Grid Integration of Solar Energy, Flexibility and Role of Storage

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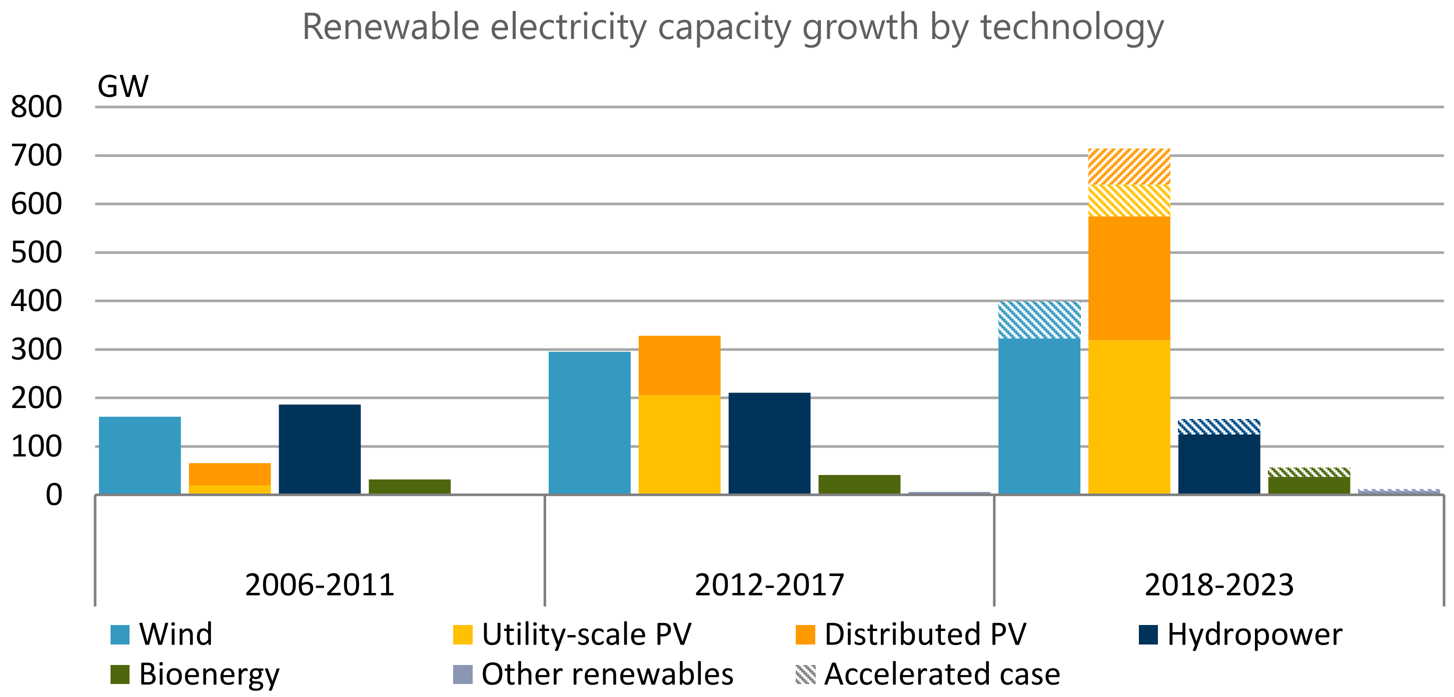
Outline

- **Overview of IEA work and introduction**
- Handling challenges during initial phases
- Mastering higher shares – system transformation

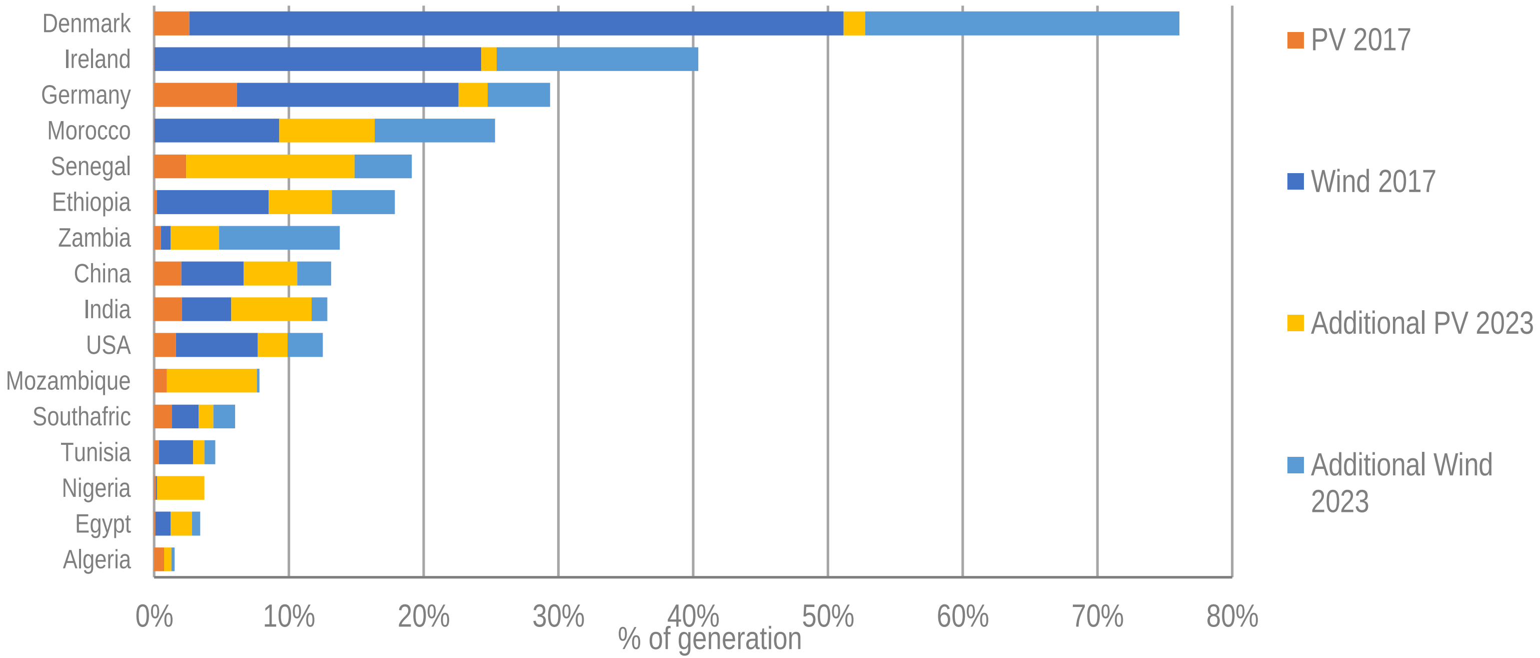
Solar PV expansion in electricity larger than all renewables combined



Distributed generation capacity growth makes the difference in solar PV's leadership
Cumulative PV capacity could reach 1.1 TW and wind over 0.9 TW by 2023 under the accelerated case

Variable Renewable Energy (VRE) on the rise

VRE share in annual electricity generation, 2017-23



A substantial increase of VRE will occur over the next five years across the globe.

