IRENA
International Renewable Energy Agency

# The Knowledge Framework for Power Sector Transformation

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**IRENA Power Sector Transformation Knowledge**
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# Introduction

- Is a transition to 100% RE power system possible?
  - ✓ Hydro and PV + Battery exist today
- Is there a single pathway or recipe for the transition?
  - ✓ No, depends on enablers and specific country conditions.
- What is changing to make it feasible?
  - ✓ New technologies, cost reduction and enablers (e.g. storage, power electronics)
  - ✓ Learning by doing on policies, regulations and system operations as low-cost, high-impact

- Why is a knowledge framework necessary?
  - ✓ To learn from successful measures put in place by front runners
    - ✓ Need to locate measures in time
    - ✓ Understand applicability of measures to other countries based on common enablers
- Is it technically feasible to go 100% without certain enablers in place?

**VRE Integration**

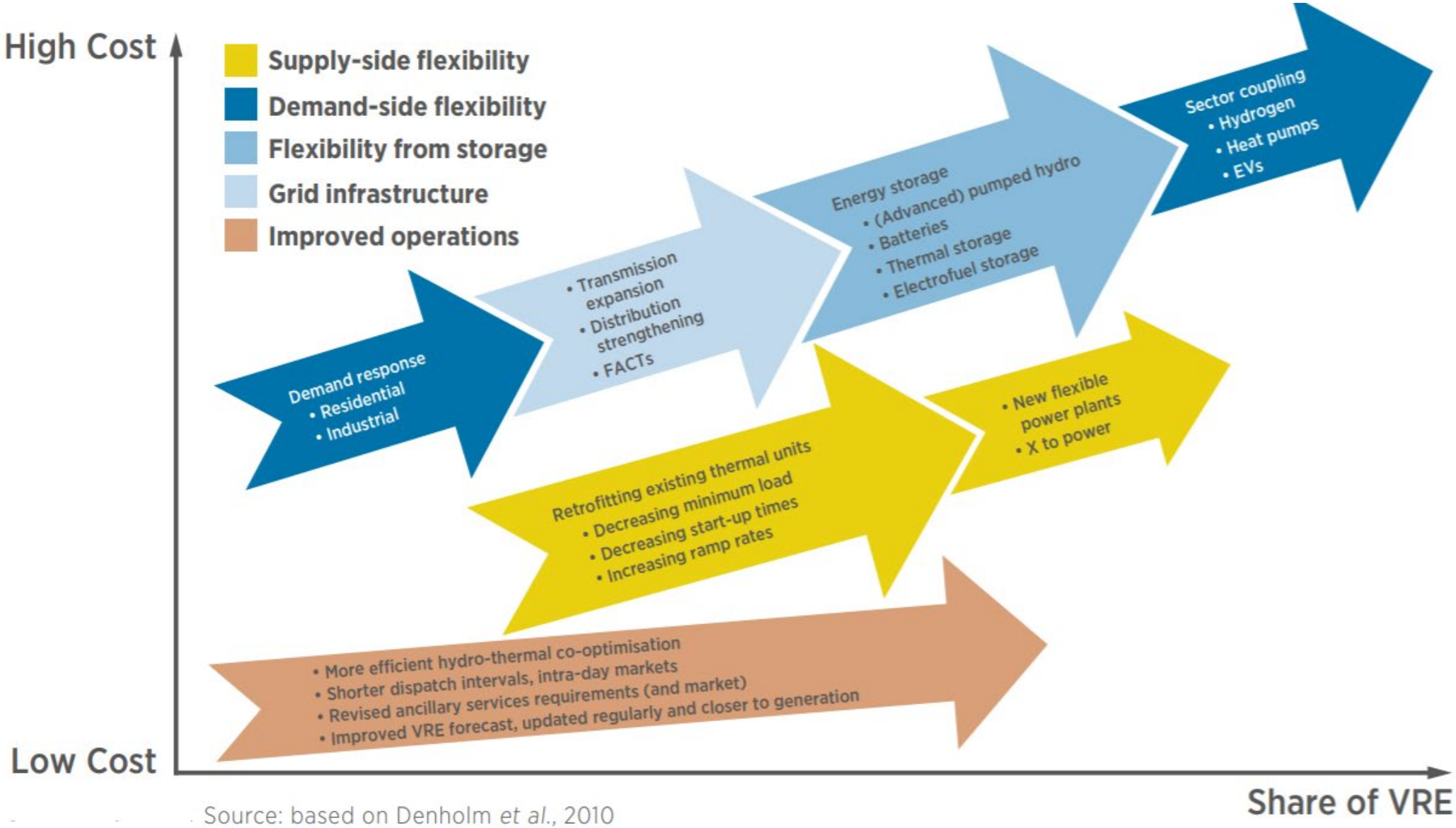
- **Carrying capacity** (from which VRE "breaks" the grid)
- **Nearly always there is a technical solution**
- Focus on economic carrying capacity as metric
  - Operational improvements are key and should come first

