IRENA
International Renewable Energy Agency

Grid codes as enablers of the energy transition

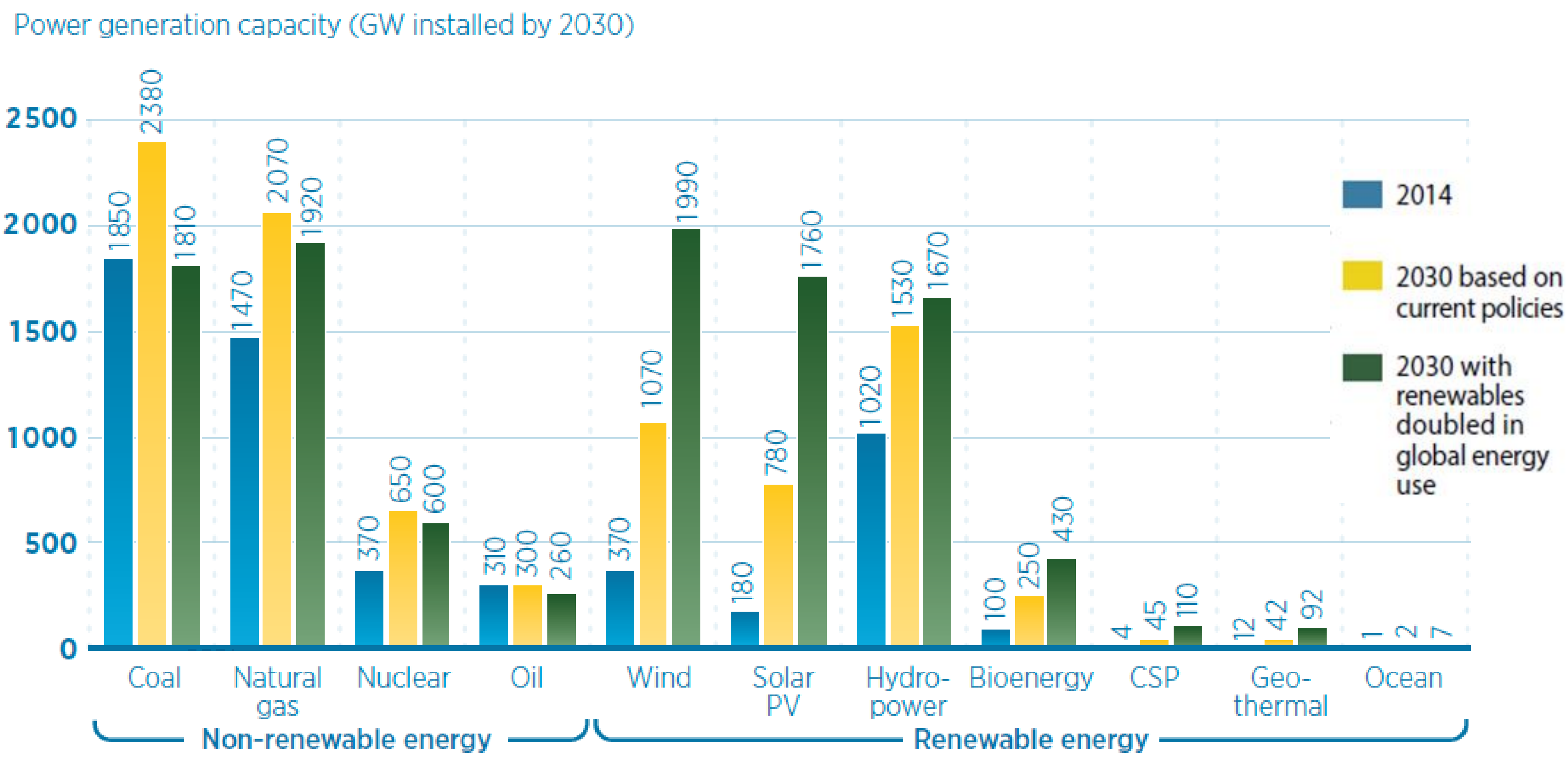
Scaling up Variable Renewable Power

World Future Energy Summit 2017

17 January 2017
Abu Dhabi, UAE

Expected growth in power technologies

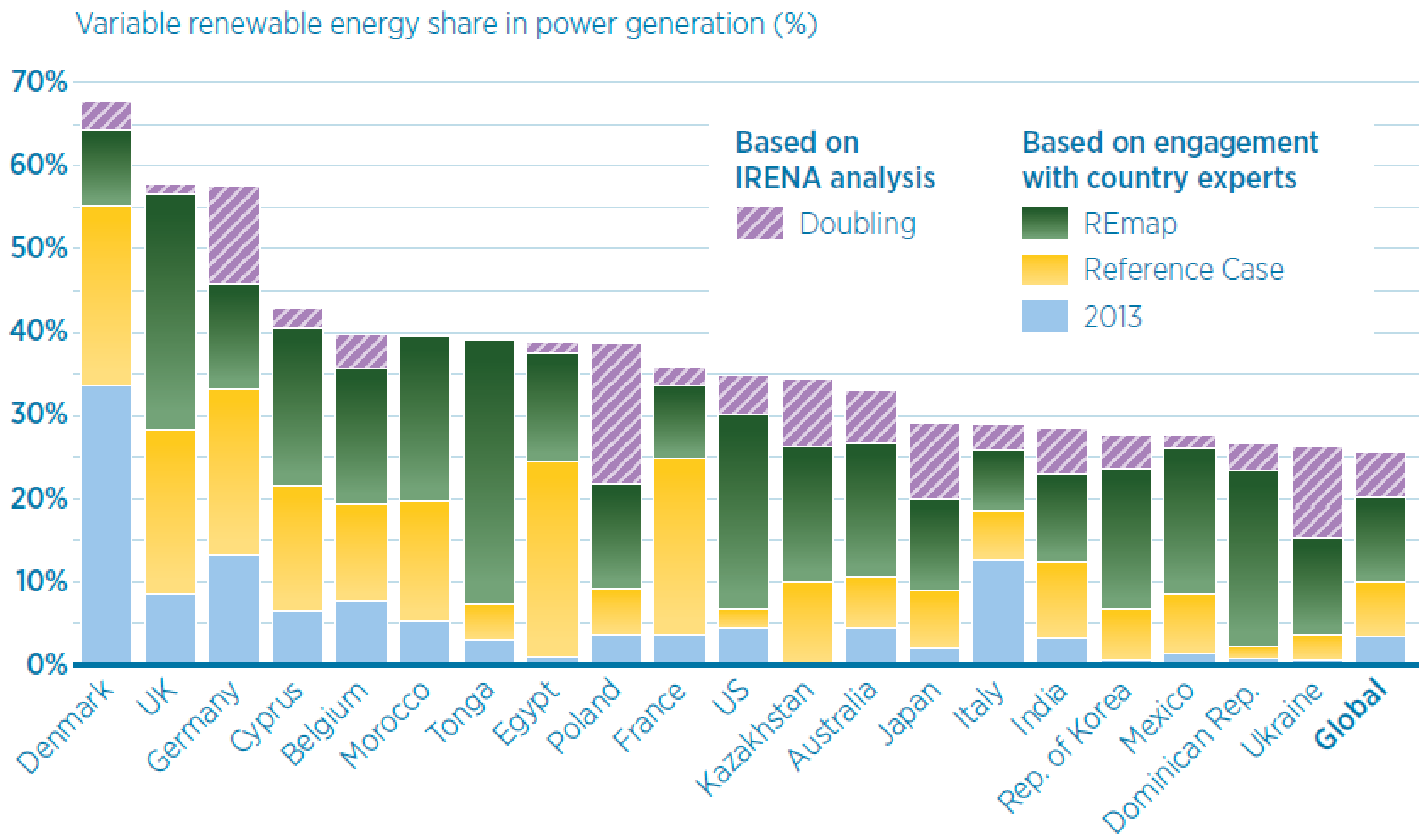
IRENA
International Renewable Energy Agency