Source: Renewable Energy Market Report, 2017

The 6 important properties of wind and solar power

Uncertainty

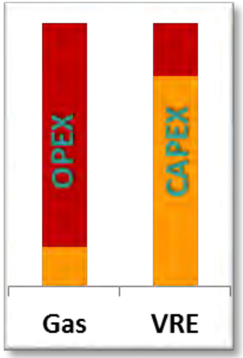
Variability

Non-synchronous technologies

Location constraints

Modularity

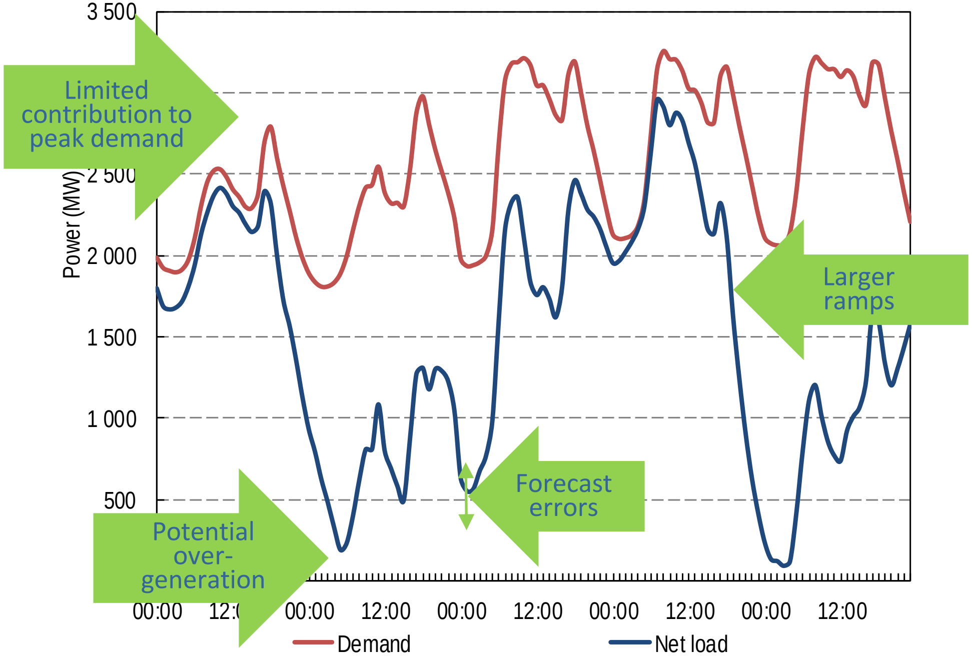
Low short-run cost



… leading to new challenges for energy security

Net load = power demand minus wind and solar output

New operational requirements



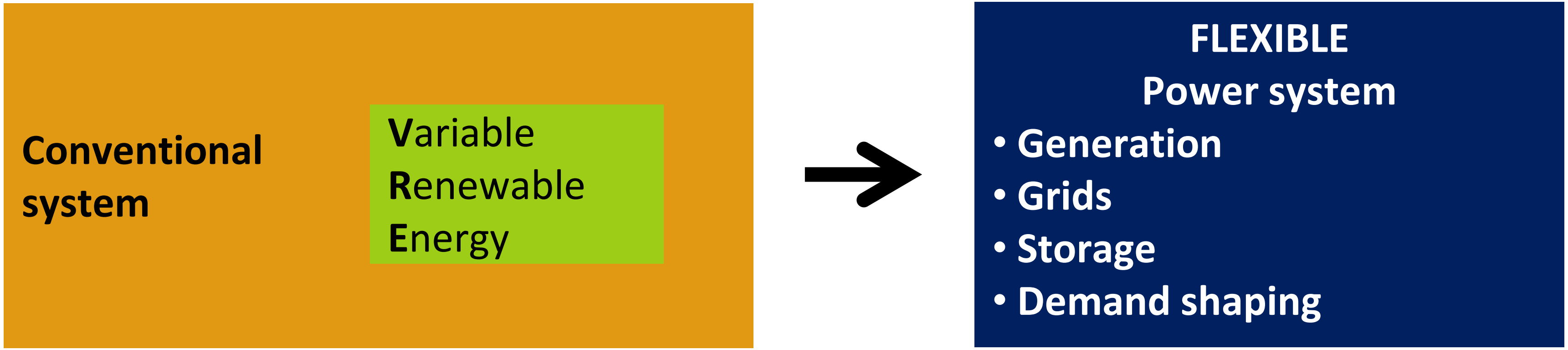
Higher shares of variable renewables pose new challenges for power systems

Three main messages on system integration

1. Very high shares of variable renewables are technically possible

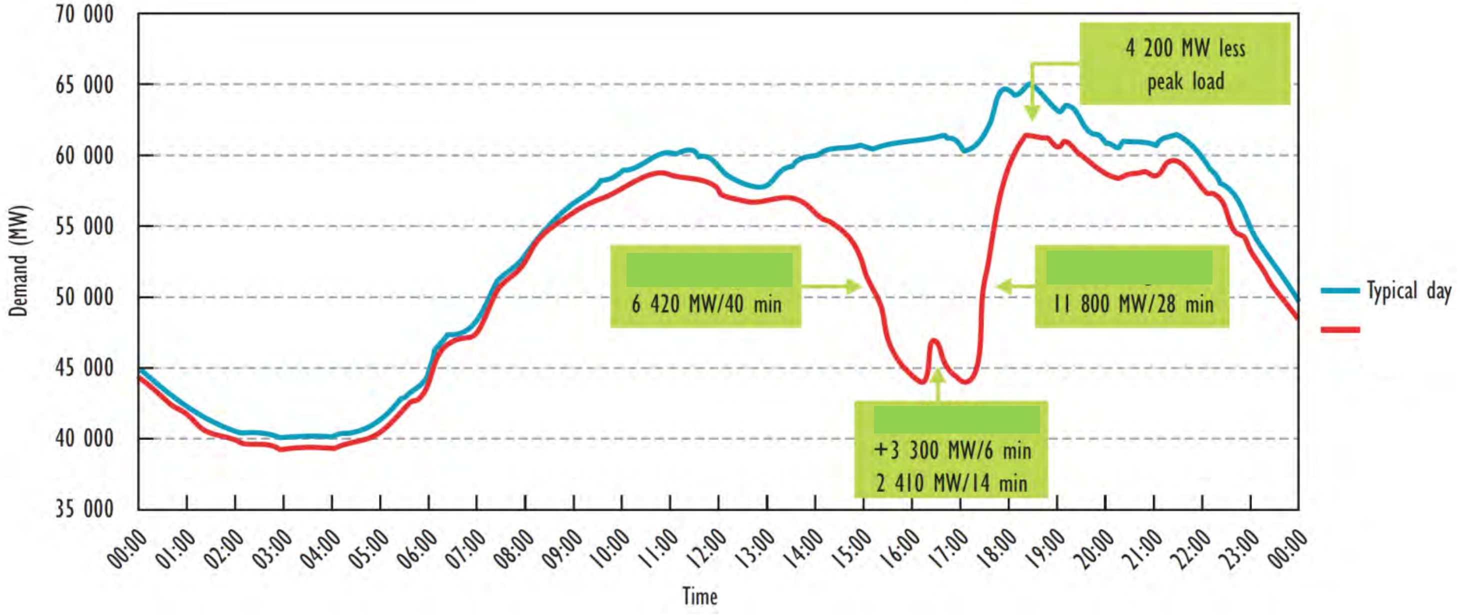
2. No problems at low shares, if basic rules are followed