**Transfer of measures and Optimization**

- Typically a **product of "learning-by-doing"**
- Learning from Country A may be applied on country B, provided similar enabling condition/profiles are in place

Learning by Doing

# Introduction




Source: based on Denholm *et al.*, 2010

# Different Transition Pathway based on Countries Profiles

**Front runners: DK: 40% / IE: 20%**

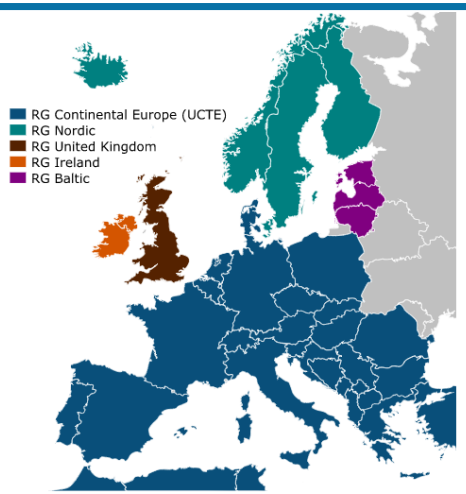
- Low domestic storage
- High PPs Flexibility

**Size of national grid compared to synchronized power system (2015)**

- DK: 1.28% <-> IE: 74%

**Interconnectors (2015)**

- DK: 50% <-> IE: 7%




- **Same measures but at different times**
- **But also different measures**

**DK**

2.2% → 3.5% → 3.8% → 8.3% → 13.9% → 15.6% → 18.4% → 19.8% → 24.4% → 30.9% → 35.8% → 46.0%

- Improved Flex (CHP Plants)
- First grid code for wind
- Regulation Power Market
- Wind in Regulation Market

**IE**

0.2% → 1.1% → 2.6% → 7.1% → 8.4% → 10.5% → 16.2% → 15.5% → 17.3% → 19.6% → 24.3%

- Intention for first grid code
- First grid code (general)
- Specific grid code for Non-Synchronous
- Potential Technical-Max SNSP

**Integration should not be approached by one-dimension only – VRE generation share – but in a multi-dimensional way**

# IRENA Knowledge Framework

- **Goal: provide tailored advice to countries facing integration challenges by mining a database of measures based on the experience** from front-runners
- **Provide a semi-automated quick insight** to countries on where to look next
- Define a **set of quantitative indicators** to identify country-specific profiles/enablers
  - **Link countries** experiencing challenges with front-runners that solved such issues
- What was the measure, year and impact on key indicator?

| Identify **RE integration challenges** that have been resolved by front-runners | Identify **key measures** used to resolve the challenges | Measure the **impact of such measures** on integration indicators | **Estimate the applicability of each measure** based on enabling conditions |
|---|---|---|---|
| • **Line Congestion**<br>• **Lack of system Inertia** | • **Dynamic Line rating**<br>• **Synchronous condensers** | • **Curtailment variations**<br>• **Negative prices** | • **Filter Measures:**<br>  • **Statistical Inference** |

# What can IRENA do for its Members using the Knowledge Framework?

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## Synergies with other IRENA Products

