



# Phases of VRE integration and flexibility

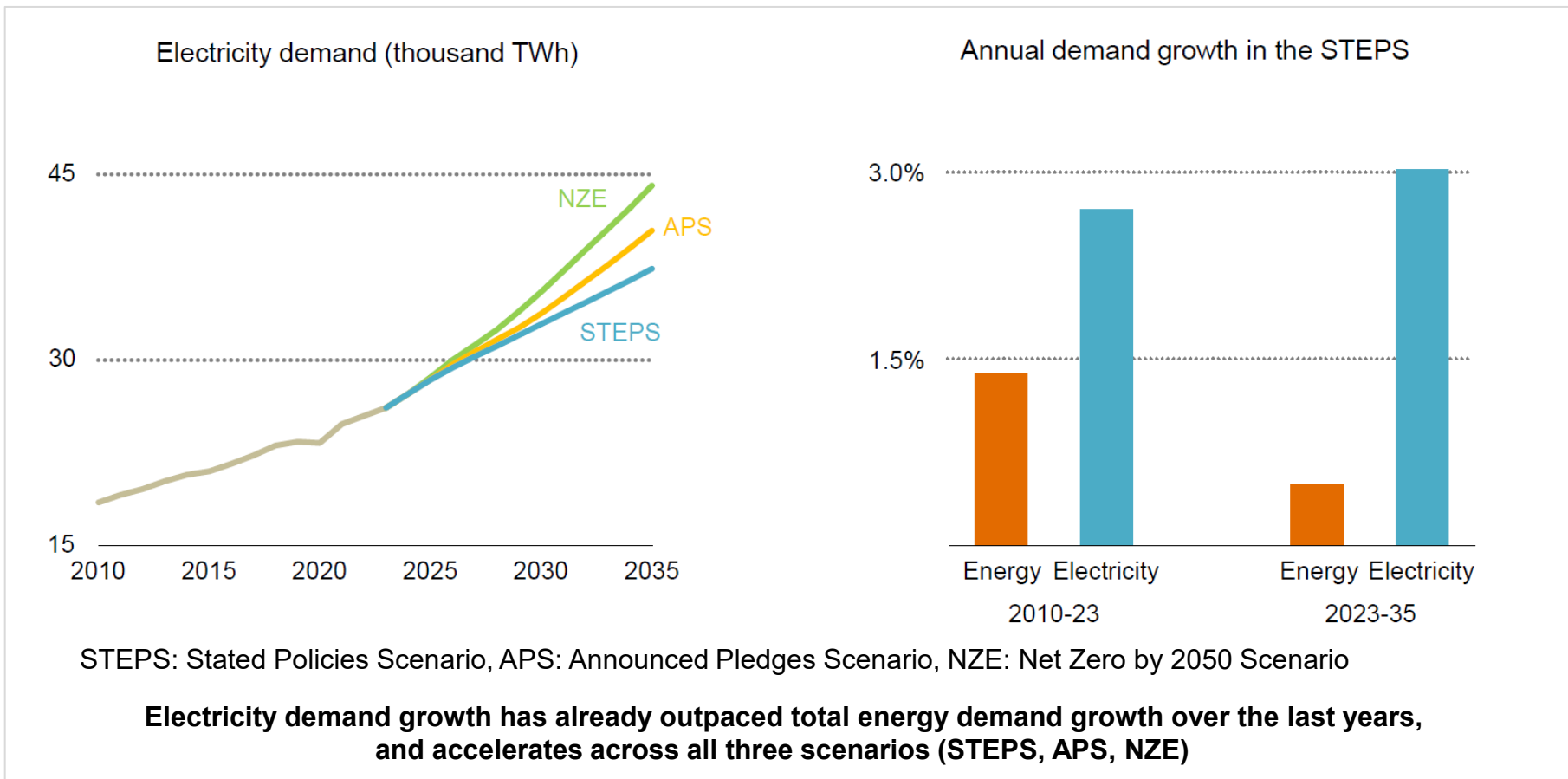
Edward McDonald

EU4Energy workshop, 13 November 2025

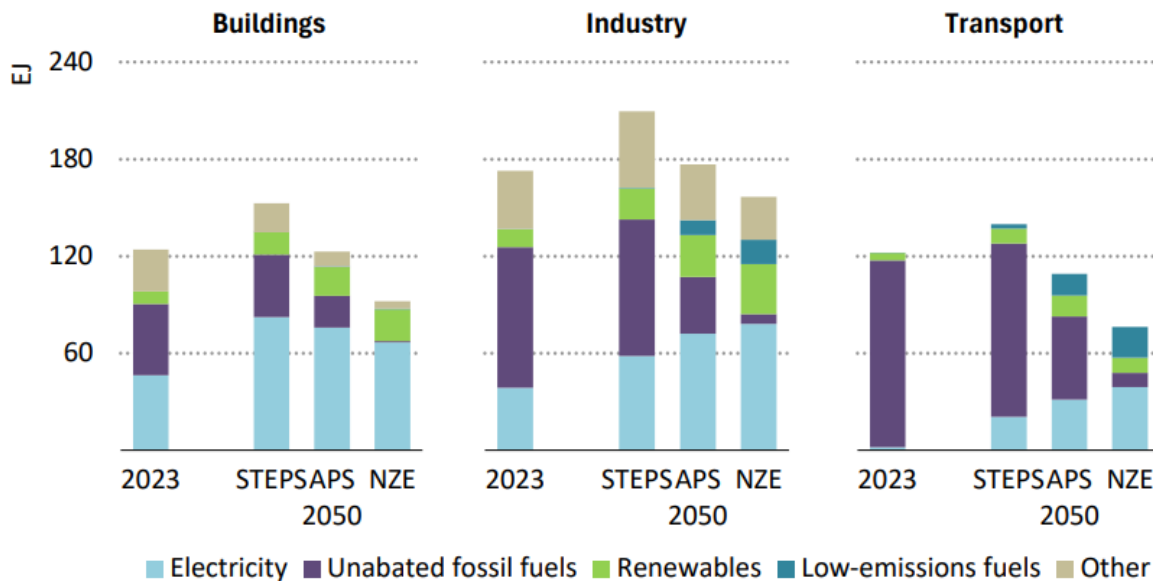
1. Global context
2. What is system flexibility? What are we asking of the system?
3. Why are flexibility needs increasing?
4. How are flexibility needs evolving?
5. How can flexibility be unlocked?

