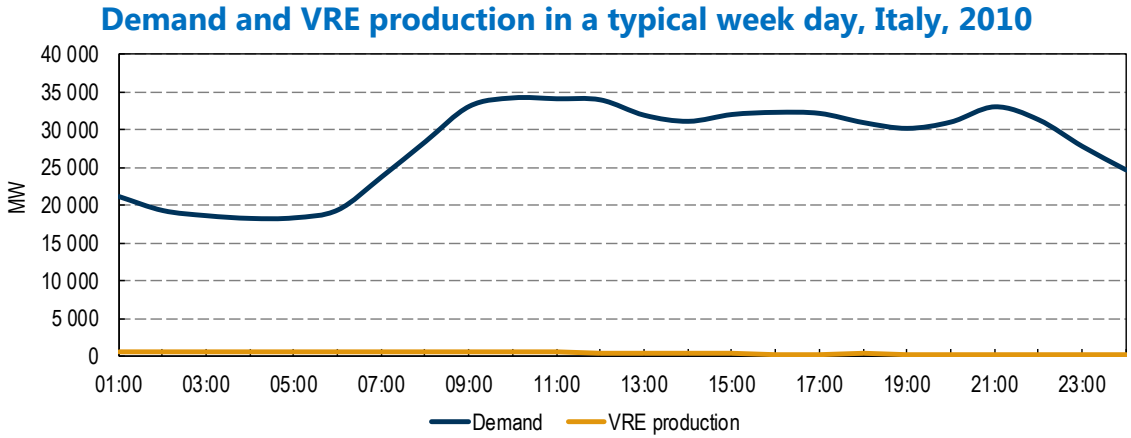
Grid integration study

Different Phases of VRE Integration

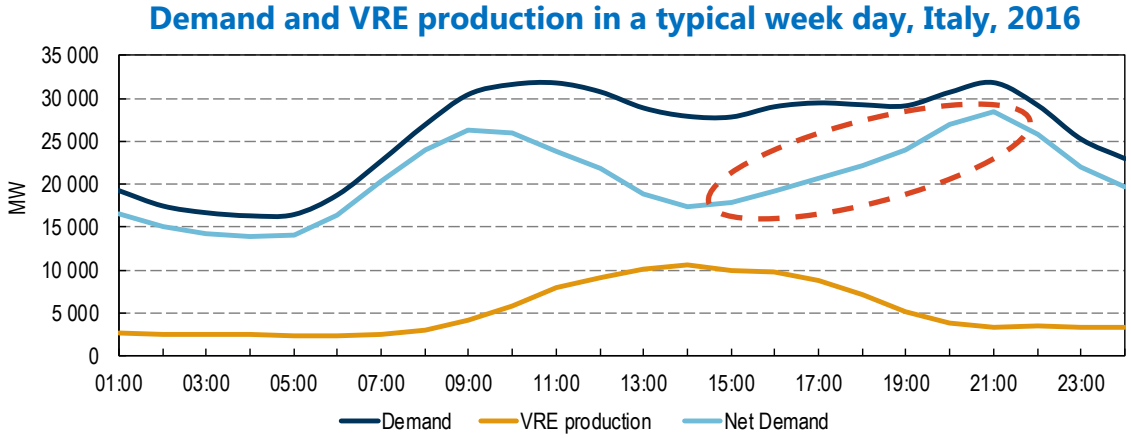
Phase	Description	Country Examples
1	VRE capacity is not relevant at the all-system level. No noticeable impact on the system	Most countries, e.g. Mexico, Indonesia, South Africa
2	VRE generation becomes noticeable to the system operator but has a moderate impact	Brazil, China, India, Sweden, Texas
3	Flexibility becomes relevant with greater swings in the supply/demand balance	Italy, Germany, Portugal, Spain, UK
4	Stability becomes relevant. VRE capacity covers nearly 100% of demand at certain times	Ireland, South Australia, Denmark,
5	Growing amounts of VRE surplus; electrification of other sectors becomes relevant	
6	Seasonal surplus or deficit of VRE supply; seasonal storage & synthetic fuels	