3. Reaching high shares cost-effectively calls for a system-wide transformation



Variability – a familiar challenge

Exceptionally high variability in Brazil, 28 June 2010



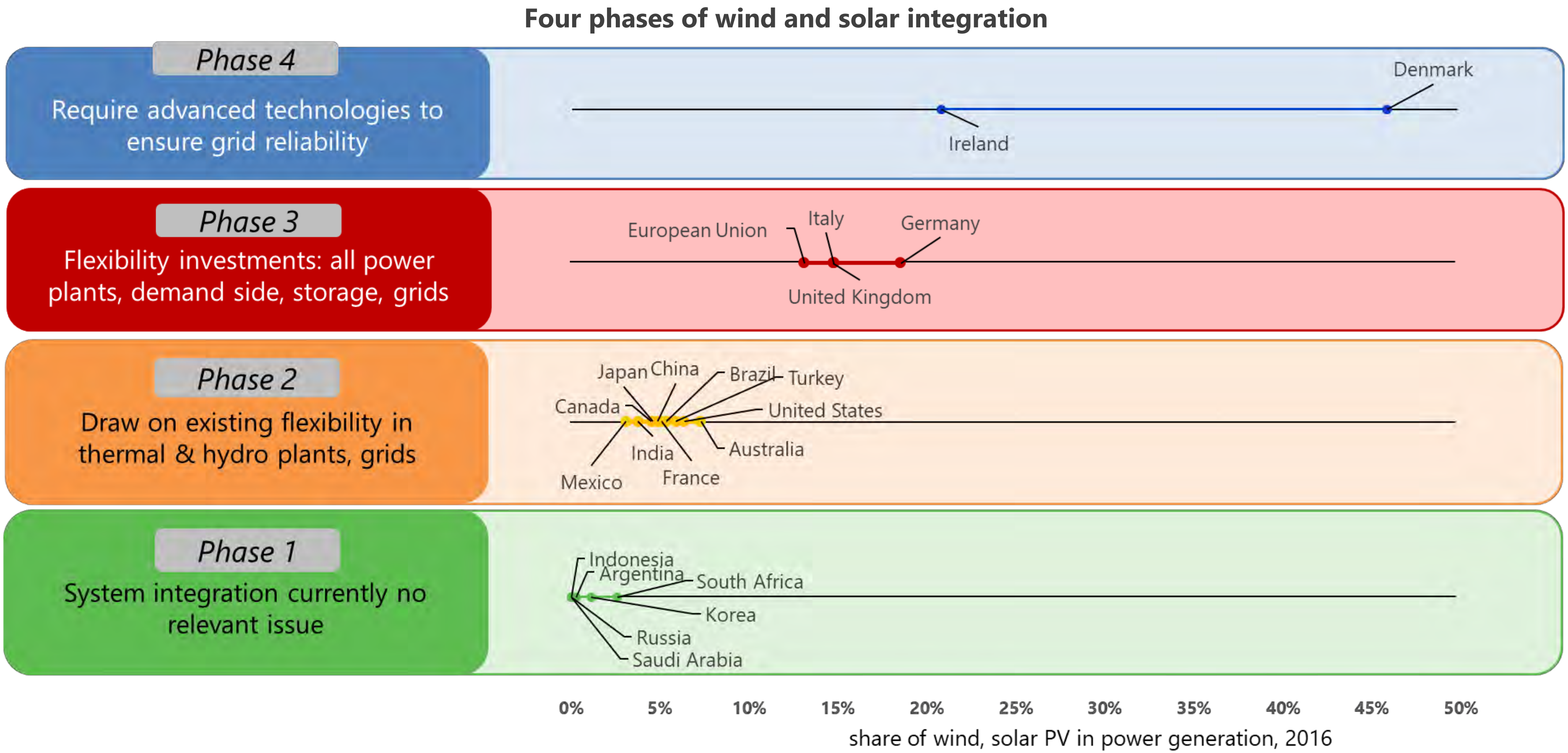
Power systems already deal with demand variability; they have flexibility available from the start.

Source: ONS, Brazil

Different Phases of VRE Integration

Phase	Description
1	VRE capacity is not relevant at the all-system level
2	VRE capacity becomes noticeable to the system operator
3	Flexibility becomes relevant with greater swings in the supply/demand balance
4	Stability becomes relevant. VRE capacity covers large majority of demand at certain times
5	Structural surpluses emerge; electrification of other sectors becomes relevant
6	Bridging seasonal deficit periods and supplying non-electricity applications; seasonal storage and synthetic fuels

Wind & solar making strong inroads, but new challenges may emerge



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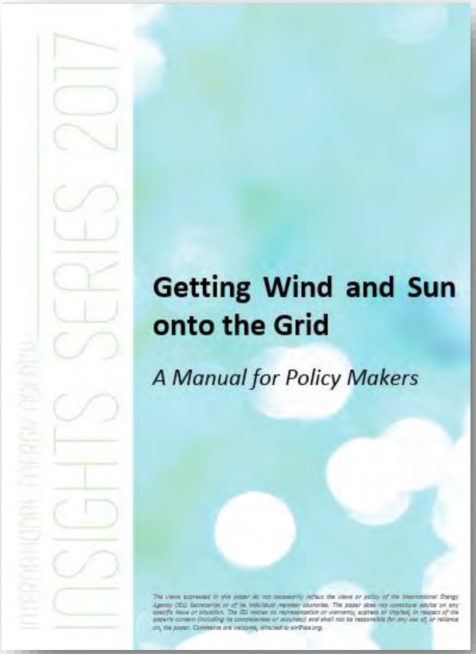
Phases 1 & 2: Getting Wind and Solar Onto the Grid

Myths related to wind and solar integration

1. Weather driven variability is unmanageable
2. VRE deployment imposes a high cost on conventional plants
3. VRE capacity requires dedicated “backup”
4. The associated grid cost is too high
5. Storage is a must-have
6. VRE capacity destabilizes the power system