Variable renewable energy in power generation by country, 2013-2030

IRENA
International Renewable Energy Agency

In some countries solar and wind electricity generation is **exceeding demand** at certain points in time: Denmark, Germany, Portugal

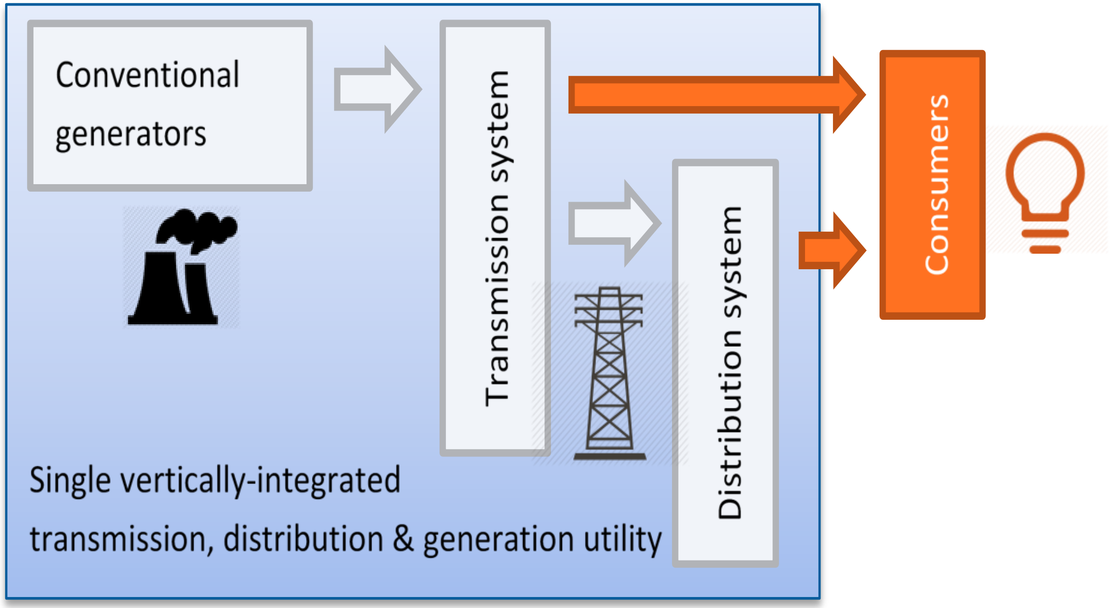


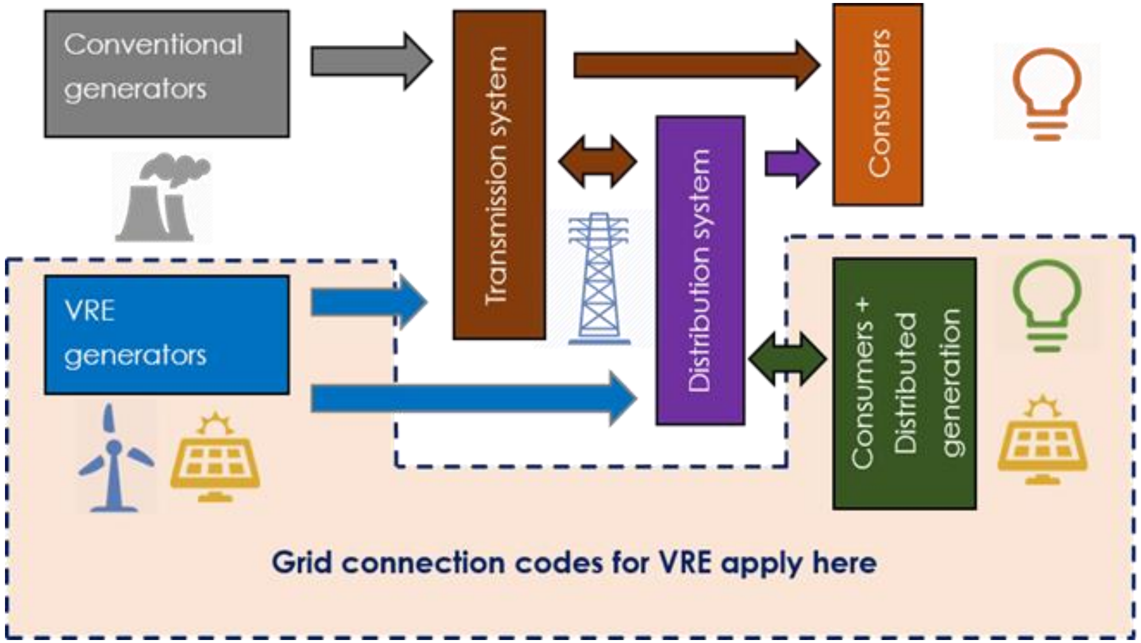
In the Reference Case, 15 of 40 countries will have a VRE share larger than 10% by 2030. With the REmap Options, 20 countries will have a share larger than 25%.

Based on IRENA estimates

Unbundling and the need to coordinate system actors

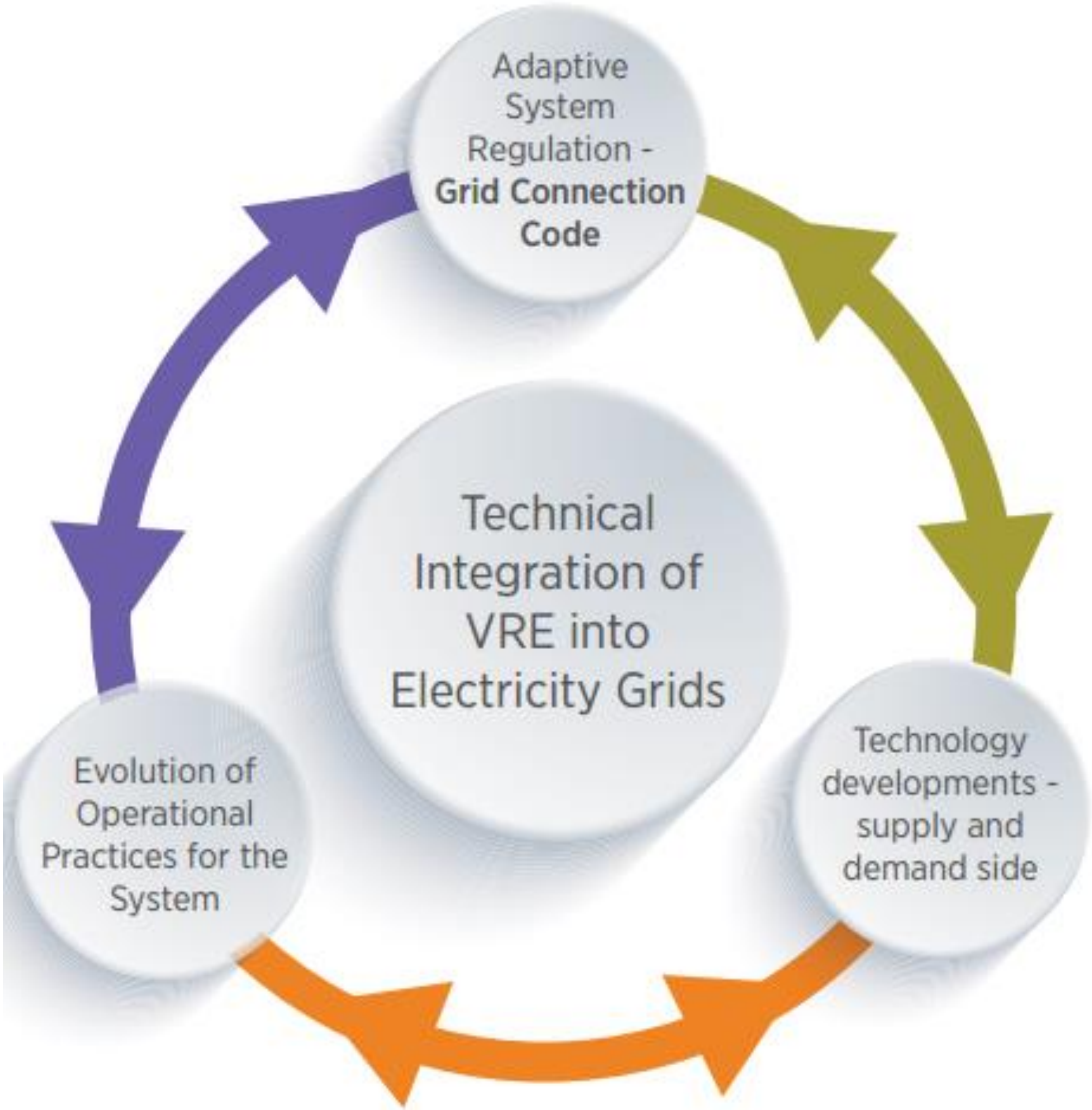
Traditional power system → **Unbundled power system**





Some technologies are more easily available to each country's economies depending on the local conditions. **Wind power and solar irradiation** come with the additional constraint of time-variability, therefore called **Variable Renewable Energies (VRE)**.