# Global context

# Moving into the Age of Electricity at pace



# Electricity demand grows from established and new sources

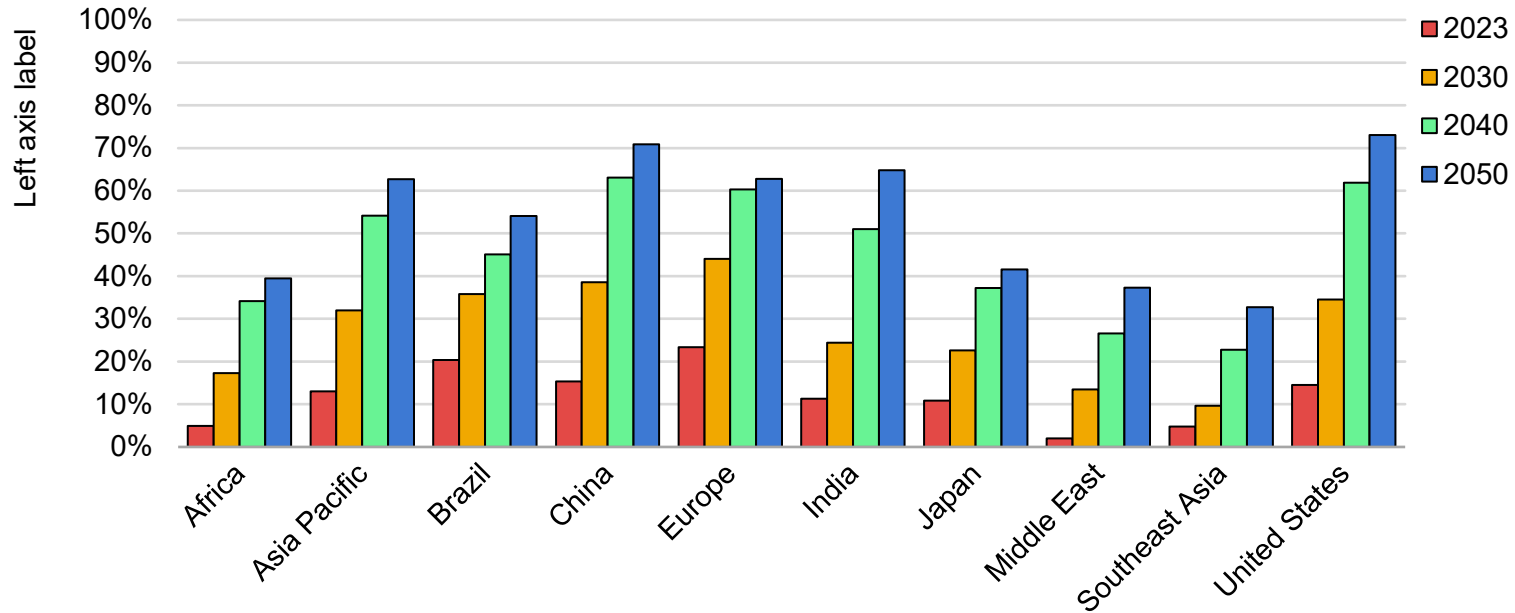


STEPS: Stated Policies Scenario, APS: Announced Pledges Scenario, NZE: Net Zero by 2050 Scenario (WEO 2024)

**Residential and industrial demand is complemented by new sources such as transport and technology loads**

# Increase in variable renewables (VRE) calls for more flexibility

Shares of solar PV and wind generation in various countries in the 2024 Stated Policies Scenario, 2023, 2030, 2040 and 2050



STEPS = Stated Policies Scenario 2024

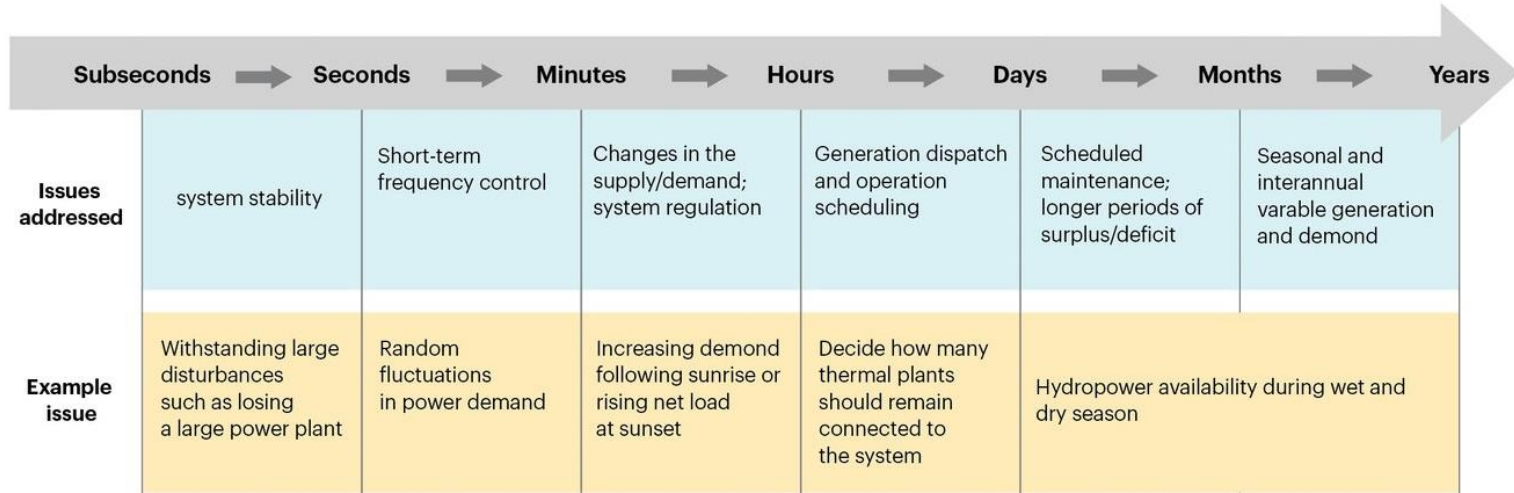
**More countries are expected to deploy higher shares of variable renewables – including in emerging economies**  
**Flexibility sources, low carbon ones in particular, need to keep up with the rapid growth in variable renewables**

# What is system flexibility?

“the **ability** of a power system to **reliably** and **cost-effectively** manage the **variability** and **uncertainty** of demand and supply across **all relevant timescales**, from ensuring instantaneous stability of the power system to supporting **long-term security** of supply” ([IEA \(2019\)](#), Status of Power System Transformation)

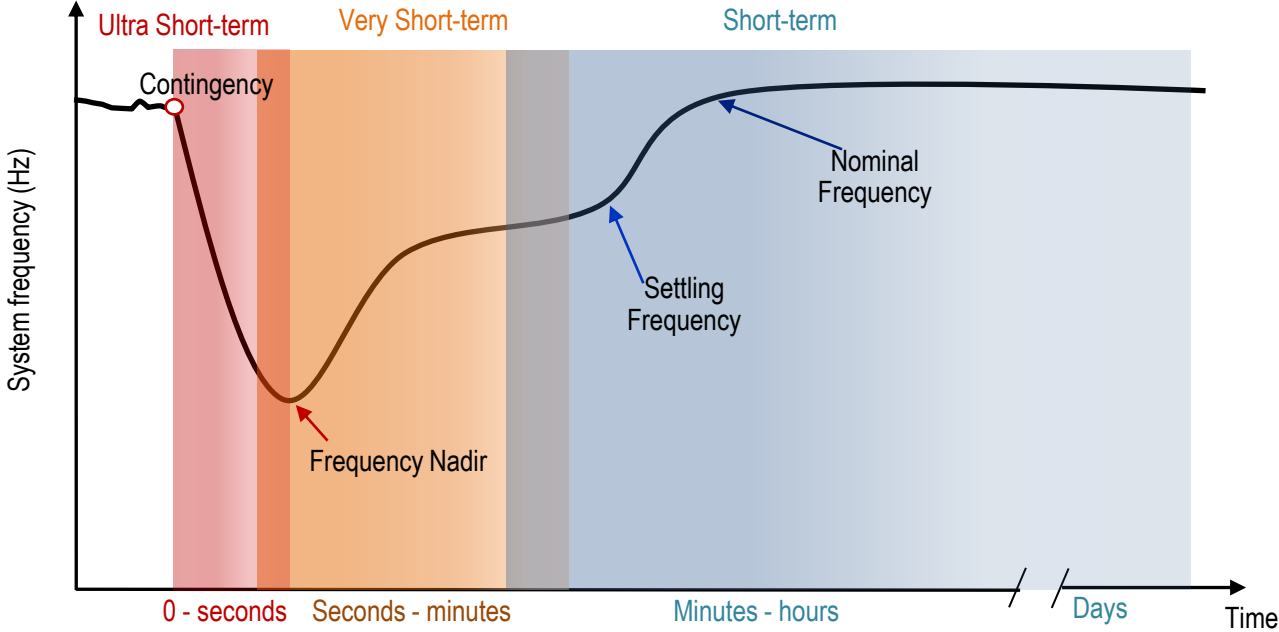
**Flexibility is a system wide capability rather than a set of technologies**