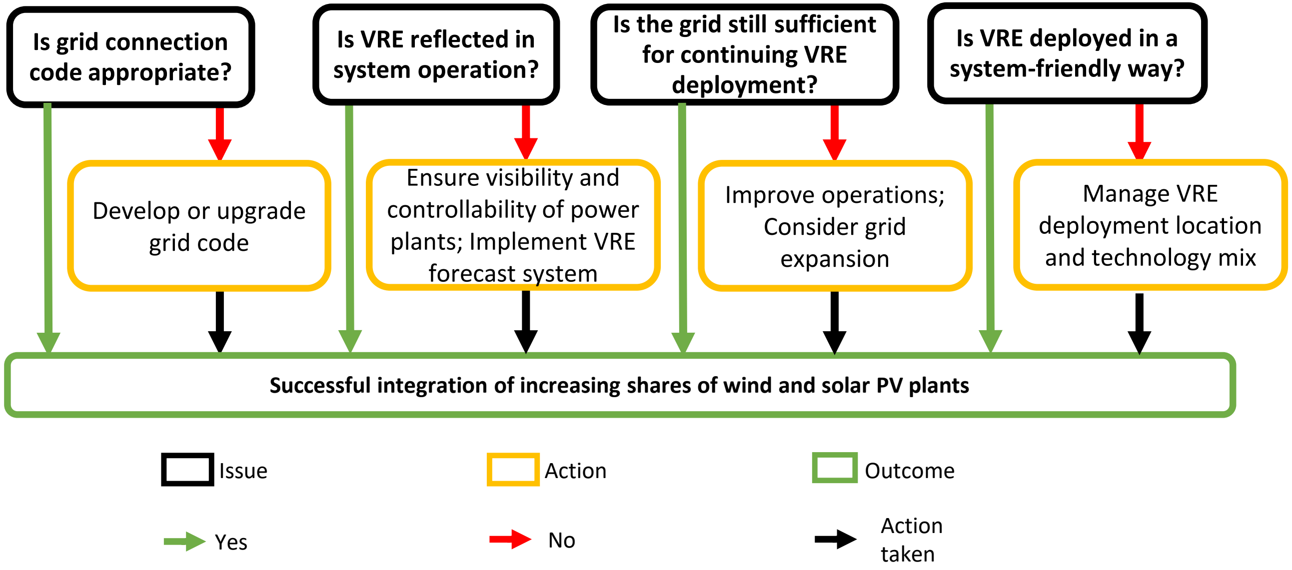
A step by step guide for initial phases of VRE deployment



Focus on Phase 2 of VRE integration

- First instances of grid congestion
- Incorporate VRE forecast in scheduling & dispatch of other generators
- Focus also on system-friendly VRE deployment

Priorities for VRE Integration – Phase 2



Source: IEA 2017, *Getting wind and sun onto the grid*

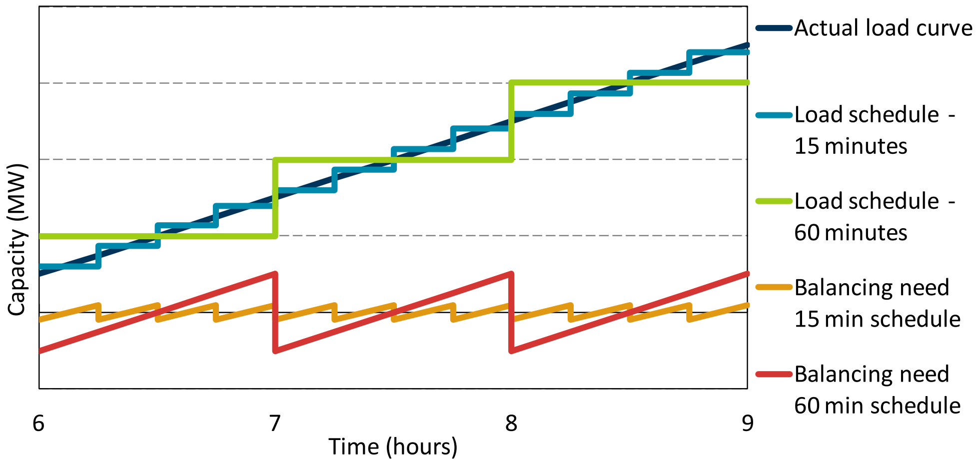
Updated system operations, sufficient visibility & control of VRE output becomes critical in Phase II

Better system operation

- Visibility and controllability of the system!
  - VRE forecasting

- Better system operations:
  - Dynamic generation scheduling
    Update schedules close to real time
  - Dynamic generation dispatch
    Short dispatch intervals
  - Dynamic use of the grid
    Update interconnection schedules close to real time; sub-hourly scheduling
  - Reward flexible operation
    Make payments based on what is helpful for the system, not just MWh
  - Allow participation of advanced technologies
    (battery storage, demand side response, VRE plants

Impact of scheduling interval on reserve requirements, illustration



Make better use of what you have already!

Legacy Power Purchase Agreements – Key in Emerging Economies

Motivation

- Rapid economic growth leading to huge electricity demand growth in 1990s.
- The need for new generation capacity… and lots of it.
- In some cases diversify the risks to private sector
- Enhance efficiency
- Promote some forms of competition

Outcomes

- Relatively inflexible PPAs over the life-time of the contract
- Risks were minimised from investor’s perspective. Government/Utilities bear most of the risks.
- Inflexible from system planning and operation perspectives
  - May leads to sub-optimal dispatch
  - Take or pay obligations
  - Inflexible contracted operating characteristics

Include flexibility provisions in any new PPAs.
Consider reforms to make existing PPAs compatible with improved operation.