Link between technical aspects



Grid Connection Codes: Two policy goals

IRENA
International Renewable Energy Agency

1- Ensure that population is served with electricity as needed

2- Increase the share of renewables in the power system

Two objectives are reconciled

Clear rules to address the challenges

IRENA
International Renewable Energy Agency

Types of Grid Codes

Connection Codes

- Generator Connection Code
- Demand Connection Code
- HVDC Connection Code

This report focuses on VRE Generator Connection Codes

Operating Codes

- Operational Security Code
- Operational Planning and Scheduling Code
- Load Frequency Control and Reserves Code
- Emergency Procedure Code

Planning Codes

- Generator Planning Code
- Network Planning Code

Market Codes

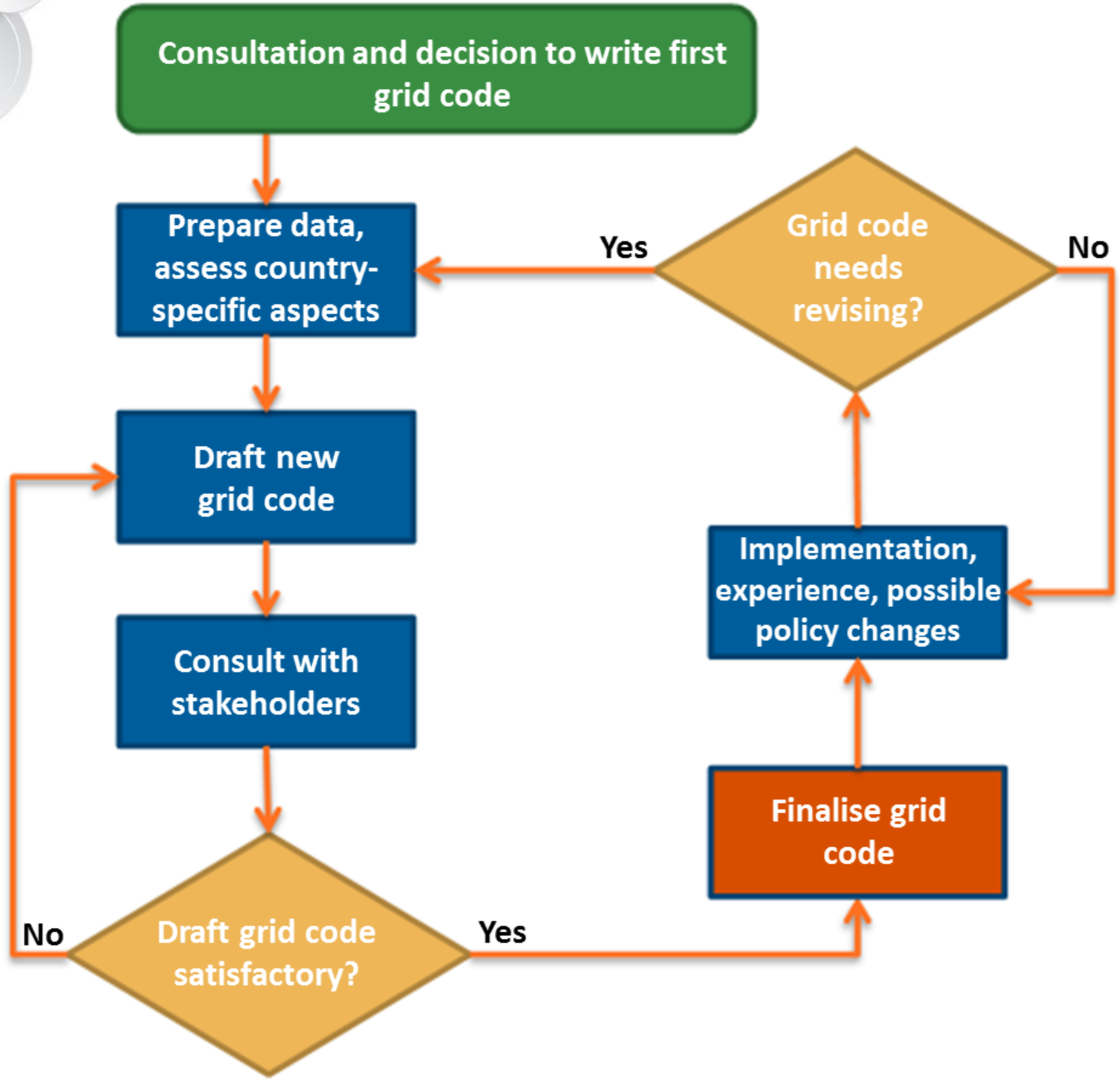
- Market Rules Code
- Network Capacity Allocation and Congestion Management Code
- Balancing Network Code

Grid codes set the rules and technical requirements for power system and energy market operation.

The different **types of grid codes** facilitate:

- The operational flexibility (required by an increasing VRE generation)
- Operational stability
- Security and quality of supply
- Well-functioning wholesale markets.

VRE Grid Connection Code Development and Implementation



All stakeholders involved in grid code issues should take part in the consultation:

- Policy makers
- generator owners/operators
- network operators
- regulators
- Generator and grid asset manufacturers
- Depending on scope: consumers

A predictable and reliable revision process is important for network and generator planning!

Technical requirements depend on context

IRENA
International Renewable Energy Agency

Power systems and their requirements for the connection of wind and solar power plants can differ in a number of ways:

- Size and capacity reserves
- Voltage levels and system frequency
- Operational practices
- Interconnec-tion level
- VRE capacities (current and planned)
- Distribution of VRE resources (current and planned)
- Capabilities of conventional generators (current and planned)
- Institutional framework
- Market design
- State of the art

Learn from front runner countries, but grid codes for each case differ in their requirements.

Determining Technical Requirements

The process of determining the requirements involves **studies investigating the needs of the power system**. Requirements must consider the capabilities of available generator systems in order not to hinder the process of VRE integration.