# Flexibility at different timescales



**The instantaneous nature of electricity systems requires second-by-second flexibility not required from other energy carriers**

# Dimensions of flexibility



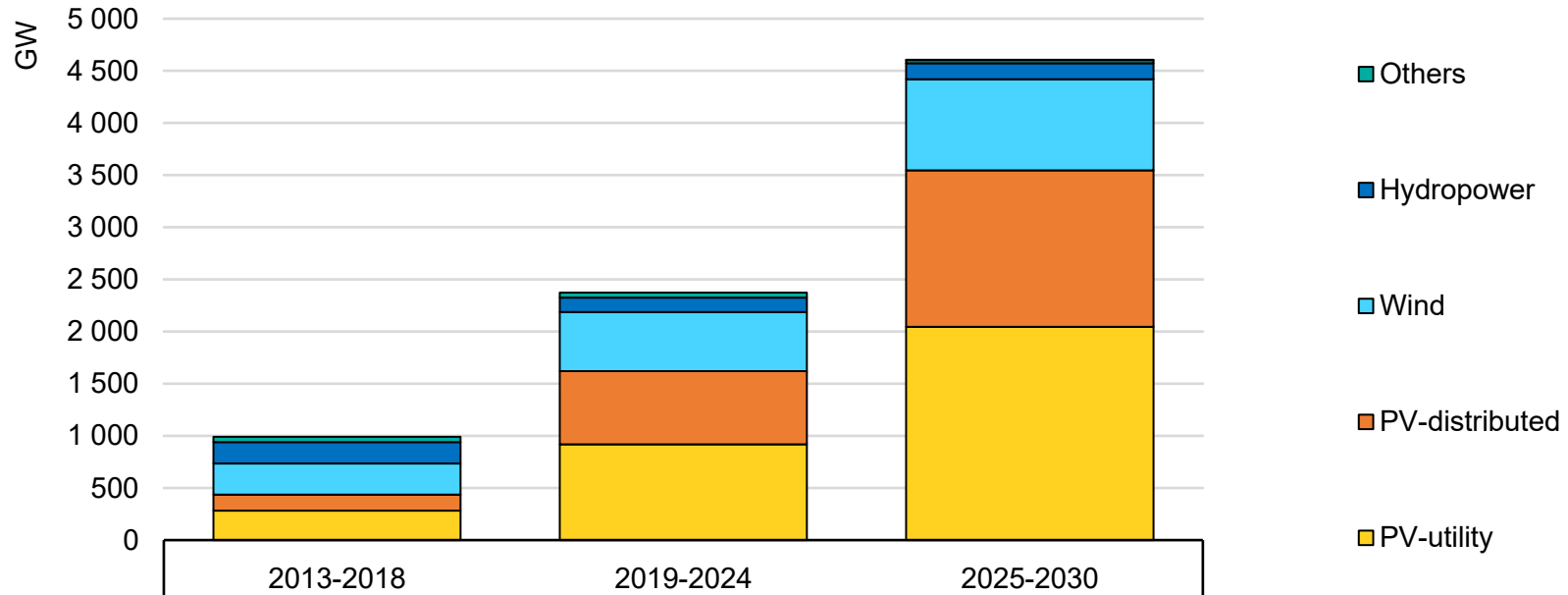
**Ultra-short-, very short- and short-term flexibility services are important for maintaining system frequency.**

# Why are flexibility needs increasing?

- Demand growth and electrification
  - Transport
  - Residential
- Supply-side changes
  - VRE growth
  - Reduction of traditional generation
- New load patterns
  - Electrification of cooling & heating; evolving appliance types
  - Data centres
- (Extreme) weather patterns
  - More extreme periods of heating and cooling demand
  - Greater share of weather-dependent generation in power systems
  - Water availability and temperature for hydro, thermal plants and commodity transport

# Renewables growth driven by solar PV remains strong amid rising headwinds

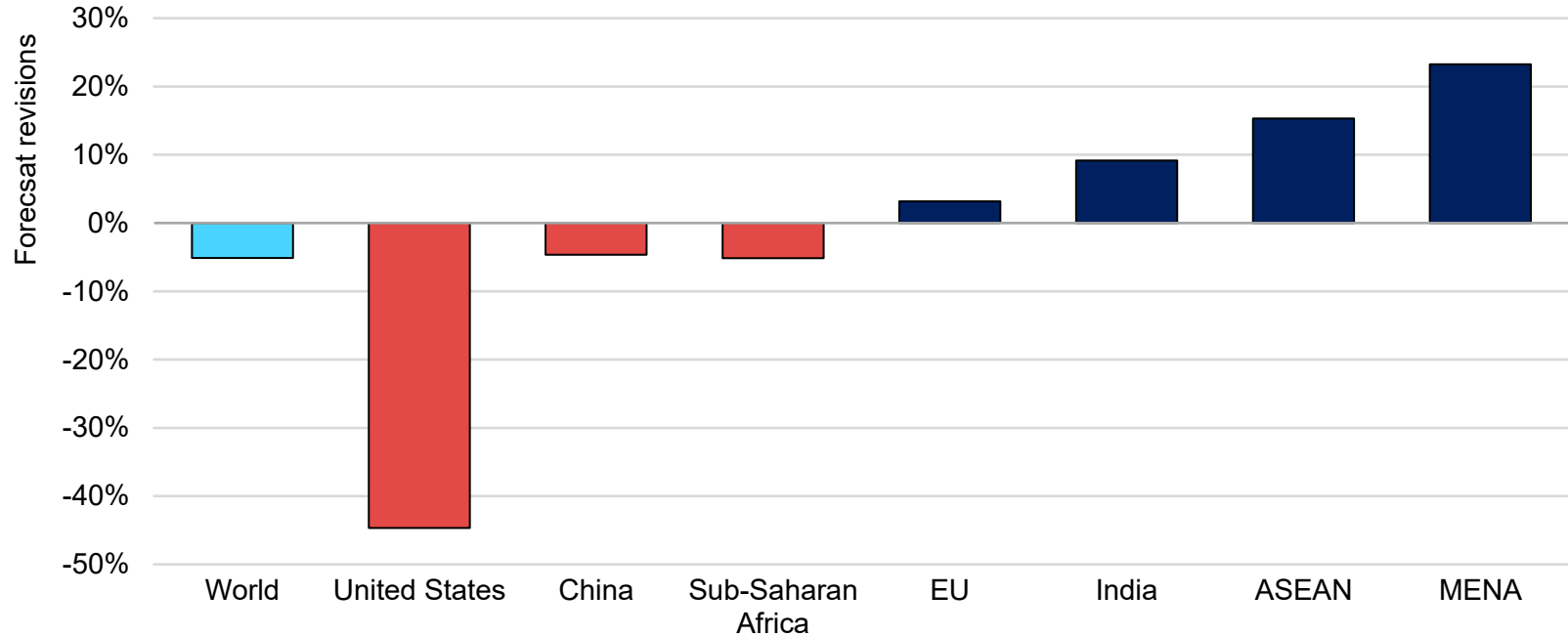
Renewable capacity additions forecast revisions for 2025-2030