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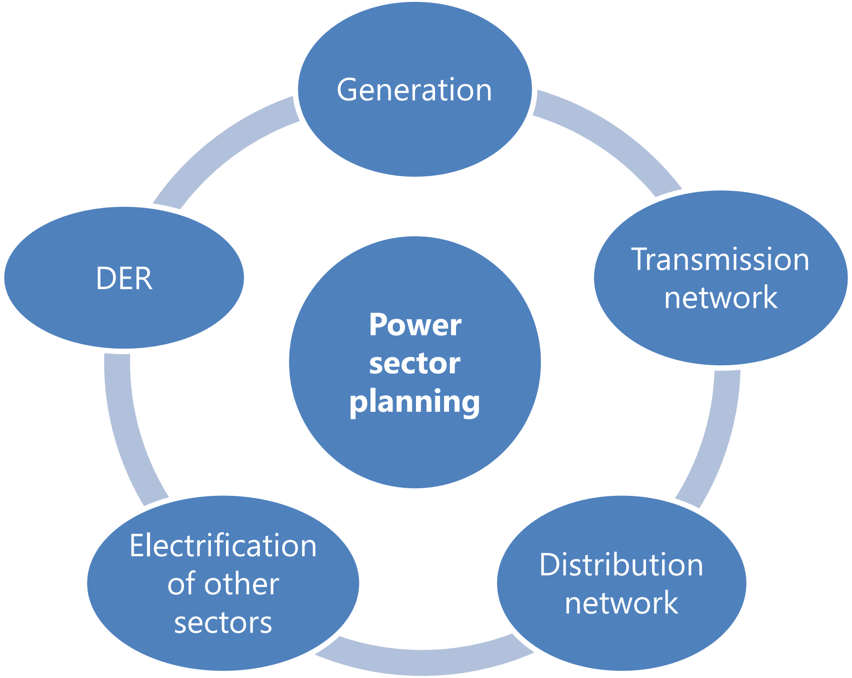
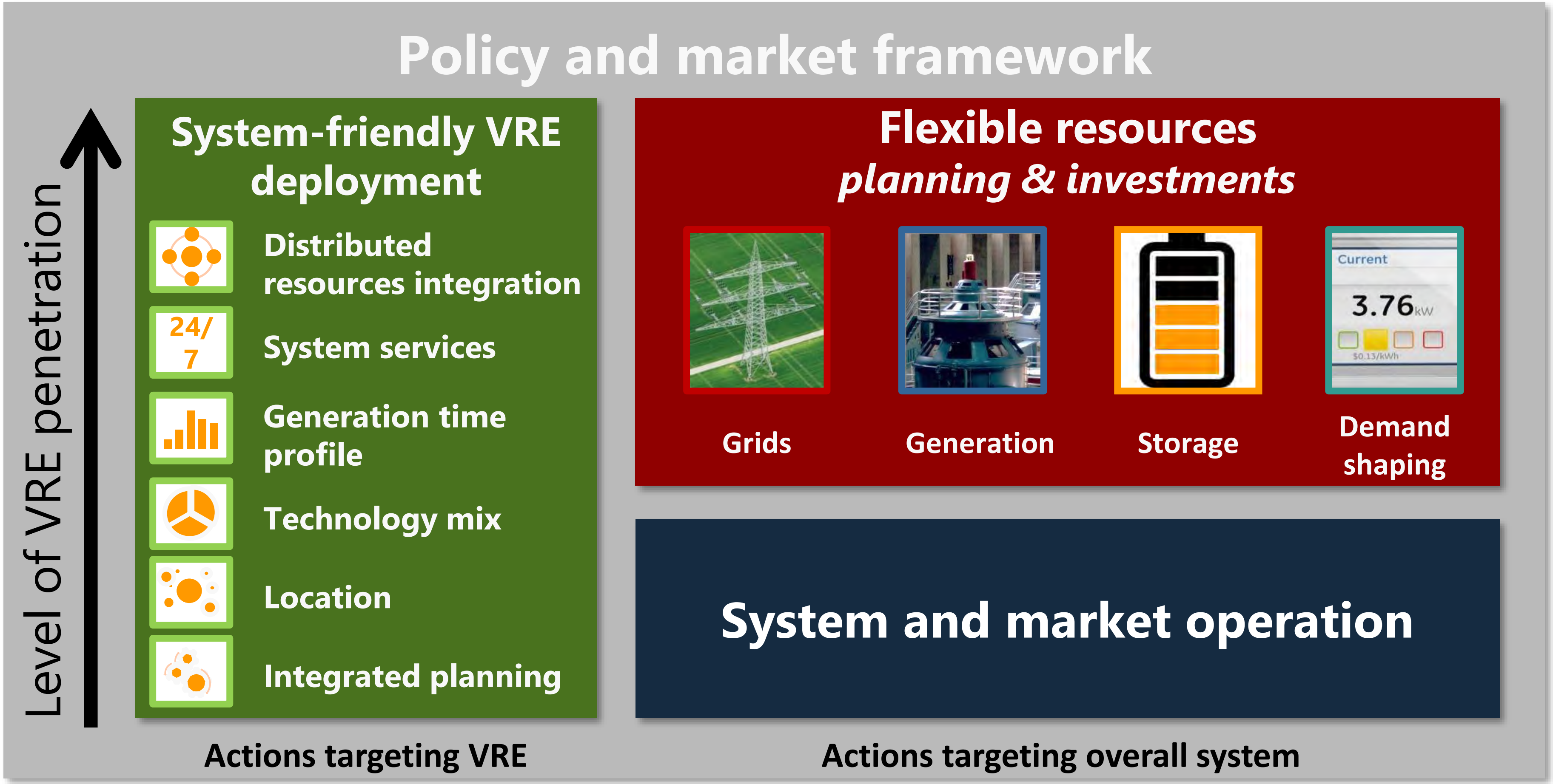
Power sector planning needs to be more integrated

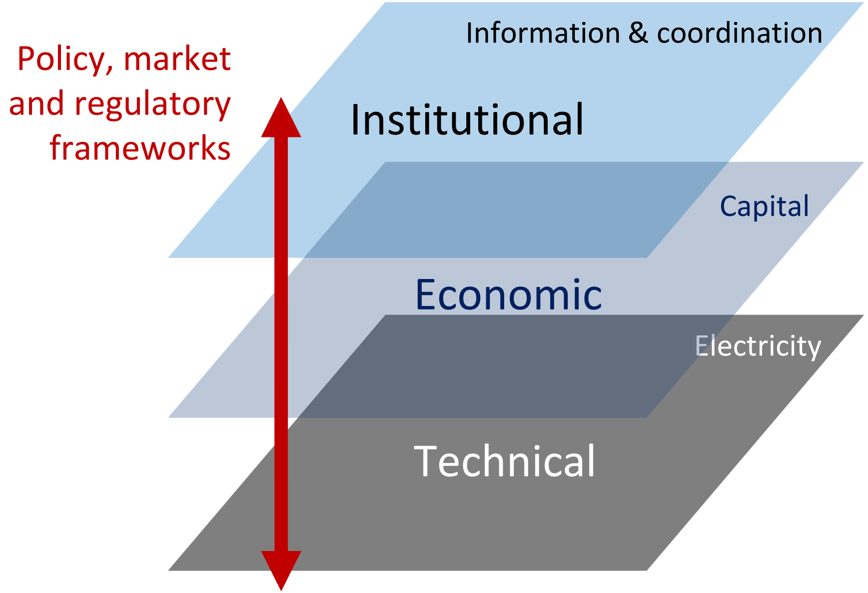


- Power sector planning traditionally focused on developing supply sources and infrastructure to meet demand
- But the landscape of the power sector is changing due to
  - Uptake of VRE, DER
  - Demand side participation
  - Electrification of transport and heat
- Implications of VRE, DER, should be taken into consideration in power sector planning

System transformation



System transformation requires holistic approach



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

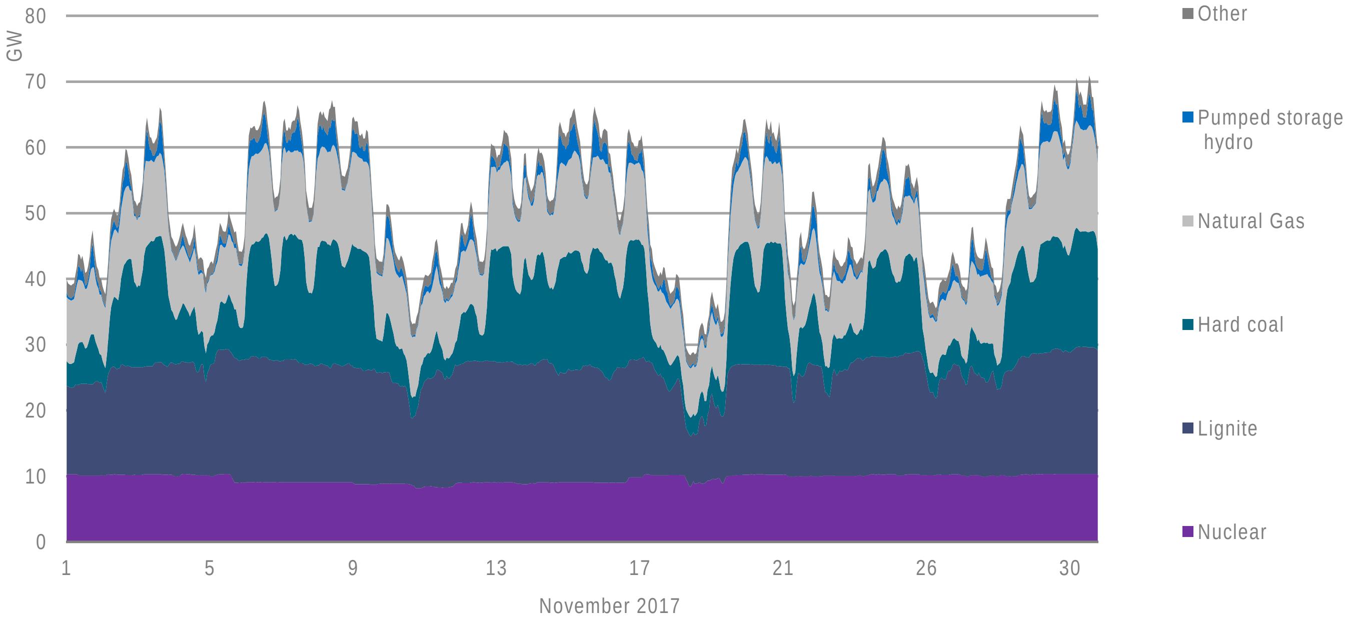
Policies, markets and regulatory frameworks link technical, economic and institutional aspects

Power plants – a cost-effective source of flexibility

Advanced Power Flexibility

- Clean Energy Ministerial Campaign, 14 partner countries and 14 industry and NGO partners
- Results published at CEM9
- Continued with broader scope: Power System Flexibility

Conventional electricity generation in Germany in November 2017



Significant system flexibility lies latent in many power plants; a range of strategies are available to unlock low-cost flexibility, many non-technical.