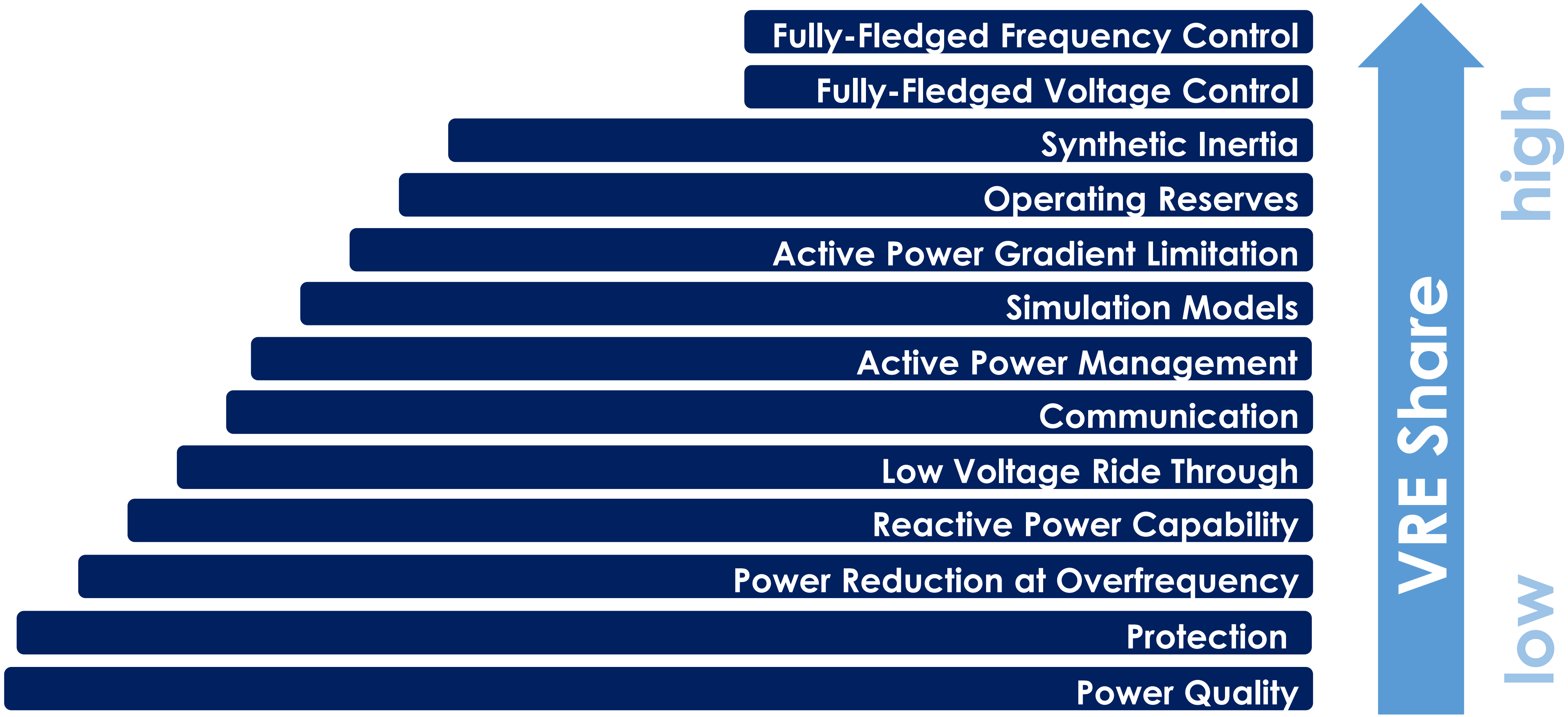
The following studies are usually needed:

- **Load flow study** to investigate the needed reactive power capabilities of generators
- **Static and dynamic short circuit studies** for evaluating protection and LVRT requirements,
- **Load frequency control studies** for reserve requirements and gradient limitations, ideally including frequency stability study.

This list **only includes studies in the context of VRE grid code parameterization** and should be added to the studies that need to be performed for system planning and operation purposes.

Technical Requirements - When are they needed?

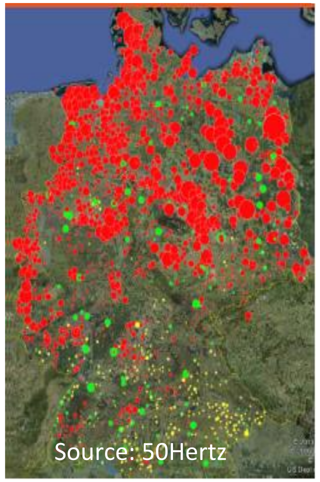
The most important driver for necessity of certain technical requirements for VRE generators is the **VRE share** in the power system:



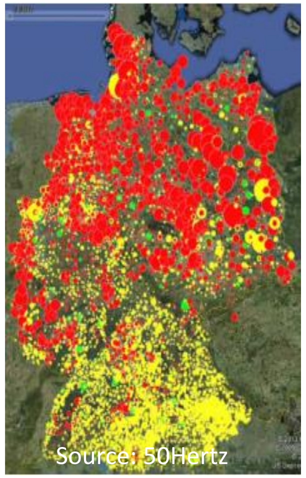
Grid Codes and their Relation to Energy Policy (I)

IRENA
International Renewable Energy Agency

around 30.000 plants



around 220.000 plants



around 1.500.000 plants

2000 | 2006 | 2014

Wind | Photovoltaics | Biomass

- **Unbundling of power systems** and increasing shares of **decentralized generation** are major drivers of grid code development.
- Too **onerous requirements** can prevent reaching energy policy targets.
- Too **lax requirements** can cause reliability or stability issues if renewable installations surpass expectations.
- Well-structured **Grid Code revision** processes are crucial.
- **Anticipate the needs of a changed system!**

Certification and Verification of Technical Requirements

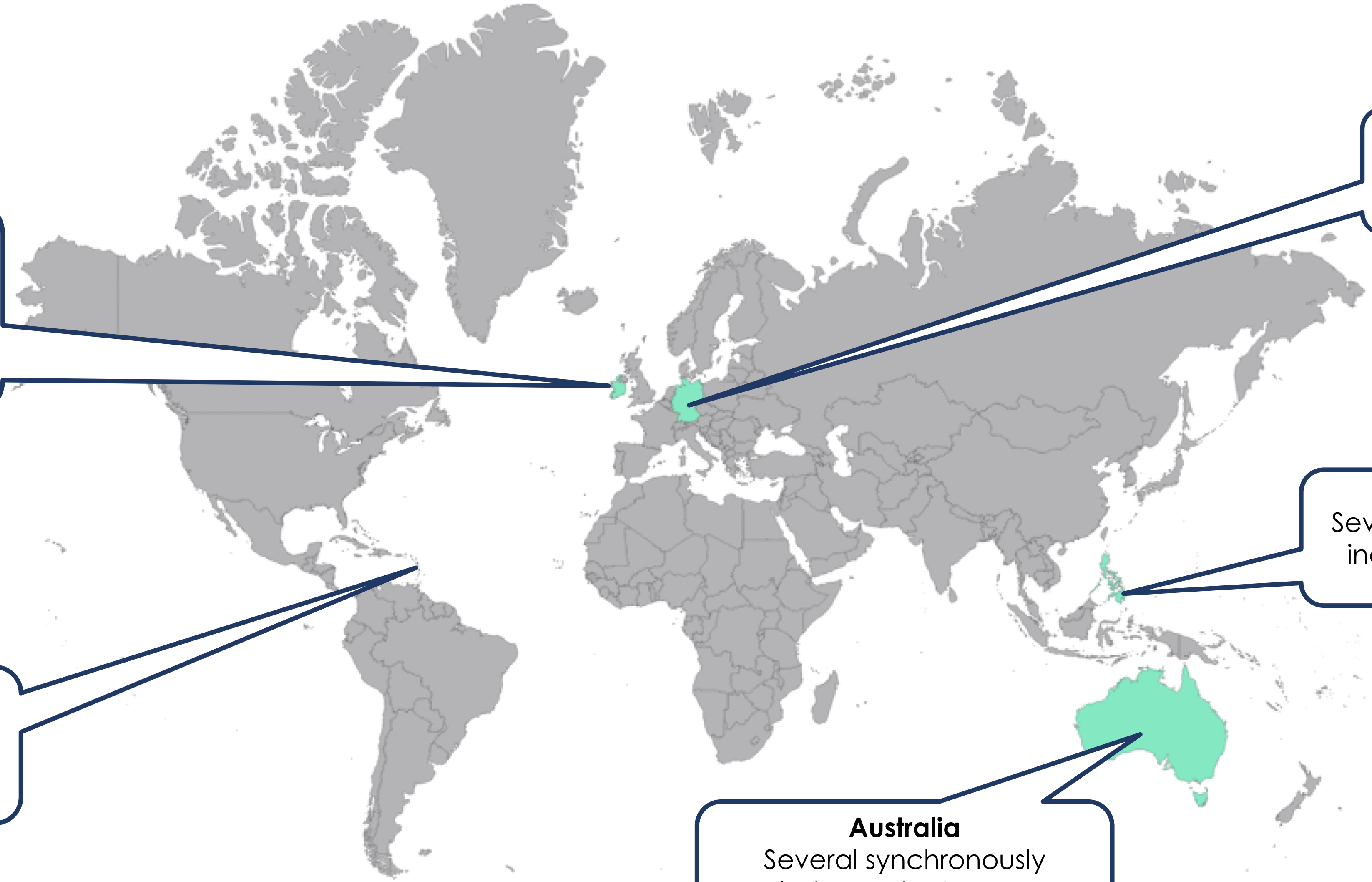
Mechanisms for verification of compliance with the codes:

- On-site inspections,
- Use of certification systems,
- Verification of plants instead of units,
- Requiring manufacturer statements of conformance,
- Post-disturbance evaluation of system event

Effective and reliable certification system may come with the highest level of trust per required effort. However, infeasible for small system regulations due to significant organizational overhead

Harmonization of requirements and resource sharing between countries can make it feasible!

Study Cases - Overview



% represents VRE share of yearly load

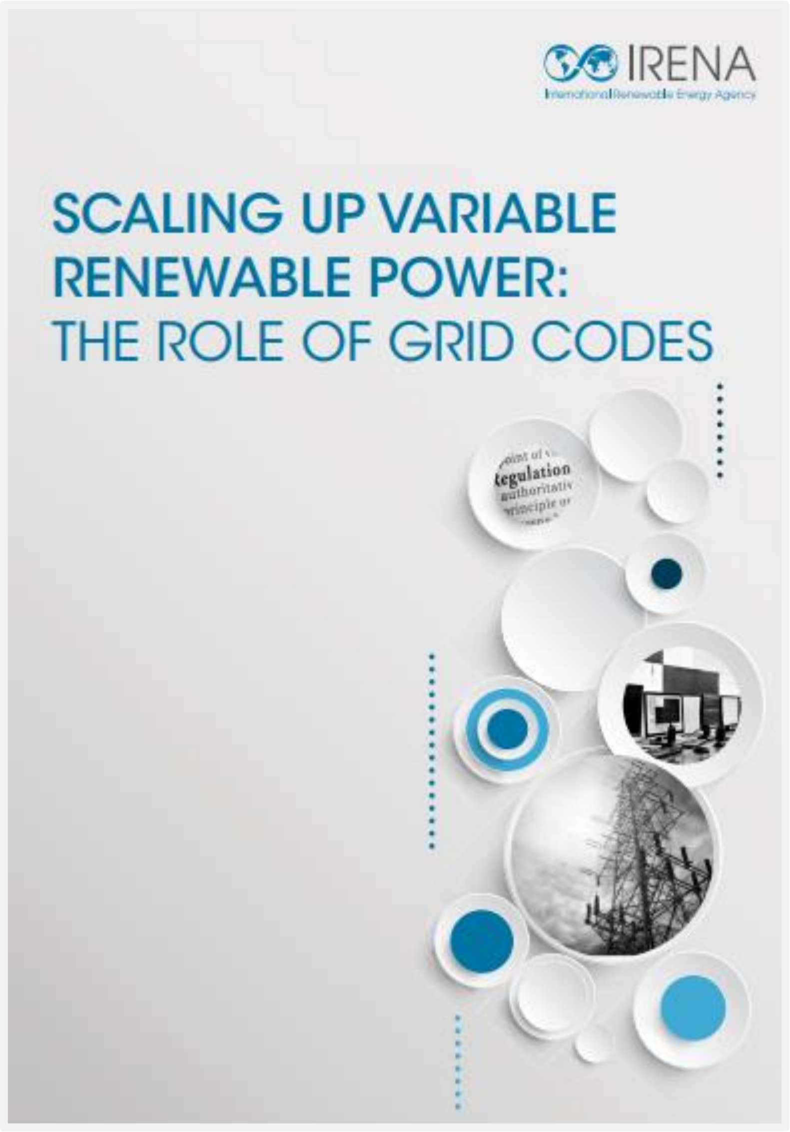
Source: IRENA, Scaling up variable renewable power; The role of grid codes

Recommendations

- Design a **predictable and reliable grid** code revision process.
- Consult with all **relevant stakeholders**.
- Anticipate requirements of a **dynamic changing system**.
- Join regional initiatives to **harmonize requirements** and share resources.
- **Learn from other countries**, but design the grid code to your country context.

Download full report for free

IRENA
International Renewable Energy Agency



Link:
http://www.irena.org/DocumentDownloads/Publications/IRENA_Grid_Codes_2016.pdf

Thank you

Please contact for more information:

- Francisco Boshell – Fboshell@irena.org
- Alessandra Salgado – Asalgado@irena.org

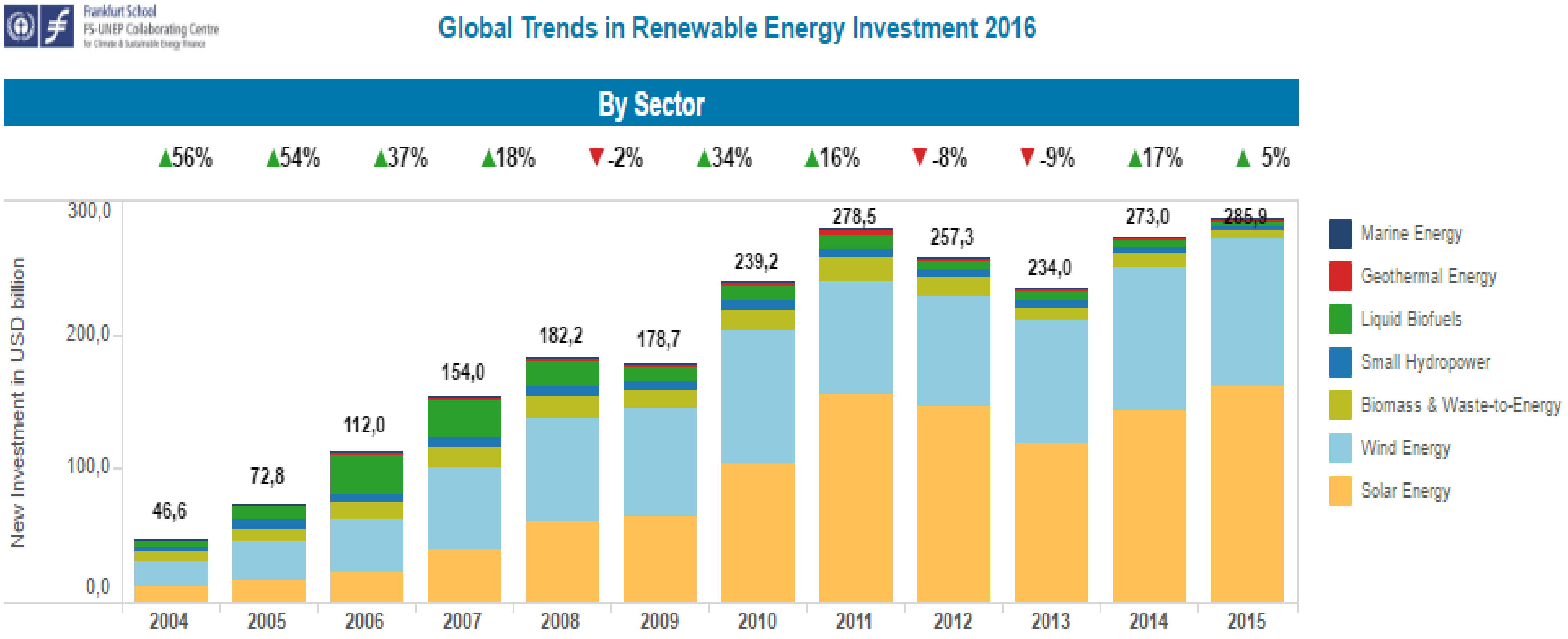
www.irena.org/publications

Back Up

World Future Energy Summit 2017

Renewable power investments per technology

IRENA
International Renewable Energy Agency



Source: Frankfurt School-UNEP Centre/Bloomberg New Energy Finance (2016), *Global Trends in Renewable Energy Investment.*
Note: Investment volume adjusts for re-invested equity. Total values include estimates for undisclosed deals.