**Low costs, faster permitting & broad social acceptance continue to drive solar PV expansion. Wind capacity doubles despite supply chain issues, rising costs and slow permitting. Pumped storage hydro & geothermal growth accelerates.**

# Global renewable growth forecast revised down slightly

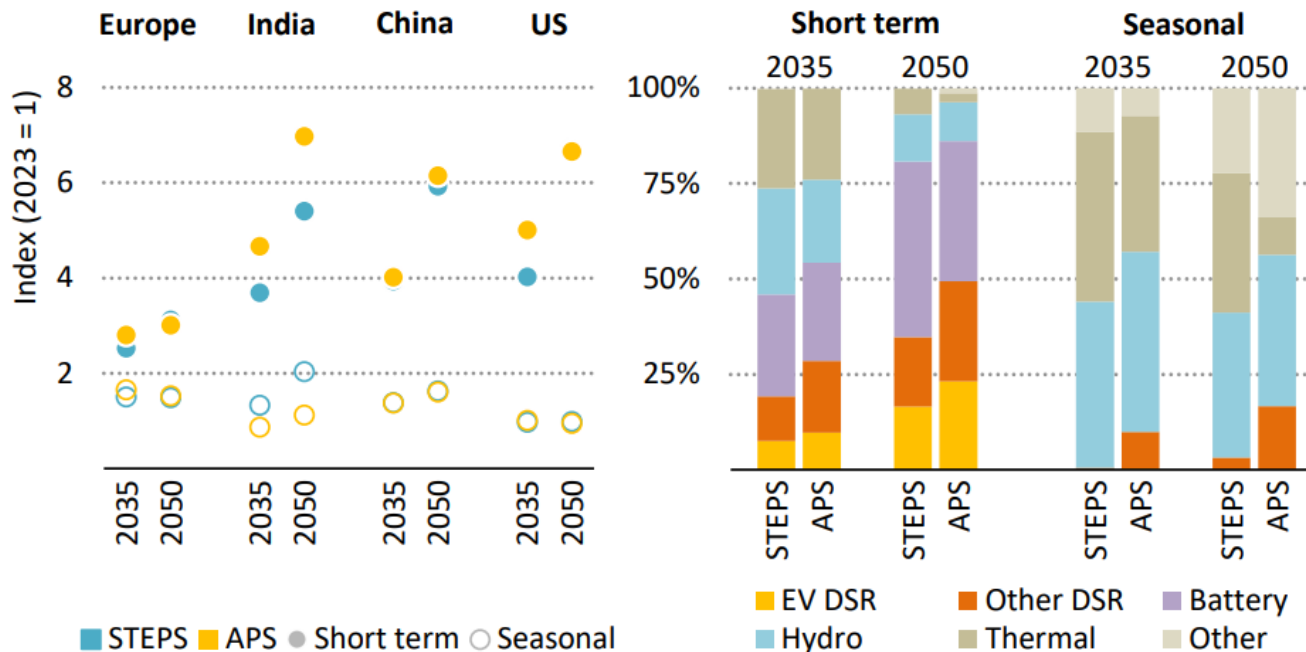
Renewable capacity additions forecast revisions for 2025-2030



**Policy changes in the United States and China are the main reasons behind global downward revision of the forecast. In India, Europe, MENA and in most emerging and developing economies the outlook is more optimistic.**

# Consumers can address increasing flexibility needs

Power system flexibility requirements in selected regions and global flexibility provision in the 2024 STEPS and APS