Electricity only accounts for around one fifth of total final energy demand today. The next rise in renewables will require multiplying their uses in buildings, industry and transport

Net load comparison for different phases of VRE integration



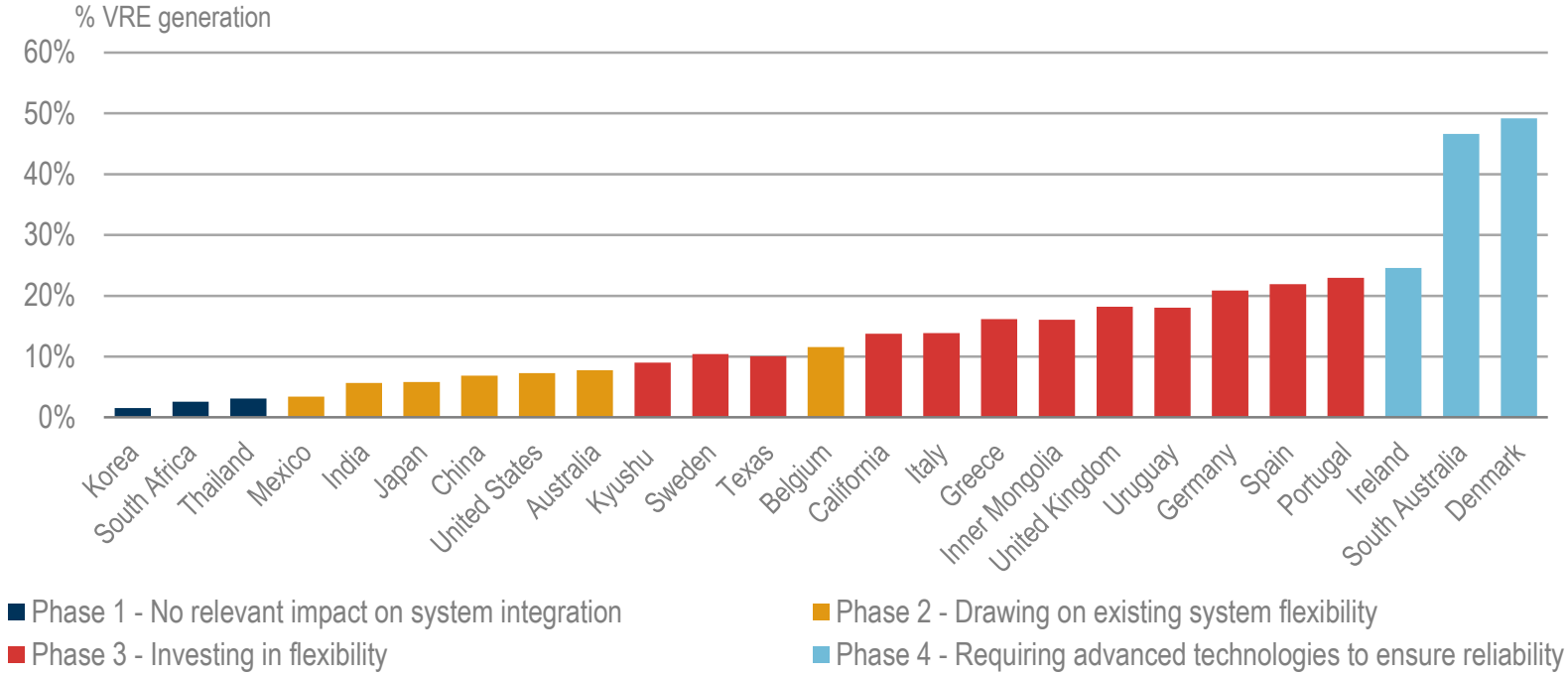
No difference in net load
(Phase 1 of VRE integration)