REmap
A Renewable Energy Roadmap

» Enhance a plan for a target year by suggesting measures

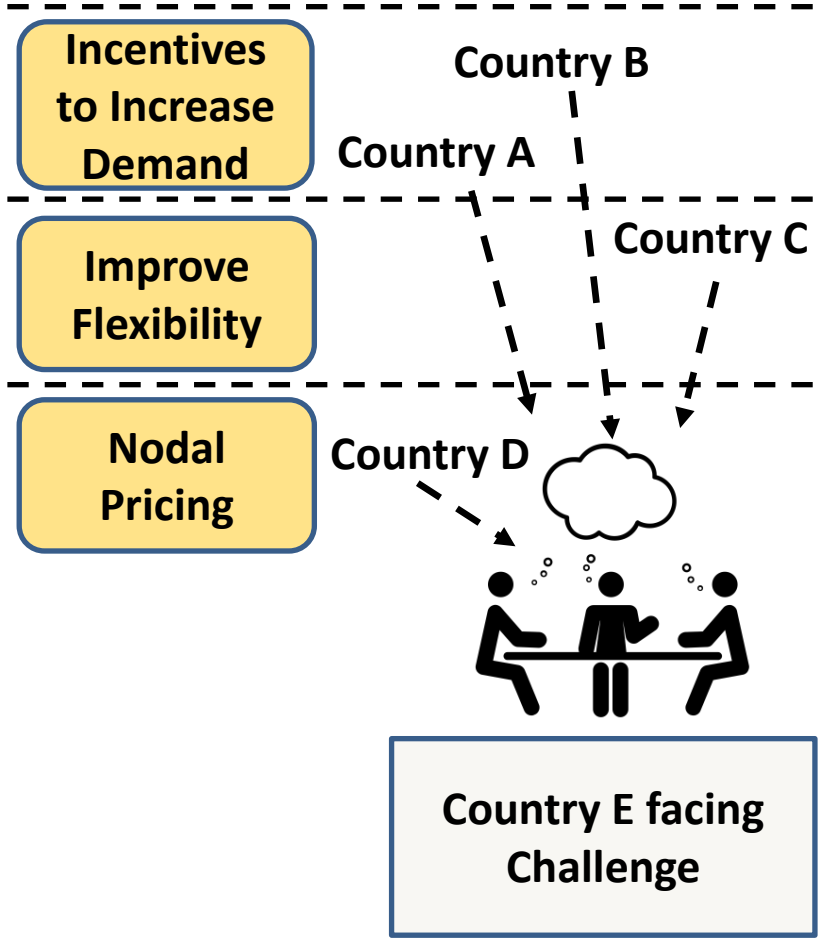
IRENA FLEXTOOL CASE STUDY

» Identify the need for a flexibility assessment

Integration Costs Discussion

» identify first and likely low-cost measures in a country's pathway

## Workshops: Sharing of best practices

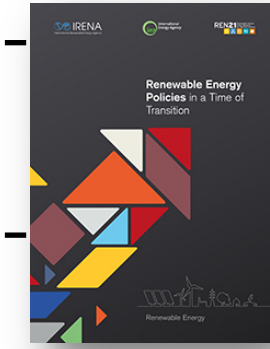



## IRENA Reports and others relevant literature

Incentives to Increase Demand

Improve Flexibility

Nodal Pricing



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# Knowledge Database

# Knowledge Framework – Profiles and Measures Database


- **Country Profile in year Y**
  - Indicator A $_{y}$
  - Indicator B $_{y}$
  - Indicator C $_{y}$
- **Country Profile in year Y + 1**
  - Indicator A $_{y+1}$
  - Indicator B $_{y+1}$
  - Indicator C $_{y+1}$
- **Country Profile in year Y + n**
  - Indicator A $_{y+2}$
  - Indicator B $_{y+2}$
  - Indicator C $_{y+2}$

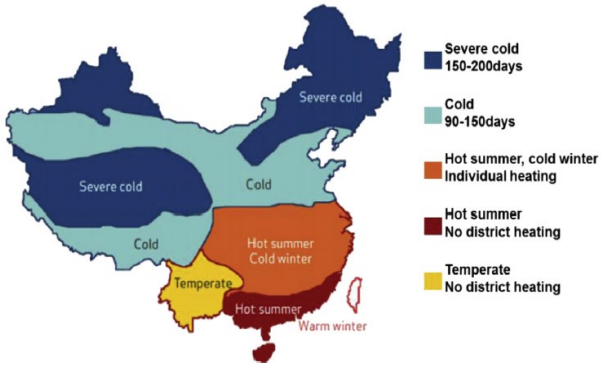
**Country Profile following years**

- **Solution applied in year Y**
  - **Year Y**
  - **Indicators**
  - **Enabling Conditions** (can be a solution previously applied)
- **Solution applied in year Y+1**
  - **Year Y**
  - **Indicators**
  - **Enabling Conditions** (can be a solution previously applied)
- **Solution applied in year Y + n**
  - **Year Y**
  - **Indicators**
  - **Enabling Conditions** (can be a solution previously applied)