2015: **286 USD billion.** Solar PV and wind leading

Source: www.irena.org/resource

Shift towards renewable energy

IRENA International Renewable Energy Agency

In 2015

- 47 GW PV, 63 GW wind power installed – **more than 25% growth** from the previous year

- **USD 360 bln investments**

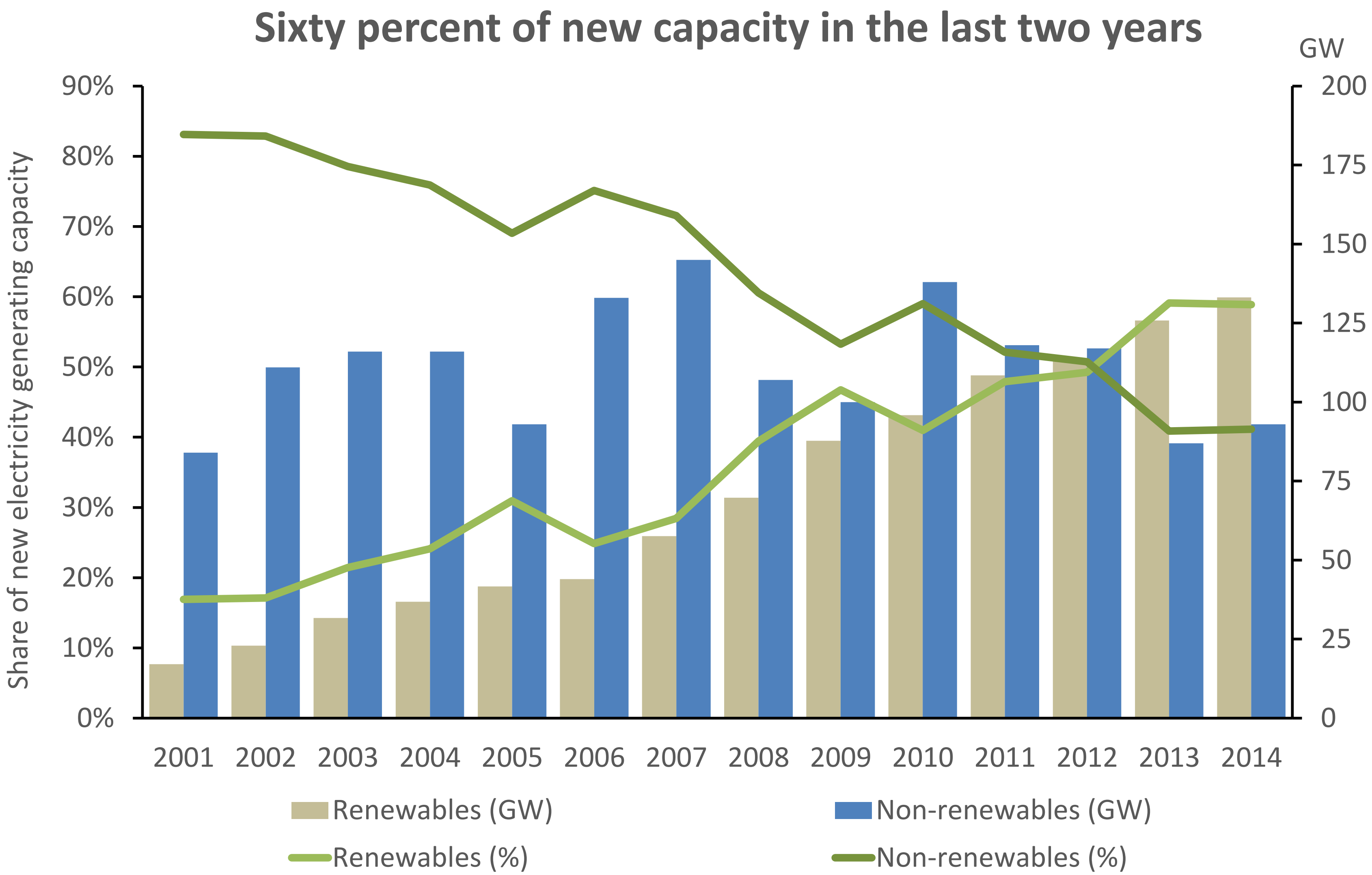
- **Cost continue to fall**
  - Solar PV **USD 30-48/MWh** in Dubai, Mexico, Peru
  - Wind **USD 30-37.5/MWh** in Morocco and Peru

- **164 countries** with RE policies in place

The global energy transition is ongoing

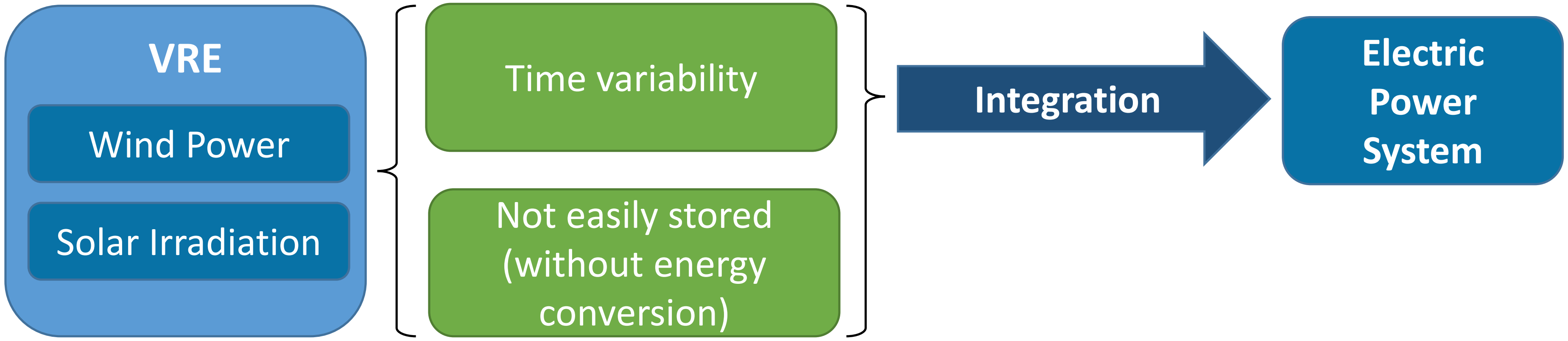
Renewables investments have overtaken non-renewables – despite low oil prices

IRENA
International Renewable Energy Agency

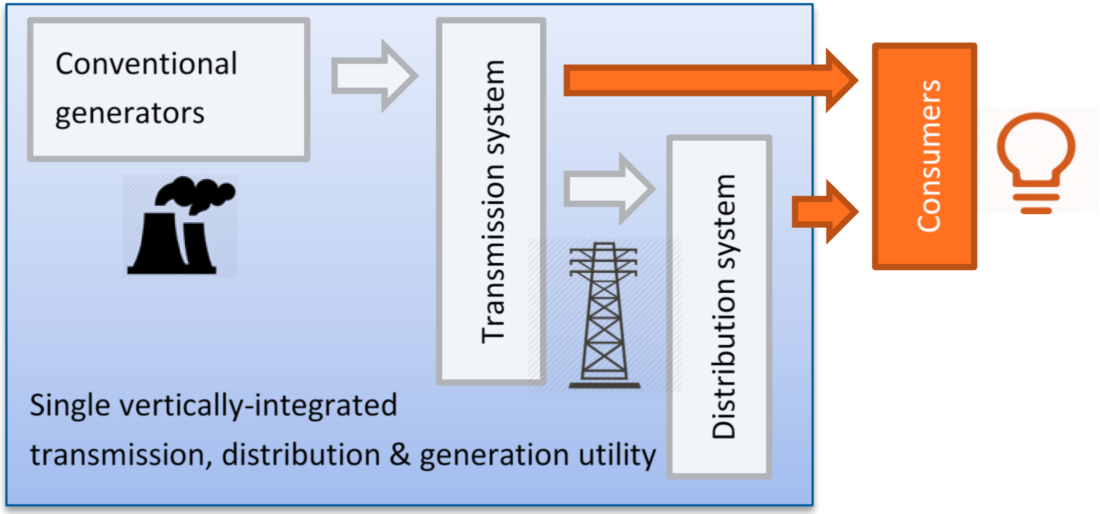


Energy resources in power systems

Depending on local conditions, some of these are more easily available to each country's economies. Especially **wind power and solar irradiation** come with the additional constraint of time-variability, therefore called **Variable Renewable Energies (VRE)**.