Flexibility is key to manage variability in net load
(Phase 3 of VRE integration)

VRE deployment phase in selected countries

VRE share in annual electricity generation and system integration phase, 2017

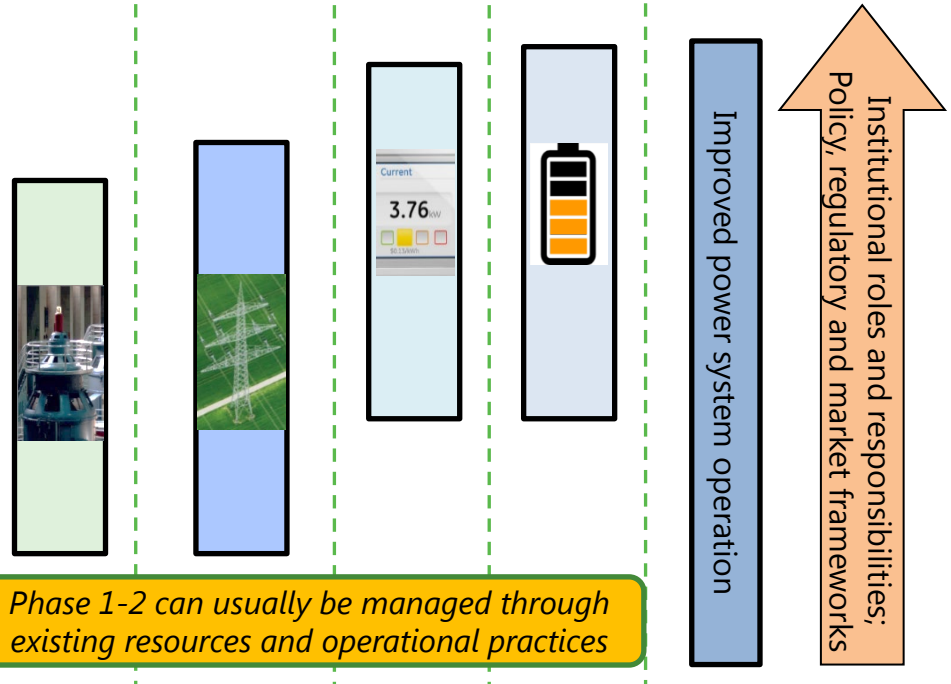


Each VRE deployment phase can span a wide range of VRE share of generation; there is no single point at which a new phase is entered

Key transition challenges and flexibility resources

Phase 6	Need for seasonal storage and use of synthetic fuels or hydrogen
Phase 5	Coping with longer periods of surplus or deficit of energy
Phase 4	Ensuring robust power supply during periods of high VRE generation
Phase 3	Greater variability of net load; changes in power flow patterns on grids
Phase 2	Minor changes to operating patterns of existing power plants
Phase 1	

Key transition challenges



Key flexible resource examples to enable transition

Increasing VRE is driving power system transformation

Policy and market framework

Level of VRE penetration

System-friendly VRE deployment

- Distributed resources integration
- 24/7 System services
- Generation time profile
- Technology mix
- Location
- Integrated planning