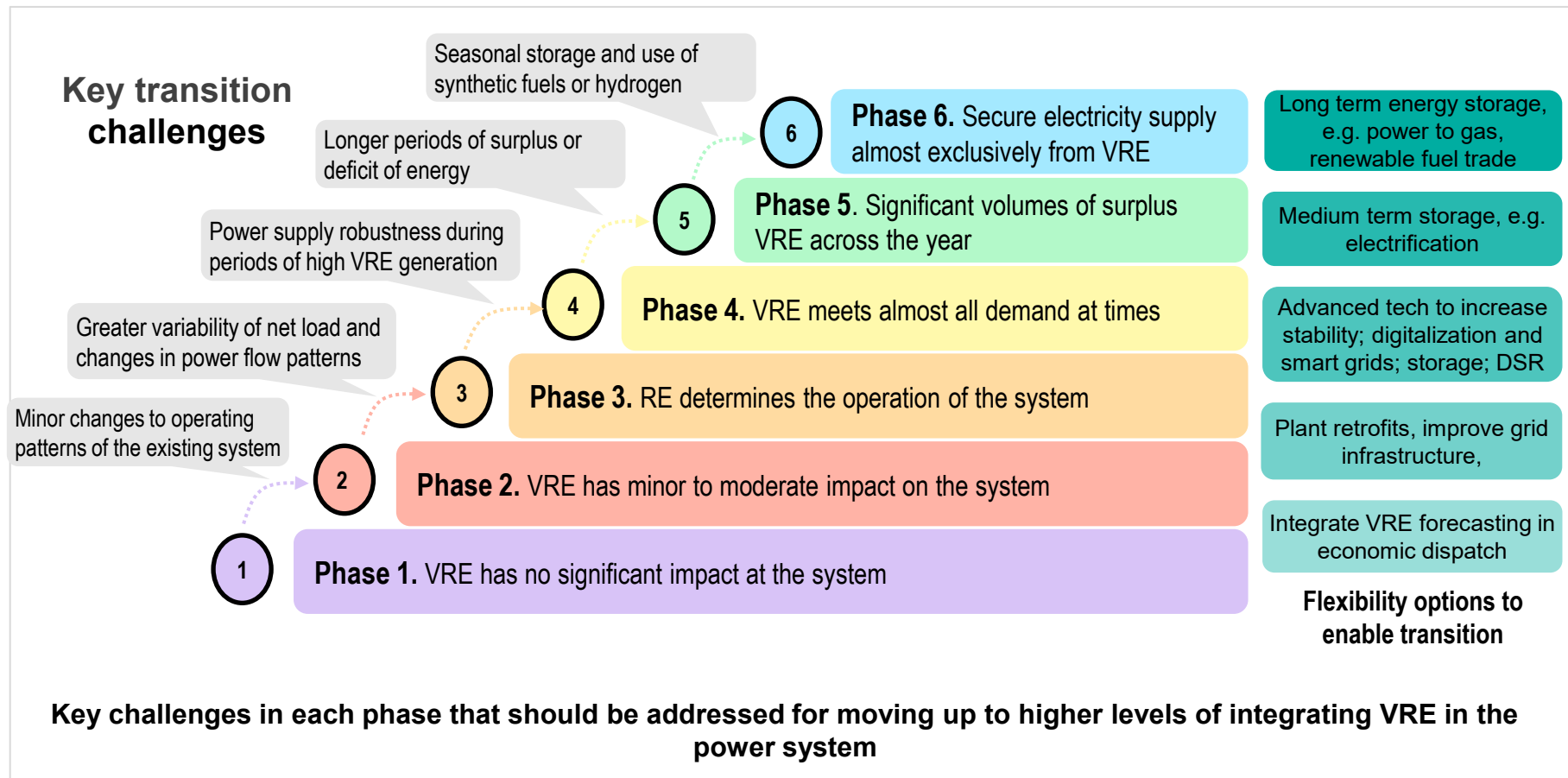


IEA. CC BY 4.0.

**The change is not only in the amount but also in who provides flexibility services. Demand-side resources play a greater role in short-term flexibility**

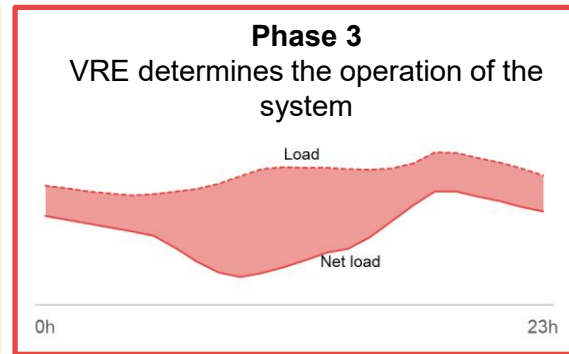
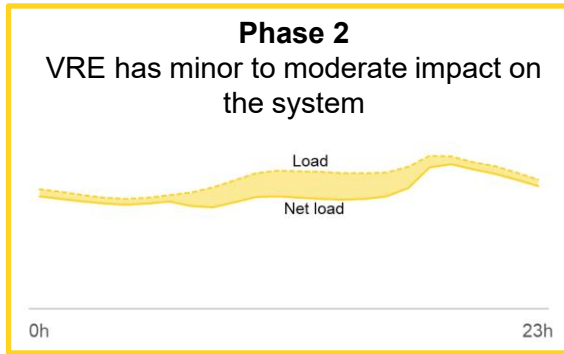
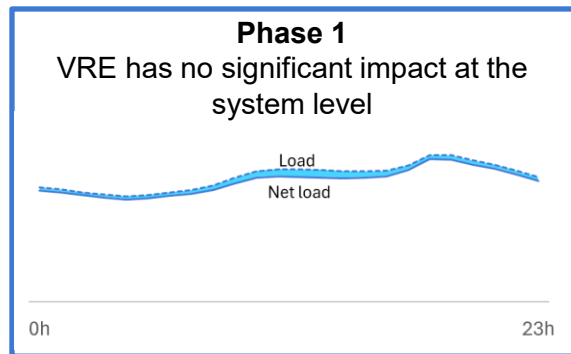
# How are flexibility needs evolving?

# Phases of system integration and evolving priorities

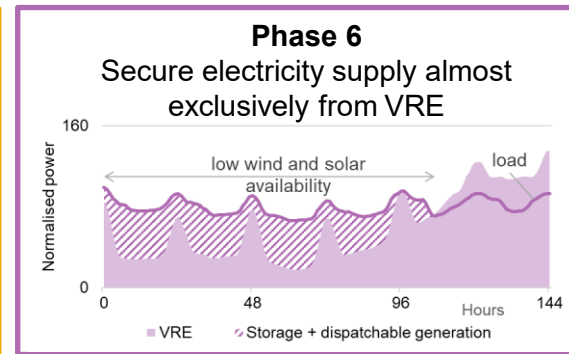
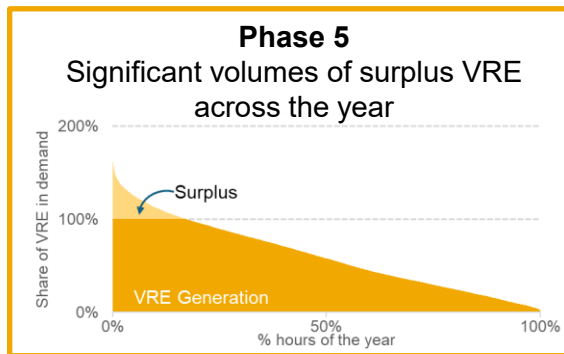
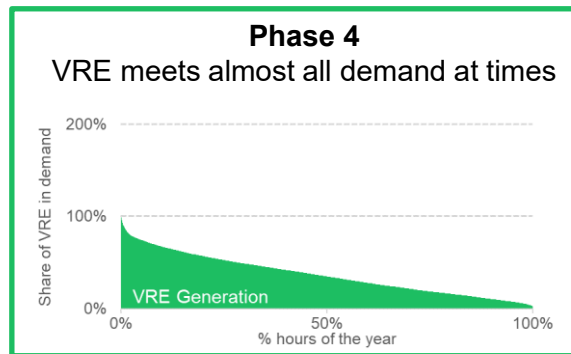