Source: Agora (2018b), Die Energiewende im Stromsektor: Stand der Dinge 2017

The role of energy storage in the power system

- Storage can play a key role to integrate high shares of VRE
- Pumped hydro storage accounts for the majority of storage technologies that are currently being deployed.
- Some storage technologies can provide system services to the grid.
  - Batteries can provide frequency response – Examples in Australia, Chile and PJM
- Storage makes economic sense today, if several benefits can be 'stacked'
  - Avoided or deferred grid investment
  - Reduced load shedding
  - Arbitrage
  - System services

Electricity storage can provide grid services

Jurisdiction	Detail
Chile	• Battery storage is used for grid stabilisation purpose
Italy	• More than 40 MW of battery storage technologies have been deployed to solve grid congestion and to provide frequency regulation
National Grid UK	• Procured 200 MW of FFR through tenders in 2016. Most of which are battery projects
PJM	• 250 MW of electricity storage can provide fast frequency response
Australia	• Hornsdale 100MW/MWh battery in South Australia • Able to provide frequency control ancillary services

Summary

- Challenges for integrating wind and solar are often smaller than expected at the beginning
  - Power systems already have flexibility available for integrating wind and solar
- Challenges and solutions can be group according to different phases
  - Measures should be proportionate with the phase of system integration
  - Making better use of available flexibility is most often cheaper than ‘fancy’ new options
  - Barriers can be technical, economic and institutional, all three areas are relevant
- Challenges can be minimized via system friendly deployment
  - Integrated planning is the foundation for long term success
  - Renewable energy policy should seek to maximize value while minimizing costs
- To reach high shares cost-effectively, a system-wide approach is indispensable
  - Battery electricity storage is competitive today for very specific applications, where multiple benefits ‘stack’

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- **Implications for renewable energy policy**

Factoring in value

← Less useful: *Lower value*

More useful: *Higher value* →

The value of electricity for the power system depends on where, when and how it is generated.

	Low value electricity	High value electricity
When	When electricity is abundant	When electricity is most needed
Where	Far away from demand	Close to demand
How	No additional system services	Provides additional services for system

Going beyond generation costs – system value

LCOE

- Installation costs
- Operation and maintenance costs (fuel, emissions)
- Financing cost
- …

SV

+

- Reduced fuel and emission costs
- Reduced costs/ need for other generation capacity

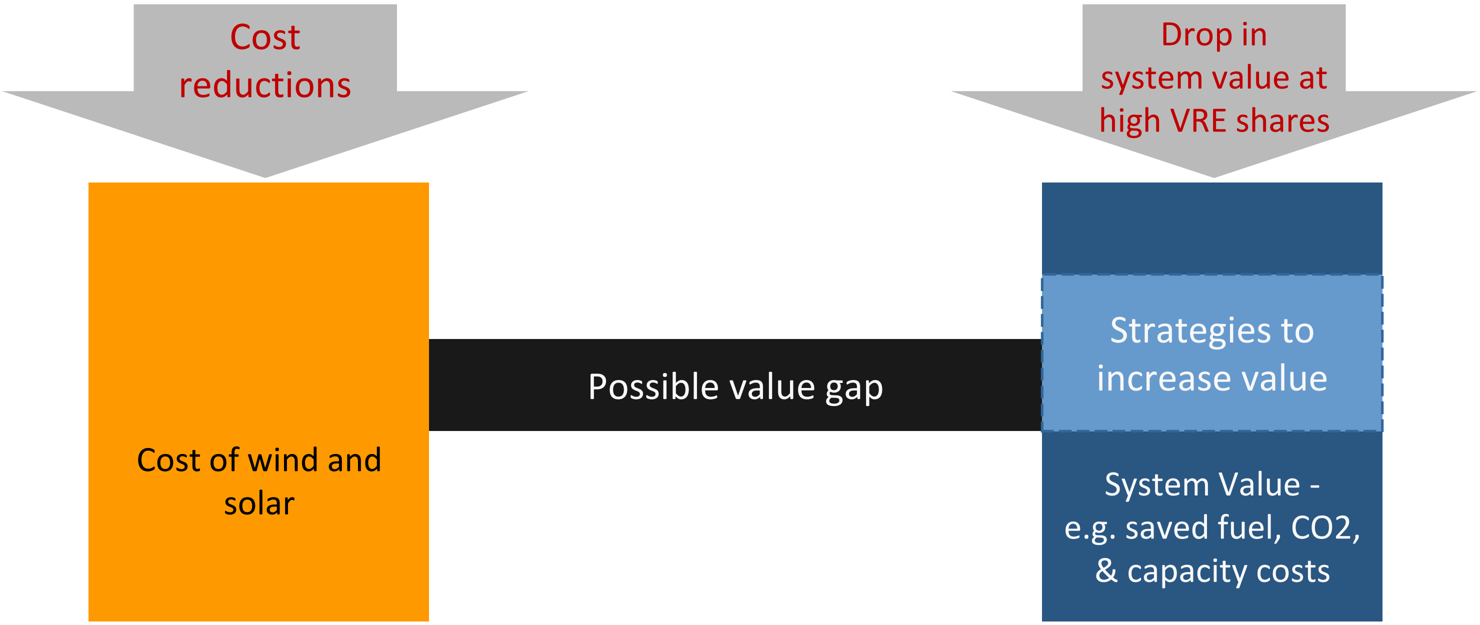
–

- Increased operational costs for other power plants
- Additional grid infrastructure costs
- Curtailment

LCOE and System Value (SV) are complementary:
LCOE focuses on the level of the individual power plant, while SV captures system-level effects

Why do we need to look at the value of wind and solar power?

The link between cost, value and competitiveness



Strategies to increase the value of VRE as important as reduced generation costs, in particular at high shares.

Image source: http://avalonenergy.us/blog

Implications for deployment priorities

	Traditional approach	Next generation approach
When *is electricity produced?*	Not considered	Optimised: best mix of wind and solar; advanced power plant design; strategic choice of location
Where *is electricity produced?*	Best resources, no matter where	Optimised: trade-off between cost of grid expansion and use of best resources
How *is electricity produced?*	Do not provide system services	Optimised: better market rules and advanced technology allow wind and solar power to contribute to system services

Next-generation wind and solar power require next generation polices.