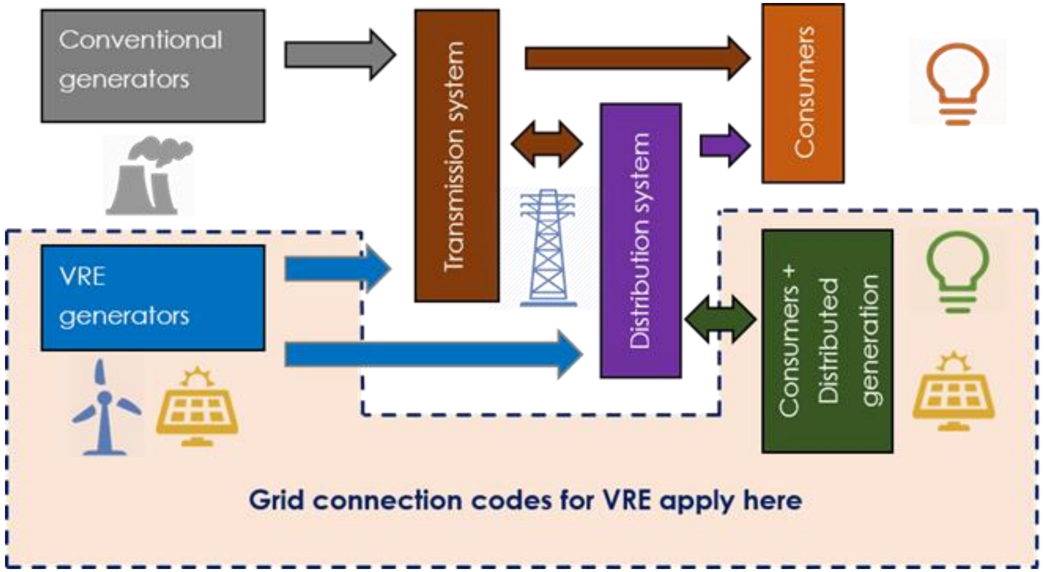


Unbundling and the need to coordinate system actors



Traditional power system

- Centralized generation
- Utility owns grid and generators
- Internal rules and requirements