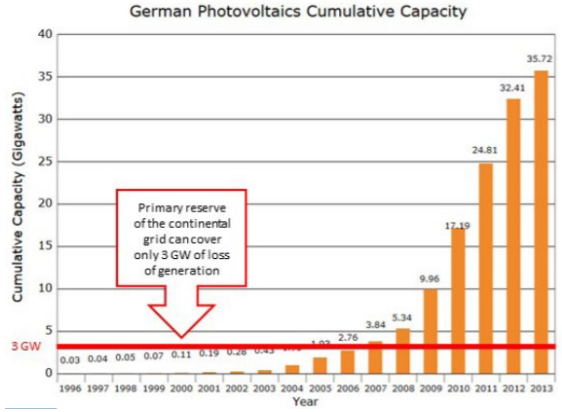
# Knowledge Framework – Profiles (Indicators) Examples

**Total: 44 indicators**

- **Flexibility (8 indicators)**
  - Temperature-wind correlation
  - CHP generation to total

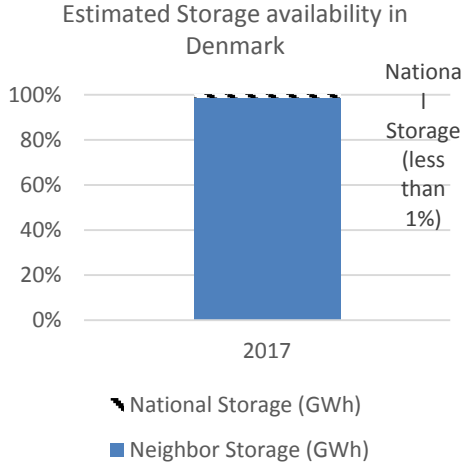



- **Operation (14 indicators)**
  - VRE capacity/primary reserve

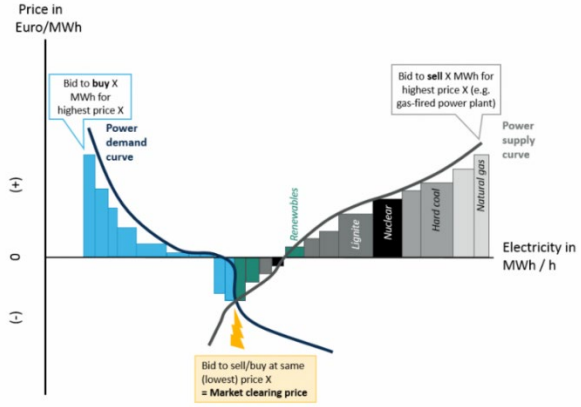



- **Transmission and Distribution grids (7 indicators)**
  - Mismatch Index (Supply-demand energy balance)