# Our framework guides a phased introduction of integration measures

Low phases

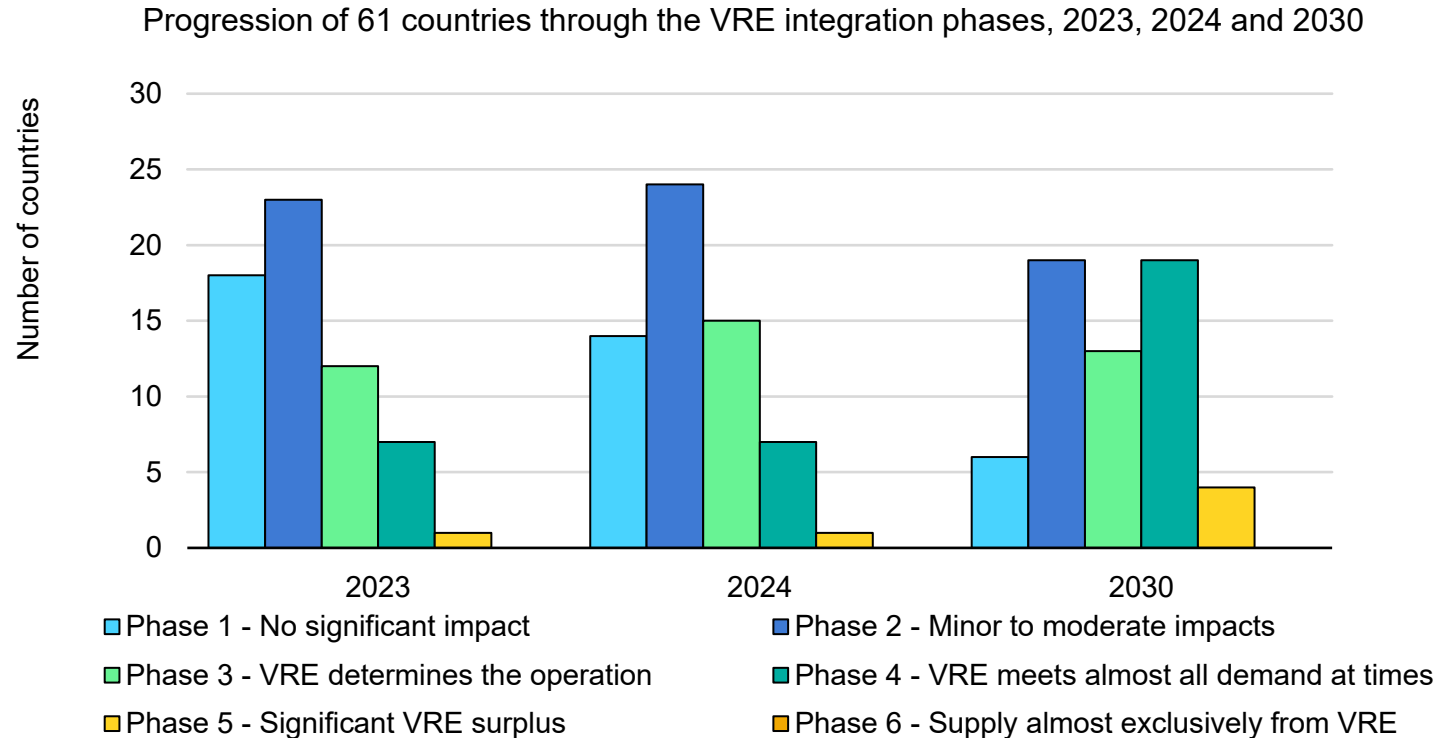


High phases



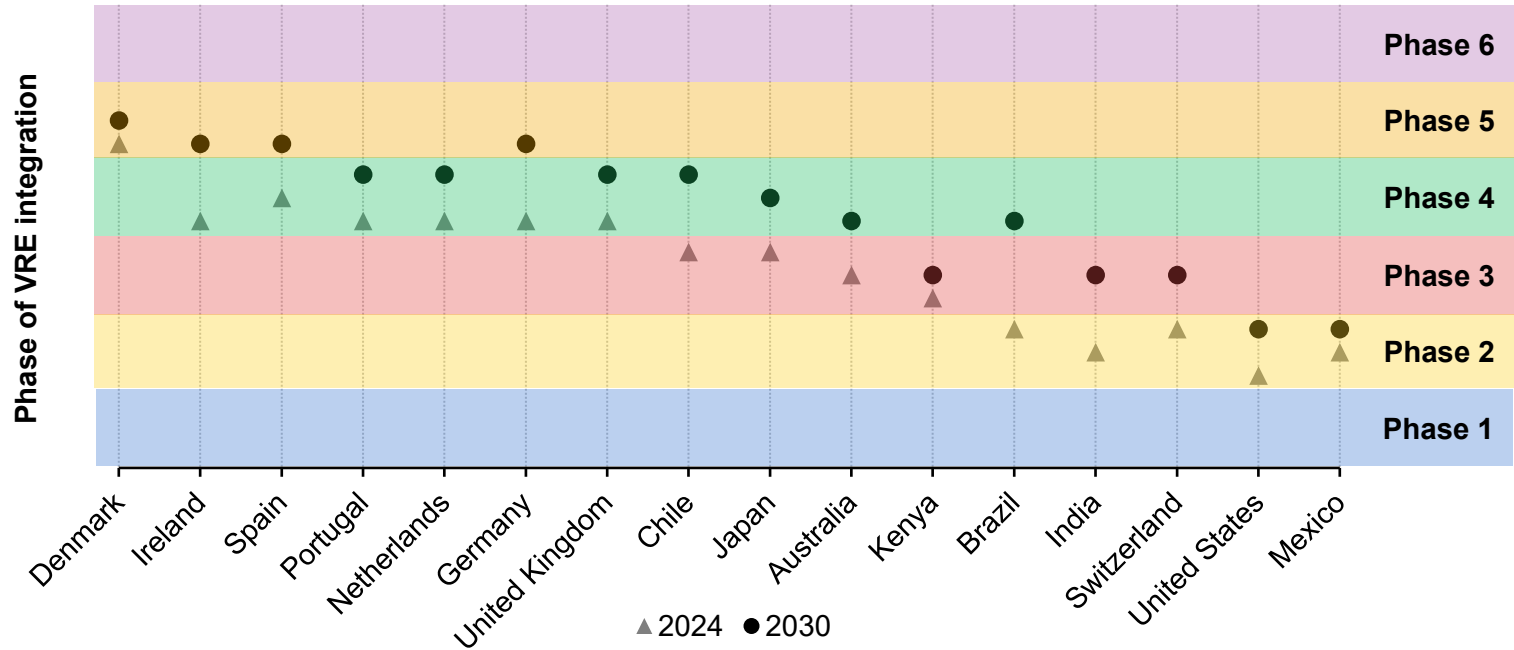
The framework allows policy makers to identify VRE integration measures that need to be prioritised at each phase to ensure its timely implementation.

# Rising VRE shares drive global shift towards the advanced stages of VRE integration



**This requires timely and enhanced integration measures, including flexibility, modernisation of grids and adaptive markets and regulation to ensure secure, reliable and affordable power system development.**