Fundamental trade-off for policy design:

Priority 1: Expose wind and solar generators to prices that reflect their value depending on location and time of generation.

Priority 2: Provide sufficient investment certainty.

Example of next generation policy priorities

Action area	Policy example
Integrated planning: wind and solar embedded in energy strategy	**Denmark:** integrated energy strategy
Location: siting VRE closer to existing network capacity and/or load centers	**Location:** new auction design for wind and PV
Technology mix: balanced mix of VRE resources can foster lasting synergies	**Technology mix:** Integrated Resource Plan
Optimising generation time profile: design of wind and solar PV plants	**California:** incentive to produce at peak times
System services: wind and sun contribute to balance system	**System services:** wind active on balancing market
Local integration with other resources such as demand-side response, storage	**Australia:** policies for self-consumption

A paradigm shift towards advanced remuneration schemes

Past

Main Policy

Providing financial support

Cost reduction via

- Technology development
- Scale up
- Learning

Present and mid term future

Enabling policy and market framework reducing financing costs

- Technology *innovation*
- Financial *innovation*
- New markets with best resources

Key characteristics of new approach

Level playing field
- Carbon pricing
- Phase out of fossil fuel subsidies

Regulation and market design
- Competition
- Predictable long-term income streams
- Short-term market value signals

System approach
- RE portfolio
- Energy System Integration

System operation and market design

Efficient operation of the power system	• Ensuring least-cost dispatch • Trading close to real time • Market integrations over large regional areas
Unlocking flexibility from all resources	• Upgrade planning and system service markets • Generation, grid, demand-side integration and storage
Security of electricity supply	• Adequacy: Improve pricing during scarcity; possibly capacity mechanisms mechanism as safety-net • Security: Ensure appropriate tools for system operators
Sufficient investment in clean generation capacity	• Sufficient investment certainty • Competitive procurement (with long-term contracts)
Pricing of externalities	• Reflecting the full cost (i.e. environmental impacts)

Different phases of VRE integration

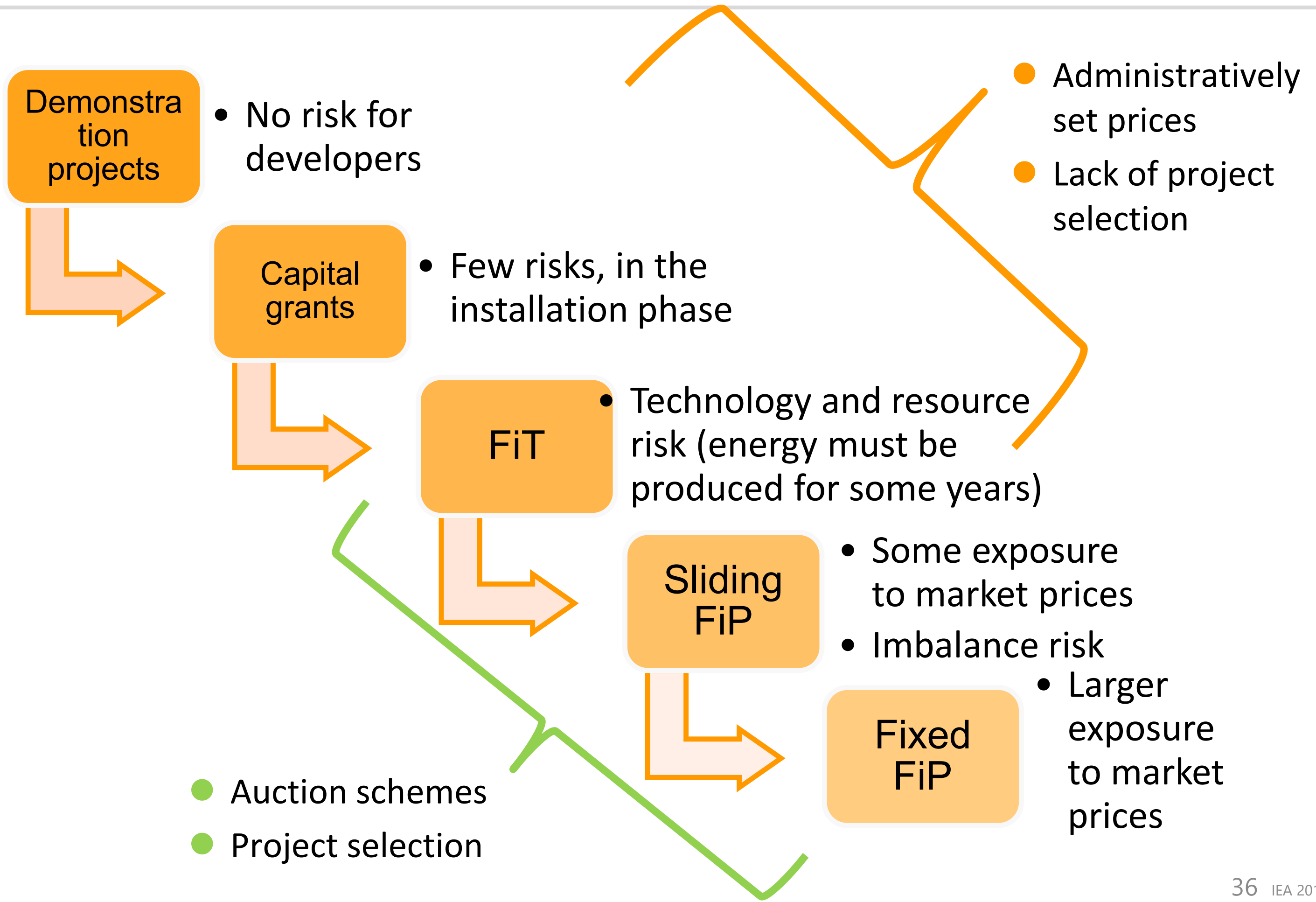
	Attributes (incremental with progress through the phases)			
	Phase 1	**Phase 2**	**Phase 3**	**Phase 4**
Characterisation from a system perspective	VRE capacity is not relevant at the all-system level	VRE capacity becomes noticeable to the SO	Flexibility becomes relevant with greater swings in the supply/demand 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

Grid code is important for VRE integration

	Always	Phase One	Phase Two	Phase Three	Phase Four
Typical technical requirements	• **protection systems** • **power quality** • **frequency and voltage ranges of operation** • **visibility and control of large generators** • **communication systems for larger generators**	• **output reduction during high frequency events** • **voltage control** • **FRT capability for large units**	• **FRT capability for smaller (distributed) units** • **communication systems** • **VRE forecasting tools**	• Frequency regulation • reduced output operation mode for reserve provision	• integration of general frequency and voltage control schemes • synthetic inertia • stand-alone frequency and voltage control

- Need to ensure the grid code is appropriate for VRE
- Prioritising technical requirements according to the share of VRE
- Need to be in the context of individual power system

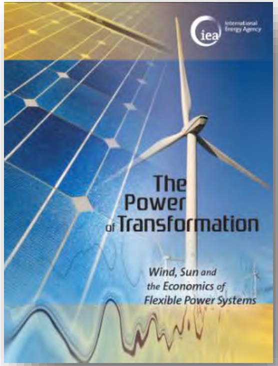
Factoring in risk



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
  - Dedicated Unit on System Integration since June 2016
  - Part of delivering the IEA modernisation strategy