- **Interconnection (4 indicators)**
  - Storage in neighbor countries




- **Market (7 indicators)**
  - Prices are allowed to go negative




- **Demand Response (4 indicators)**
- **Storage (1 indicator)**

# Profile indicators are Numbers: Flexibility Example

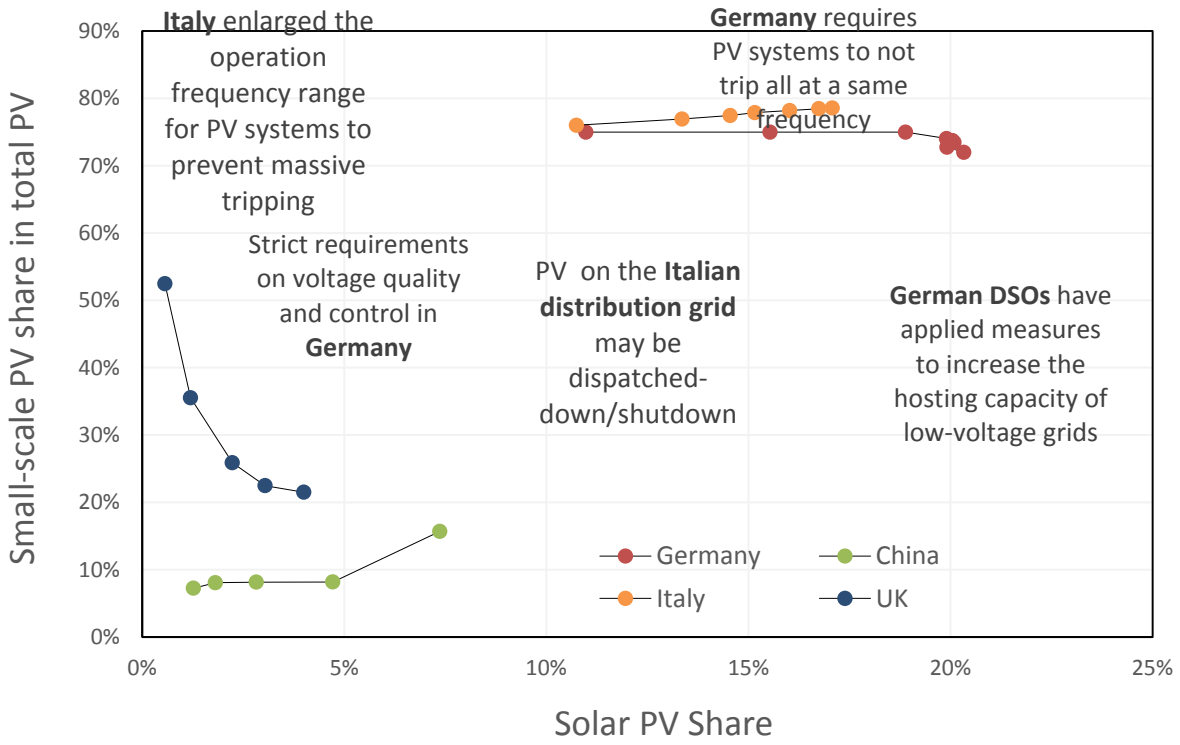
| | Profile Indicators | China | Denmark | Germany | Ireland |
|---|---|---|---|---|---|
| Heating coupling | Temperature-VRE Correlation | - 0.49 | - 0.81 | - 0.73 | - 0.49 |
| | Combined Heat Power share – Heat (%): | 46 | 73 -> 67 | 80 | 6.9 |
| | Combined Heat and Power share - ELE (%): | 13 -> 17 | 40 -> 79 | 12 -> 15 | 7.5 |
| Best avail. thermal plant | Minimum Stable Level (%): | 50 -> 35% | 35 -> 15% | 40 -> 12% | 35% |
| | Ramp (%/min): | - | 1 -> 4 | 1.5 -> 6.0 | 4 |
| Flexible fleet* | Flex Capacity Share (%): | 21 (national) ; 5 (north) | >50 | 8.7 -> 8.1 (national); 2 (north) | 17-30 |
| | Flex Generation Share (%) | 17 -> 19 | >50 | 9.4 -> 8.8 | 15 - 24 |
| | Ratio VRE-Flex capacity: | 0.27 -> 0.83 | 0.96 | 3.67 –> 4.92 | 0.73 –> 1.88 |