Flexible resources


Grids


Generation


Storage

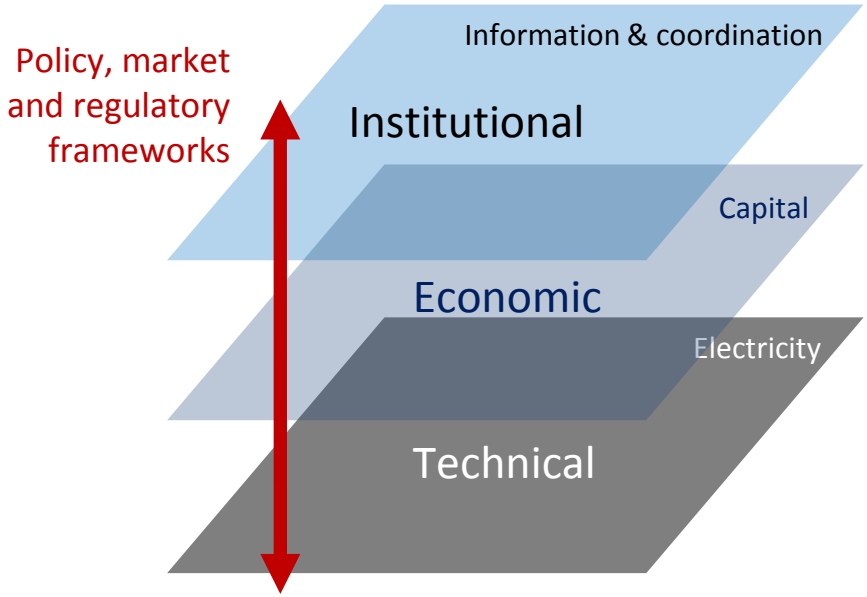
Demand shaping

System and market operation

Actions targeting VRE

Actions targeting overall system

System transformation requires holistic approach

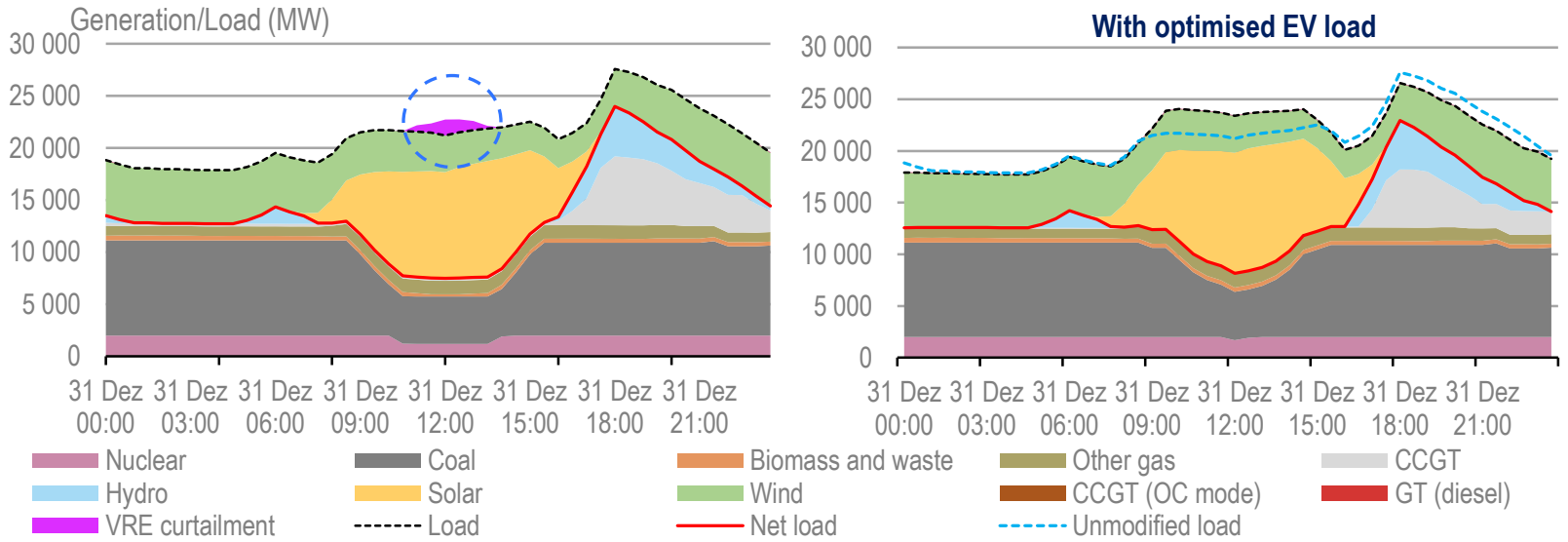


- **Institutional** – defining roles and responsibilities
- **Economic** –market design, regulation, planning frameworks
- **Technical** – operation of power system, safeguarding reliability