2014

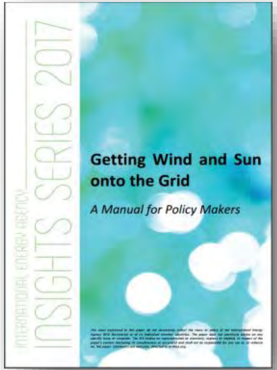


Framework, Technology, Economics

2016

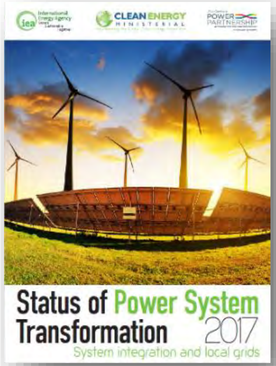
Policy

2017



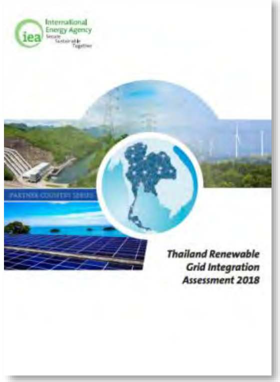
Implementation

2017



Progress & Tracking

2018



Country Engagement

UK - Limejump– BES for real-time balancing

- Background
  - BESS projects have seen decreasing opportunities in typical markets, such as 1ary reserve markets (due to saturation) and de-rating for capacity market participation.
  - UK's Balancing Mechanism, previously closed-off to assets under 50MW and without a wholesale market licence
  - BM observed prices can reach up to 2500GBP/MWh (vs avg. 50GBP/MWh in WM), and over 100GPB/MWh for a third of the time

- Approach
  - Limejump applied for a special dispensation to enter the market
  - VPP to aggregate 10 MW BESS + Colocated 10MW-PV/6MW-BESS
  - Stacking of revenues from Wholesale arbitrage, BM, **night-time** frequency respon

- Stakeholders
  - Limejump (Independent aggregator), Anesco VRE operator

- Additional comments
  - UK currently revising the role of aggregators in WM participation

DE -EnspireME - Co-located BES for grid congestion

- **Background**

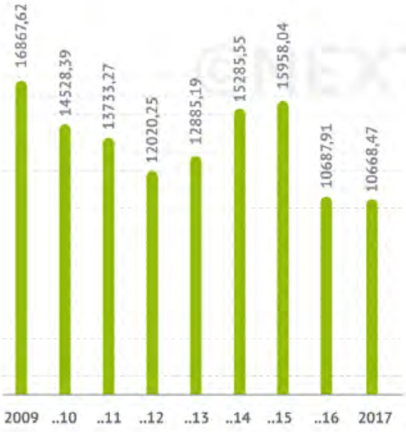
  High levels of curtailment in Northern Germany due to line congestions
  Redispatch costs have been rising so politically visible/contentious

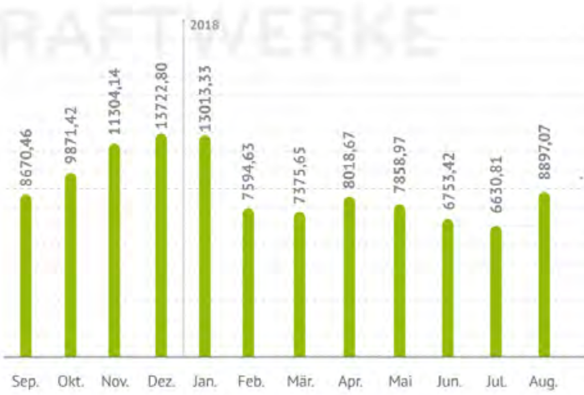
- **Approach**

  Construction of a 48MW and 50 MWh Li-ion battery next to a substation in Jardelund
  Surplus wind energy stored and offered on the primary reserve market

- **Stakeholders**
  - ENECO and Mitsubishi corporation

- **Additional aspects**
  - Issues with share-ownership of transmission and distribution businesses by stakeholders
  - Cost around 40 Mio EUR, 2 Mio EUR EU financing. Financed mainly through bank loans
  - 5-6 years expected payback-period





NL – NEXT Kraftwerke/Jedlix - BESS/V2G – Balancing services

- Background
  - NEXT Kraftwerke is one of the largest VPP operators in Europe
  - Jedlix developer of smart-charging platform for EVs
- Approach
  - NEXT bids upward and downward charging flexibility of Jedlix' managed EVs to Tennet's secondary reserve market
  - Customer's charging preferences are optimized through Jedlix platform to offer realistic predictions for NEXT to bid into SRL market with daily auctions
  - NEXT balances EV availability through additional assets on proprietary VPP platform
  - Consumer's receive explicit bill rewards depending on the level of flexibility offered. Pay-outs start from 5EURs
- Stakeholders
  - NEXT Kraftwerke, Jedlix, Tennet
- Additional aspects
  - Jedlix has signed a similar services contract in France with Total, and Renault
  - Both NEXT Kraftwerke and Jedlix are partly owned by Eneco.
  - Renault also owns a 25% share in Jedlix

AU – Hornsdale Wind and BESS

- Background
  - Need to accommodate increasing shares of VRE penetration
    - Wind 36% of IC vs 143% of MIP
    - Rooftop PV 14% vs 41% of MIP
  - Wind maximum variation of 763 MW/5min and 963MW/30 min
  - Adjacent to 315 MW Hornsdale Wind Farm, operated by Neoen

- Approach
  - 100 MW BESS, arbitrage in WM as well as participation in frequency control and ancillary services markets
  - 30MW with 4 hrs storage + 70 MW with ca. 10 min storage

- Stakeholders
  - Tesla, AEMO, Neoen

- Additional aspects
  - Battery has captured 55% of FCAS revenues in South Australia
  - “In the first four months of operation FCAS prices went down by 90%”
  - Overall Tesla and EnerNOC have captured 20% od the country’s FCAS market
  - The greatest share of revenues is from 30MW/90MWh component engaged in arbitrage
  - Price drop in FCAS needs to be balanced against increasing market volume

https://www.pv-magazine-australia.com/2018/02/06/neoen-australia-urges-caution-over-hornsdale-battery-profitability/

Figure 1 Accuracy and speed of regulation FCAS response – large conventional steam turbine

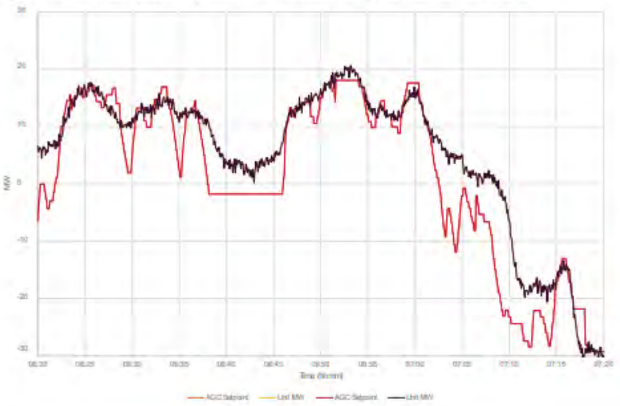


Figure 2 Accuracy and speed of regulation FCAS response – Hornsdale Power Reserve