* Flexible fleet includes Hydropower

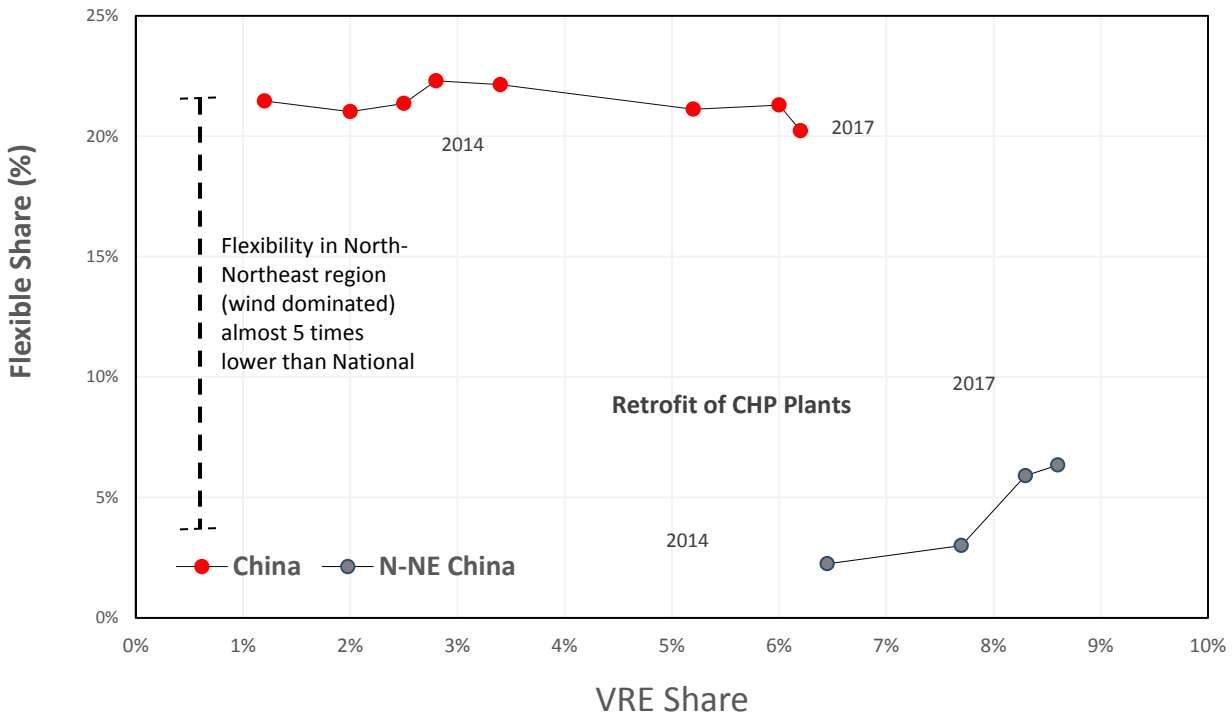
# Knowledge Framework – Indicators x Measures

## Measures related to countries profiles

- **High share of small-scale PV systems**



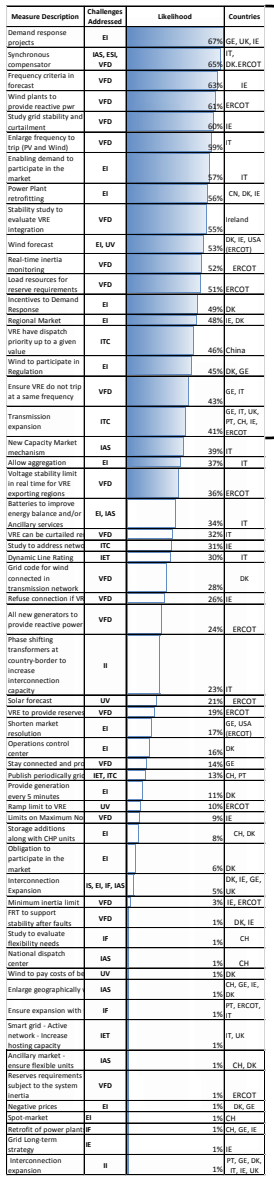

- **Bottlenecks over the transmission network may prevent the best use of power assets**



# Knowledge Framework – Filtering measures by country profile

- **Main Table Output**

**Most to less suitable measures based on country profile**



| Measure Description | Challenges Addressed | Likelihood | Countries |
|---|---|---|---|
| Demand response projects | EI | 67% | GE, UK, IE |
| Synchronous compensator | IAS, ESI, VFD | 66% | IT, DK.ERCOT |
| Frequency criteria in forecast | VFD | 64% | IE |
| Wind plants to provide reactive pwr | VFD | 63% | ERCOT |
| Study grid stability and curtailment | VFD | 61% | IE |
| Enlarge frequency to trip (PV and Wind) | VFD | 60% | IT |
| Enabling demand to participate in the market | EI | 59% | IT |
| Power Plant retrofitting | EI | 58% | CN, DK, IE |
| Stability study to evaluate VRE integration | VFD | 57% | Ireland |
| Wind forecast | EI, UV | 55% | DK, IE, USA (ERCOT) |
| Real-time inertia monitoring | VFD | 53% | ERCOT |
| Load resources for reserve requirements | VFD | 52% | ERCOT |
| Incentives to Demand Response | EI | 51% | DK |
| Regional Market | EI | 49% | IE, DK |
| VRE have dispatch priority up to a given value | ITC | 48% | China |
| Wind to participate in Regulation | EI | 46% | DK, GE |
| Ensure VRE do not trip at a same frequency | VFD | 44% | GE, IT |
| Transmission expansion | ITC | 43% | GE, IT, UK, PT, CH, IE, ERCOT |