Policies, markets and regulatory frameworks link technical, economic and institutional aspects

The role of flexibility resource in systems with high VRE

- Flexibility resources such as demand-side response are valuable with high VRE
- A case study of Thailand's system showed the role of smart EV charging
  - Utilise high solar output during the day to charge EV
  - Reduce evening peak demand



Summary

- Wind and solar lead the growth of electricity generation worldwide
  - The growth of solar PV is highest among renewable technologies
- Integrating large shares of VRE requires power system transformation
  - High VRE penetration raises the issues of system integration in technical, economic, institutional and policy & market aspects
- The integration of VRE can be categorised into 6 different phases
  - Differentiated based on the potential impact on the system, which is context specific
  - Flexibility resources are essential to address the system integration challenges and enable the system to move to higher phases of VRE
- Power system transformation involves holistic approach
  - Technical, economic, institutional and policy, market and regulatory frameworks

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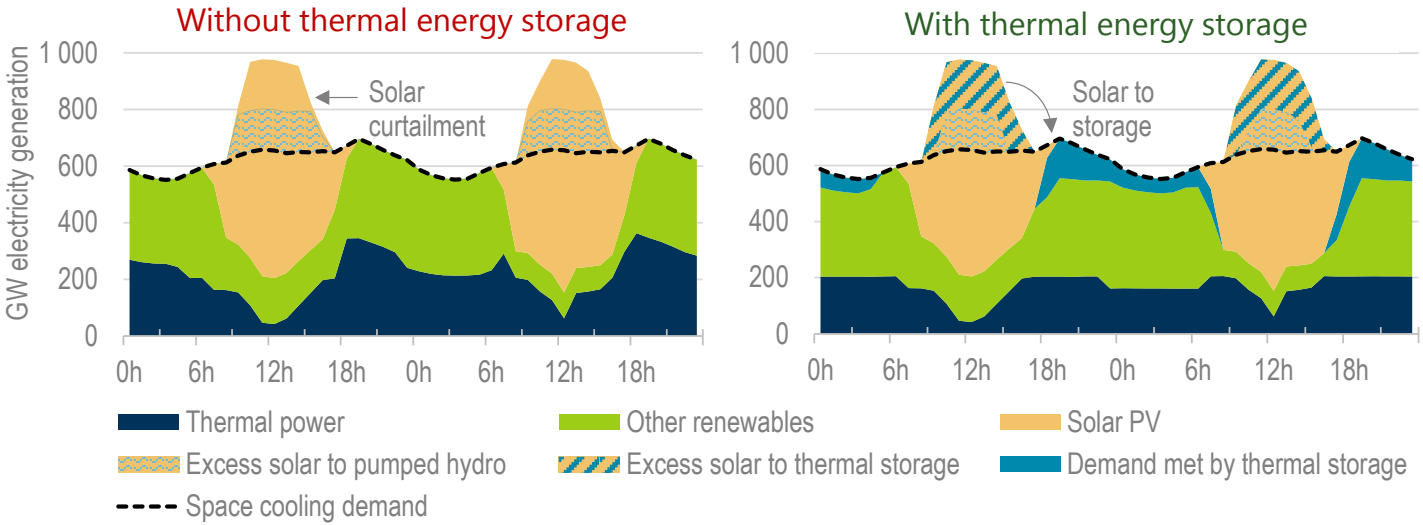
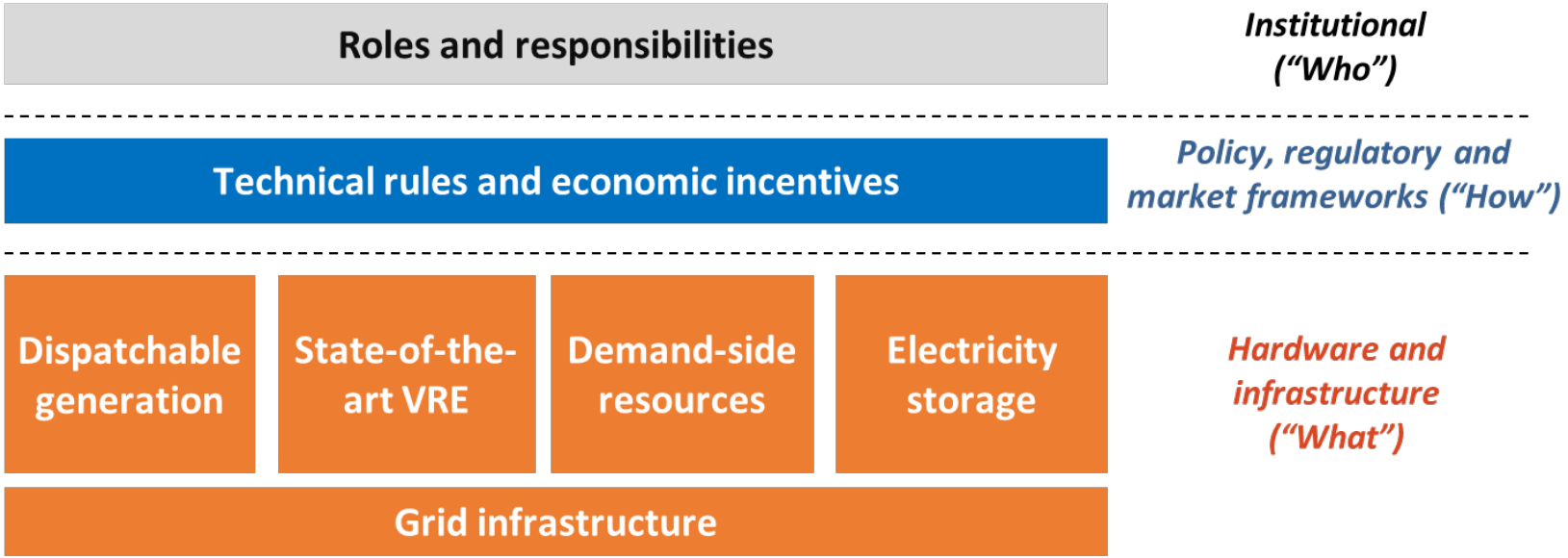
peerapat.vithaya@iea.org