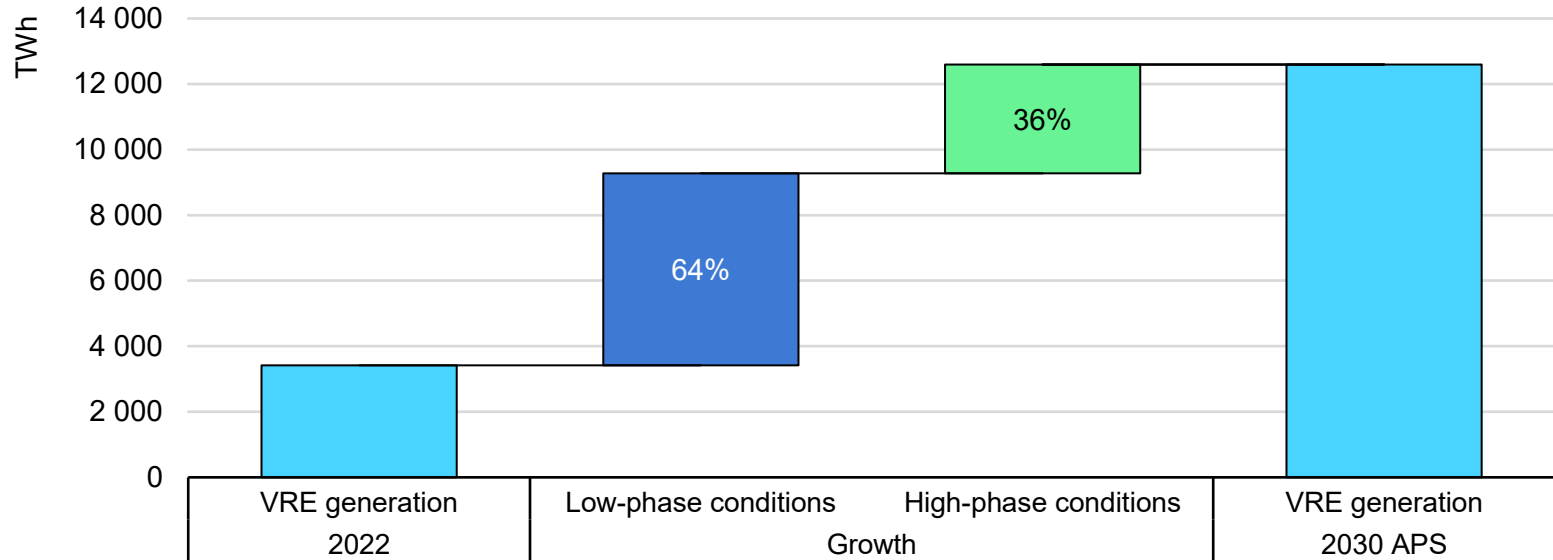
Phase assessment of selected countries in 2024 and 2030



**Lessons can be learnt from countries facing a range of phases already.**

# Most VRE growth occurs in low phase conditions

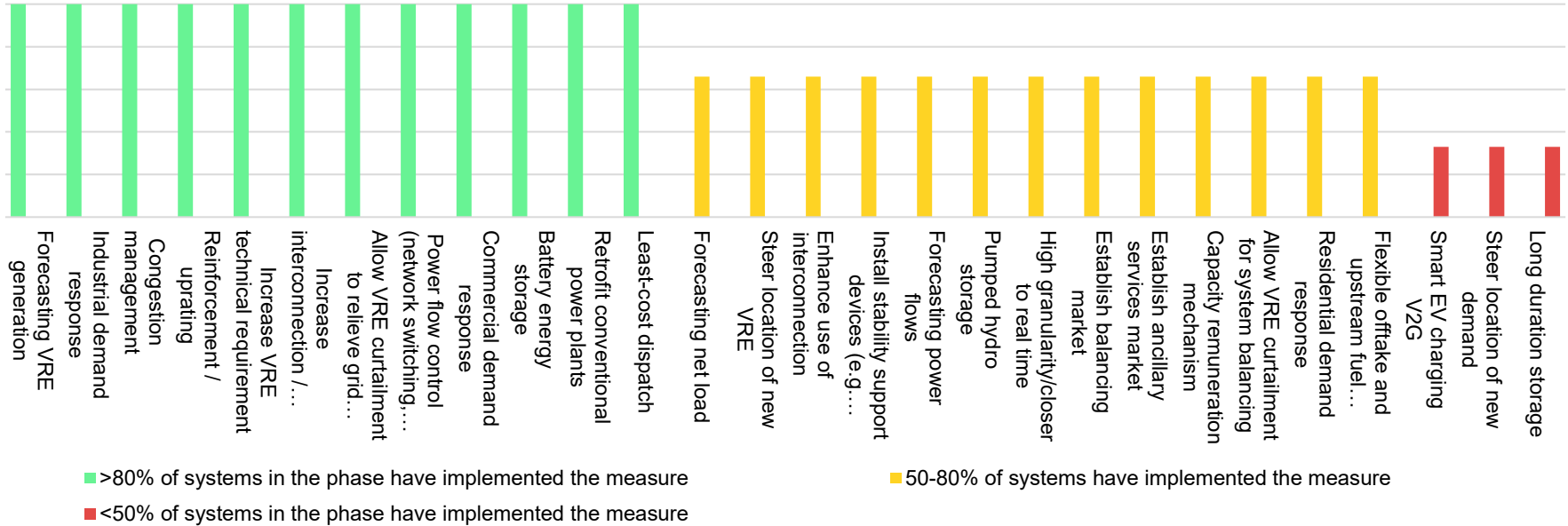
Global solar PV and wind generation growth in conditions of low and high phases of VRE integration in the Announced Pledges Scenario, 2022-2030



**64% of growth is in systems in low-phase conditions and 36% in systems in high-phase conditions.**

# Measures based on progressive and targeted adjustments can integrate most new capacity in low-phase systems

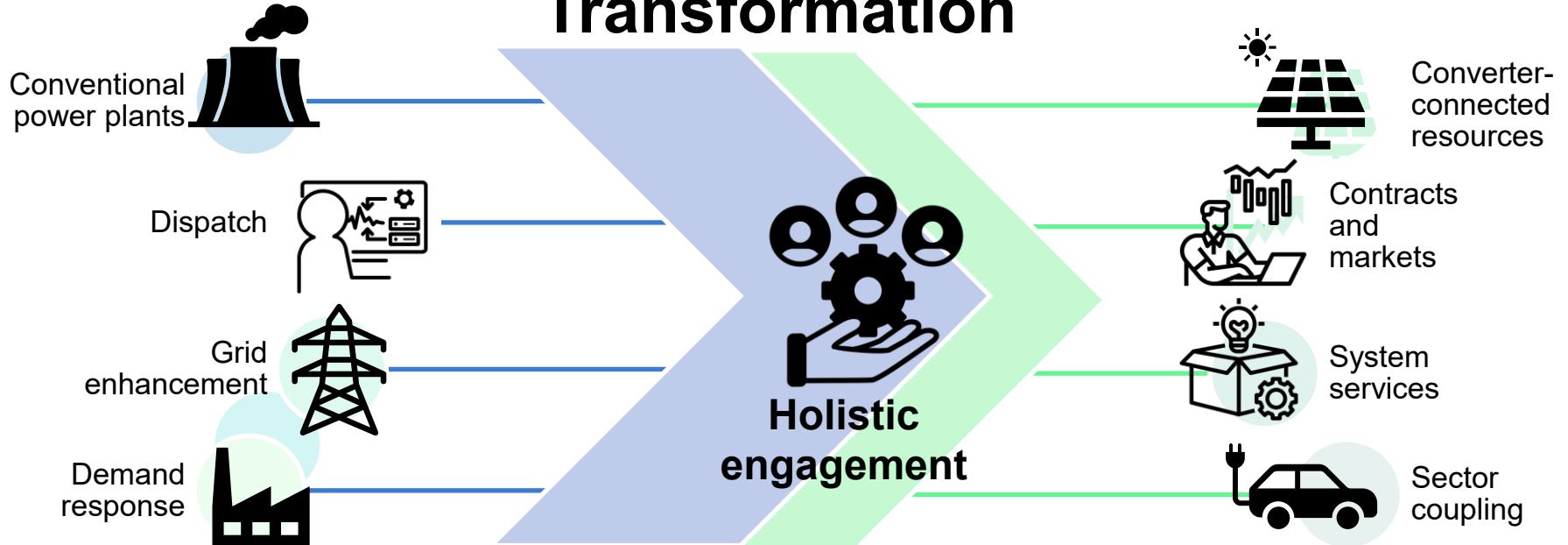
Measure implementation frequency for systems in Phase 2 and above