***Fictional Example, not related to any existing case***

**Challenges**

II - Insufficient Interconnectors
EI - Energy imbalance
IAS - Insufficient Ancillary Services
IET - Inneficient use of existing transmission lines
IF - Insufficiency Flexibility
ITC - Insufficient transmission capacity
IS - Insufficient Storage
UV - Unforseen variability
ESI - Ensure short-circuit power and Inertia
VFD Voltage and Frequency deviations

# Knowledge Framework – Assessment Flowchart (China)

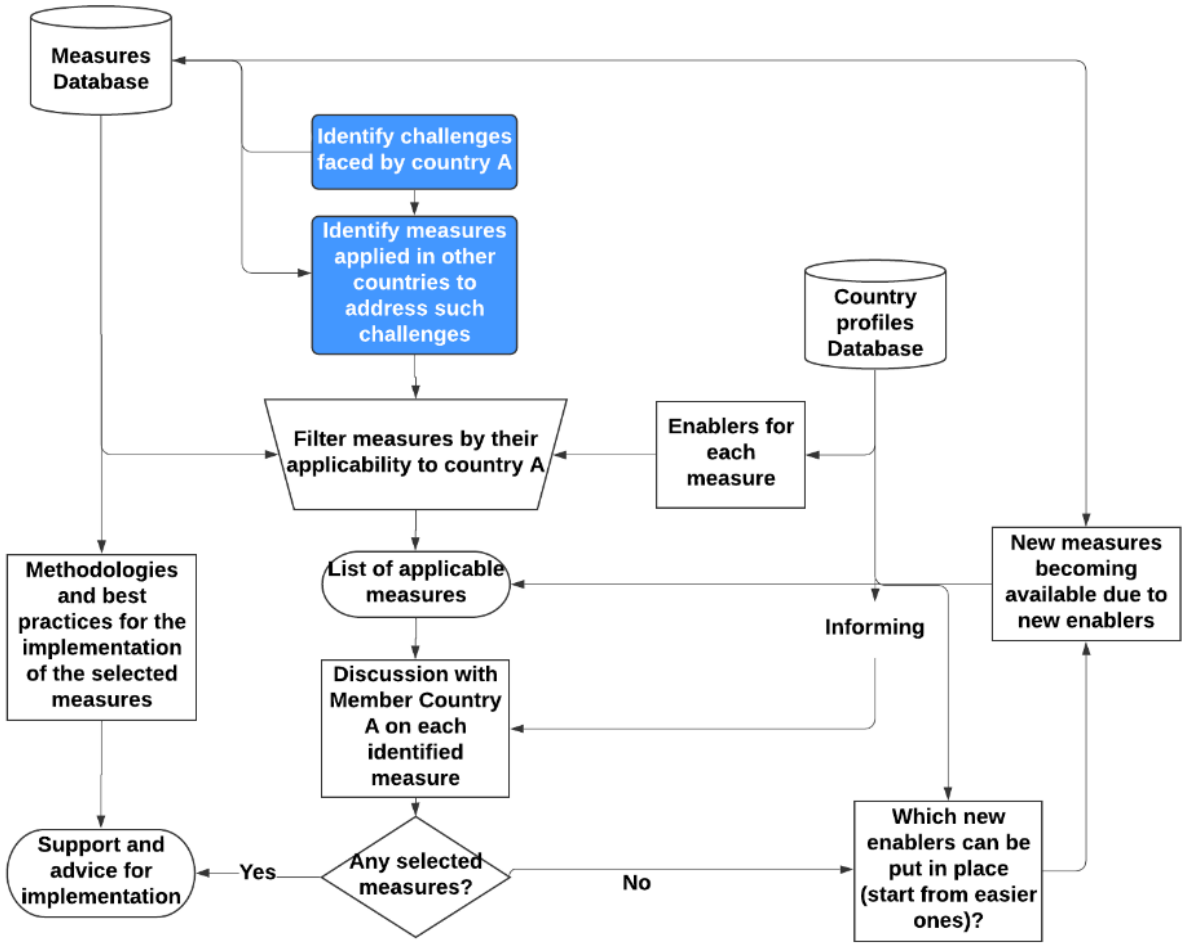
## Integration Challenges

- **Flexibility**
  - Incentives for generators to operate flexibly
- **Transmission**
  - Energy congestion throughout the grid
- **Operation**
  - Address current and potential voltage stability