The role of flexibility resource in systems with high VRE

- Energy storage is an essential flexibility resource with high share of VRE
- A case study of future India's system showed the role of energy storage with high PV
  - Utilise high solar output during the day to produce ice or chilled water
  - The ice or chilled water is used to meet cooling load in the evening – shifting evening peak to non-peak periods



Relevant dimensions for unlocking system flexibility



Technical, economic and institutional policy layers mutually influence each other and have to be addressed in consistent way to enhance power system flexibility.

Different phases of VRE integration

	Attributes (incremental with progress through the phases)			
	Phase 1	**Phase 2**	**Phase 3**	**Phase 4**
Characterisation from a system perspective	VRE capacity is not relevant at the all-system level	VRE capacity becomes noticeable to the SO	Flexibility becomes relevant with greater swings in the supply/demand balance	Stability becomes relevant. VRE covers nearly 100% of demand at times
Impacts on the existing generator fleet	No noticeable difference between load and net load	No significant rise in uncertainty and variability of net load, but small changes to operating patterns	Greater variability of net load. Major differences in operating patterns;	No power plants are running around the clock; all plants adjust output to VRE output
Impacts on the grid	Local grid condition near points of connection, if any	Likely to affect local grid conditions; congestion is possible, driven by shifting power flows	Significant changes in power flow patterns across the grid; increased two-way flows between HV and LV grids	Requirement for grid-wide reinforcement, and improved ability of the grid to recover from disturbances
Challenges depend mainly on	Local conditions in the grid	Match between demand and VRE output	Availability of flexible resources	Strength of system to withstand disturbances