**Countries that currently have low shares of VRE can typically boost deployment without enacting sweeping, system-wide changes. Well-known and tested measures – implemented gradually as the need arises – tend to be sufficient.**

# A strategic transformation is required at high phases of VRE integration

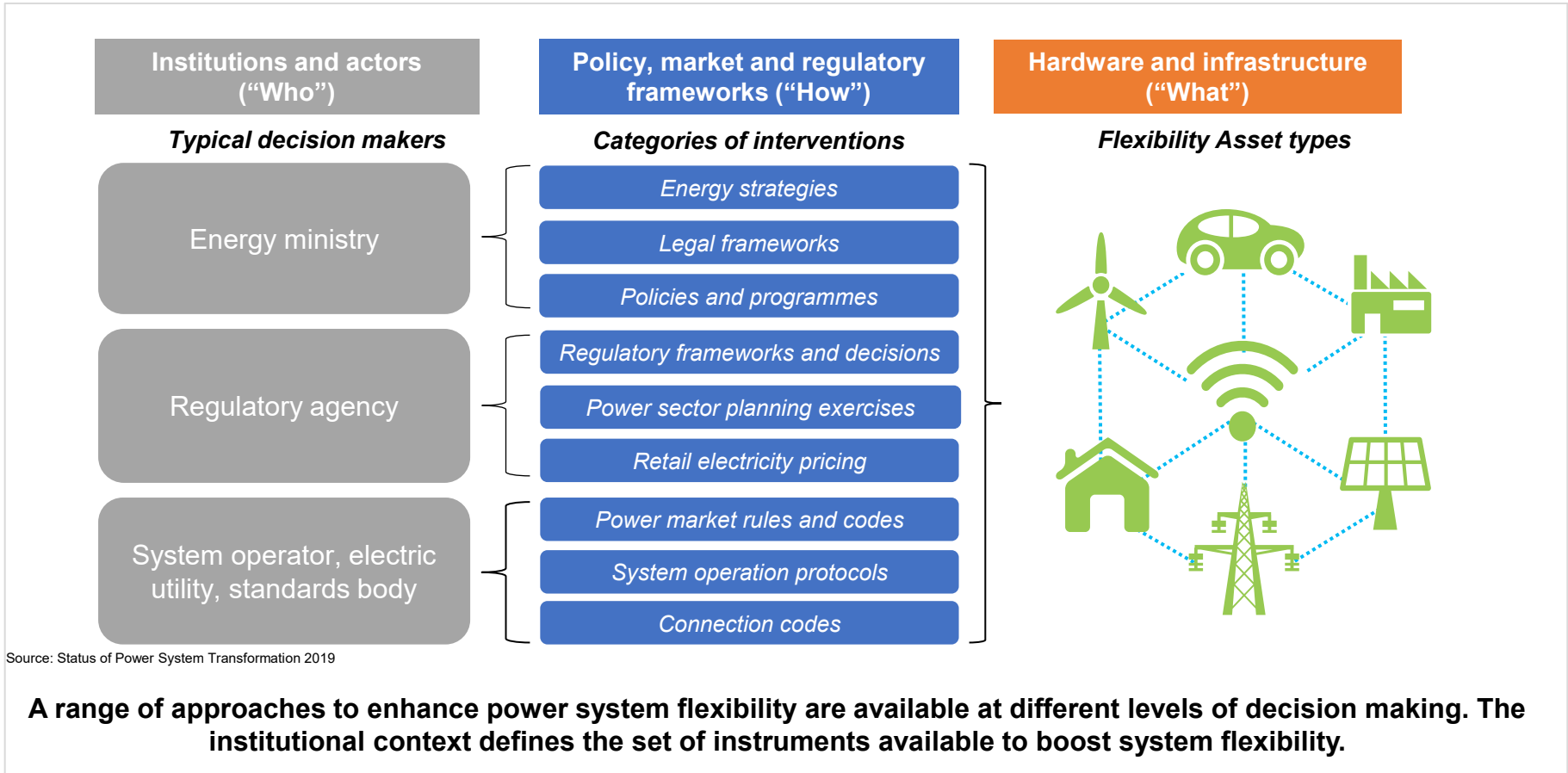
## Transformation



**New frameworks to extract further flexibility and system services from a wider range of sources, and new technologies to ensure stability and manage surplus energy, will need to be considered**




# How can flexibility be unlocked?




# A wealth of strategies can be deployed to boost system flexibility



Source: Status of Power System Transformation 2019

**A range of approaches to enhance power system flexibility are available at different levels of decision making. The institutional context defines the set of instruments available to boost system flexibility.**

- **Power Plant capabilities** 
  - Retrofitting
  - Increase VRE requirements
- **Operational practices** 
  - Forecasting VRE & demand
- **Demand side measures** 
  - Demand response programs

- **Grid capacity and use** 
  - Reinforcements; utilisation
- **System balancing** 
  - Least cost dispatch
  - Balancing/ancillary service markets
- **Storage** 
  - Battery energy storage
  - Long-duration storage

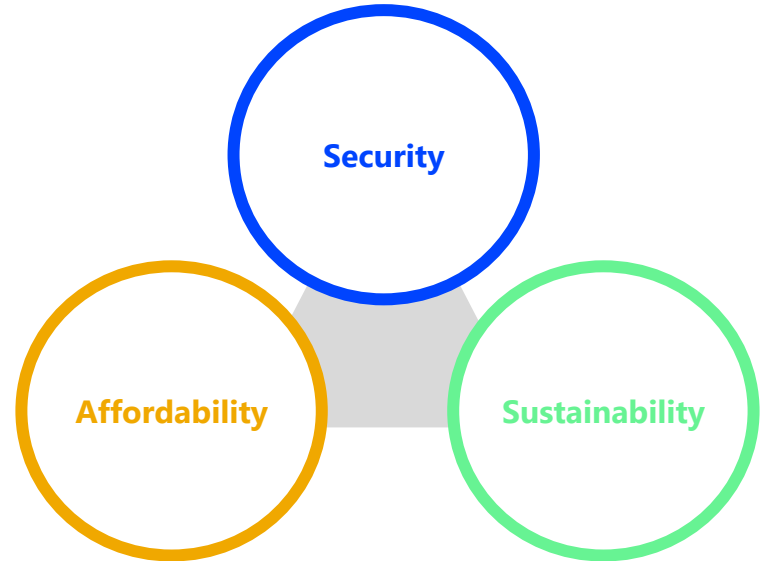
# Wholesale markets are a powerful tool to supporting electricity system objectives

**Short-term markets**  
*Spot, ancillary services, balancing*

**Medium & long-term markets**  
*Power purchase agreements (PPAs), futures, forwards*



**Complementary mechanisms**  
*Capacity remuneration mechanisms (CRMs), support schemes*



**But wholesale markets must work alongside policy, regulation and complementary mechanisms to effectively deliver electricity system objectives**



iea