## Key measures applied in countries

- Brazil
- Denmark
- Germany
- Ireland
- Italy
- Portugal
- United Kingdom
- United States of America (ERCOT)

## Assessment Flowchart



# Key Takeaways from identified Measures

- **Flexibility**
  - Include flexibility requirements in grid codes
  - Retrofitting may be instrumental under specific cases
  - Flexible sector coupling is essential, especially in countries with cold winters
- **Storage**
  - Storage technologies can provide a variety of services, including FFR, and increase flexibility in the system
- **Demand Response**
  - Regulations and Markets should be adjusted to enable demand assets to provide flexibility.
- **Transmission**
  - » Planning is critical
  - » Grid capacity maps can signal suitable spots for VRE
  - » DLR make the best use of existing assets
  - » Ultra-High Voltage DC lines is a game changer but their implementation requires carefulness
  - » Voltage stability may limit the capacity (active) of long transmission lines.

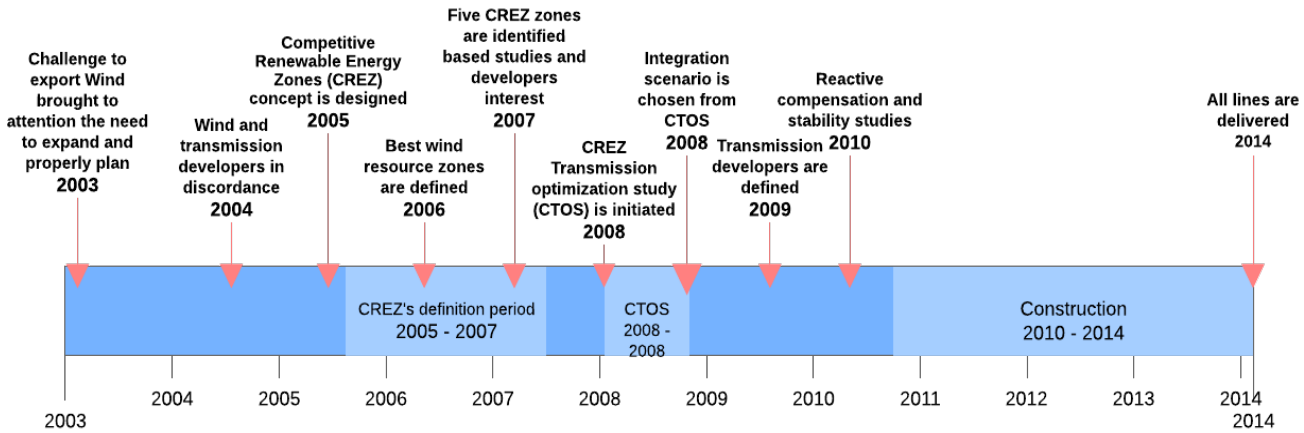



Figure - Competitive Renewable Energy Zones Project Timeline
Source: IRENA based on Matevosyan (2017), Billo (2017); Lasher (2013) and ERCOT (2008)

# Key Takeaways from identified Measures

- **Interconnectors**
  - Regional market facilitates the efficient use of interconnection assets
- **Markets**
  - The closer to real time the market is cleared the more precise are participant positions.
  - The highest the market resolution, the more efficient (less balancing), favoring flexible units.
  - Proper regulatory and market settings are essential to unlock flexibility.
- **Operations**
  - Accurate forecast has proven essential
  - Frequency and voltage response should be included in grid codes asap. Ramping limits may also be considered.
  - Reserve set dynamically may reduce reserve requirement and associated costs
  - Batteries' role to provide very fast response is prone to increase as synchronous generators are displaced in power systems, especially together with grid forming inverters
  - Synchronous compensators have reduced the number of synchronous generators committed as technical must run by adjusting reactive power at strategic points in the grid and keeping a minimum amount of inertia at all times

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# Thank you!


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