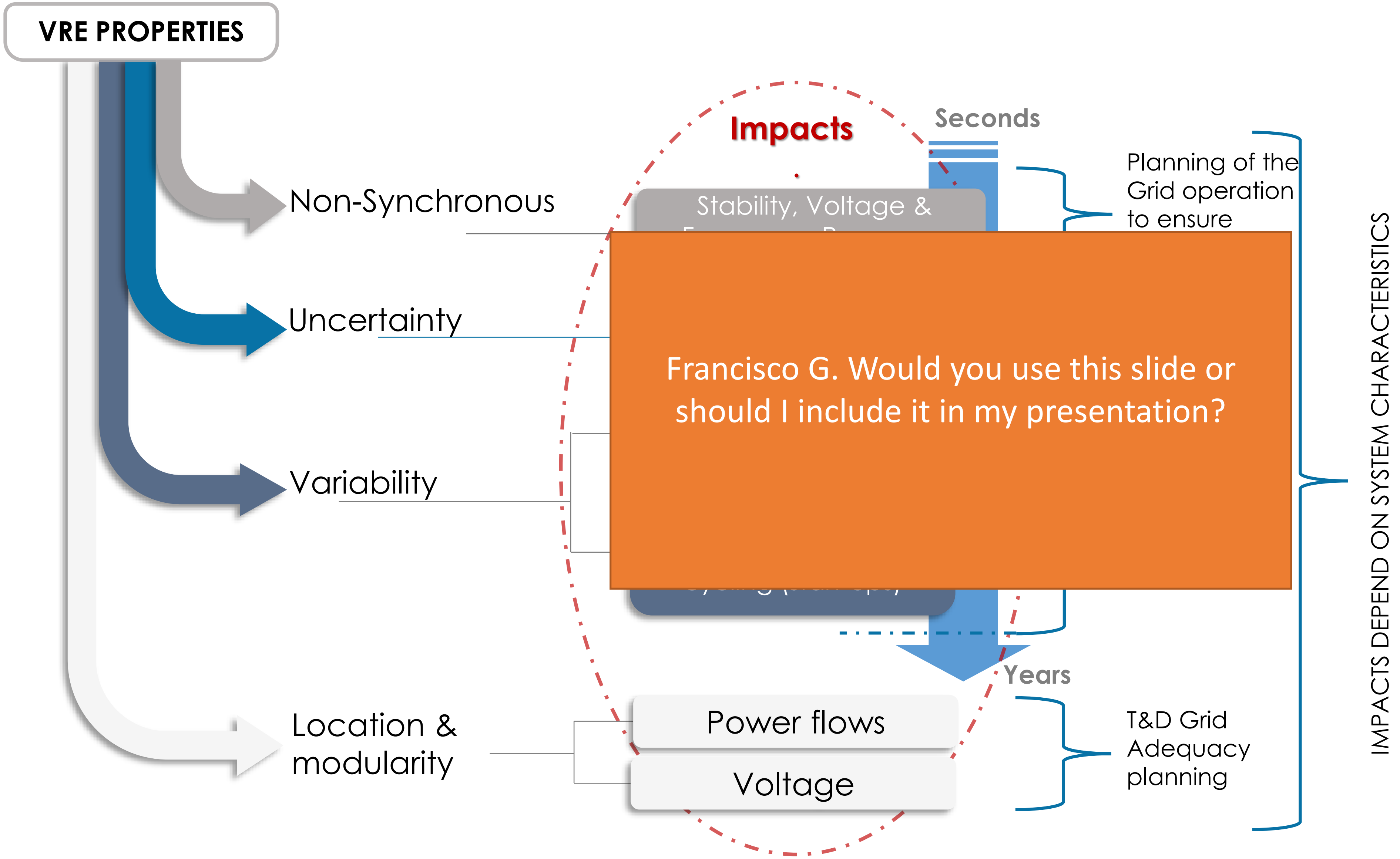


Unbundled power system

- Decentralized generation
- Separated ownership
- Need for grid code governance

Identifying the Challenges

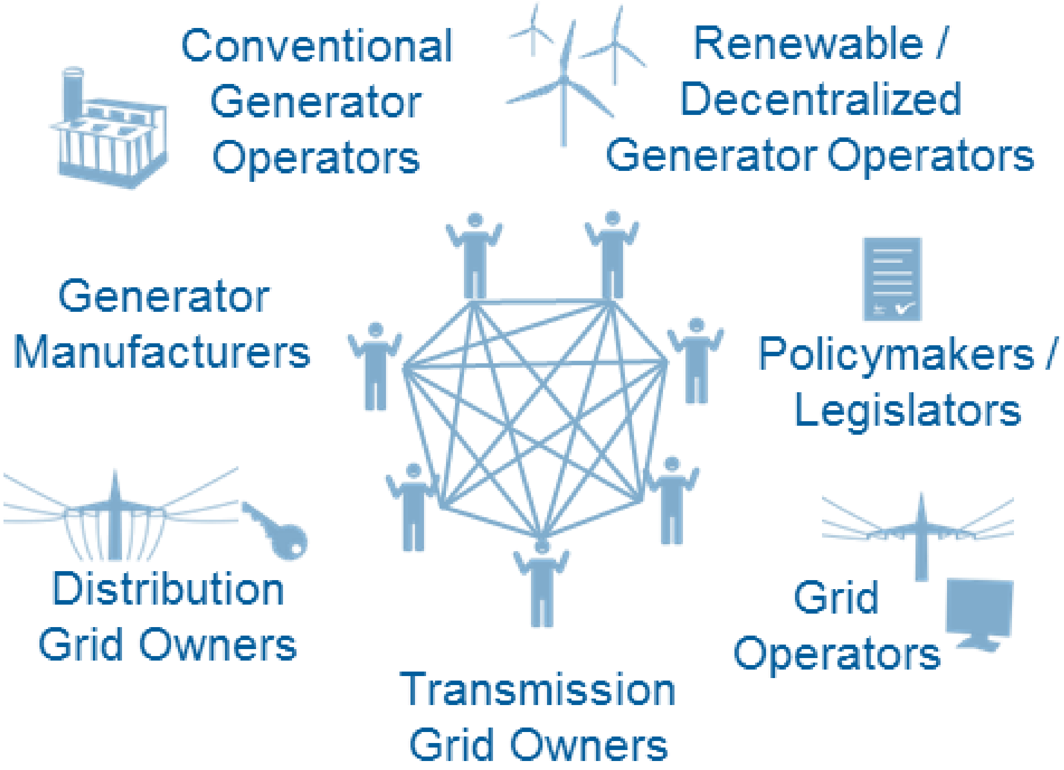
IRENA
International Renewable Energy Agency



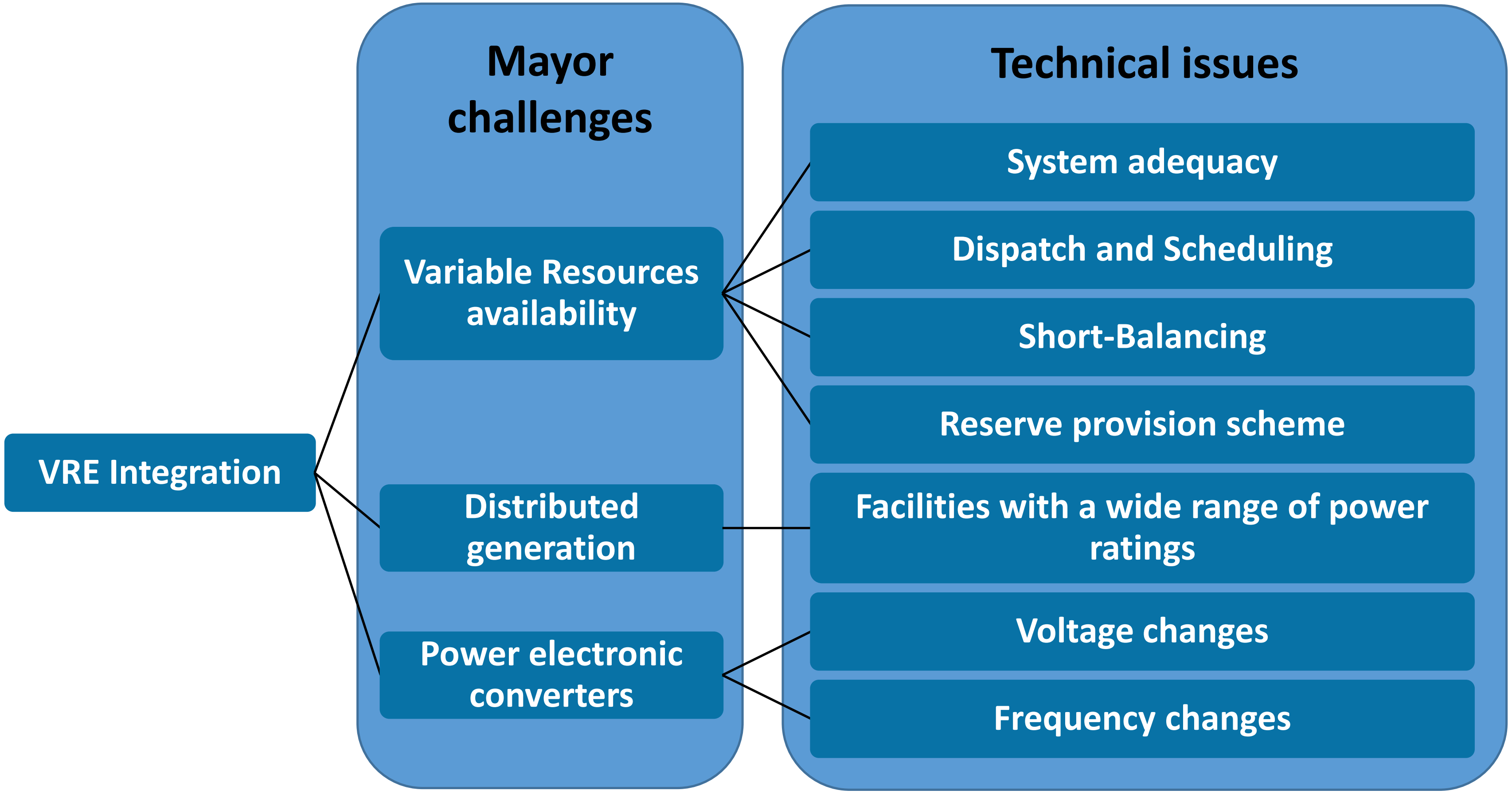
Francisco G. Would you use this slide or should I include it in my presentation?

Grid Connection Codes - Stakeholders

By applying at the boundary between power system and generator facility, technical requirements in grid connection codes affect **different stakeholders in unbundled power systems.** Grid codes are a means to achieve fair and transparent treatment of these system actors and enable efficient coordination.



Identifying the Challenges



The technical solutions for these issues require research, development, and implementation. The resulting **costs should be optimized**, and the **distribution of costs** should be **agreed on between generator manufacturers, generator owners, and system operators**.

Study Cases - Overview

Country	Germany	Ireland	Australia	Barbados	Philippines
Population	80,620,000	4,595,000	23,130,000	286,644	98,390,000
Area [km2]	357,114	70,273	7,692,024	430	300,000
Interconnected with other countries	Strong interconnection	AC interconnection with Northern Ireland on synchronously independent island of Ireland, island has two HVDCs with GB	Several synchronously independent zones	Synchronously independent island	Several synchronously independent zones
Peak load [MW]	81,738 (2014)	4,613 (2014)	33,100 (2014)	152 (2014)	11,822 (2014)
Minimum load [MW]	36,709 (2014)	1,664 (2014)	14,900 (2014)	82 (2014)	
Total conventional generating capacity [MW]	108,000 (2014)	7,405 (dispatchable 2014)	48,000 (2014)	239	17,500 (2014)
Wind [MW]	38000 (12. 2014)	2138 (2014)	3,600 (01. 2015)	0 (03. 2015)	283 (2014)
PV [MW]	38000 (12. 2014)	0 (2014)	3,440 (01. 2015)	7.6 (03. 2015)	23 (2014)
VRE capacity versus minimum load [%]	207%	128%	47%	9.30%	
Yearly load [TWh/a]	505 (2014)	29 (2014)	188 (2014)	0.968	77 (2014)
VRE share of yearly load [%]	19.56%	15.50%	7.50%	1.30%	0.22% (2014)
VRE connected to distribution or transmission level	Both	Both	Wind to both, PV mostly to distribution	Distribution	

Source: IRENA, Scaling up variable renewable power; The role of grid codes

Outlook for VRE Grid codes

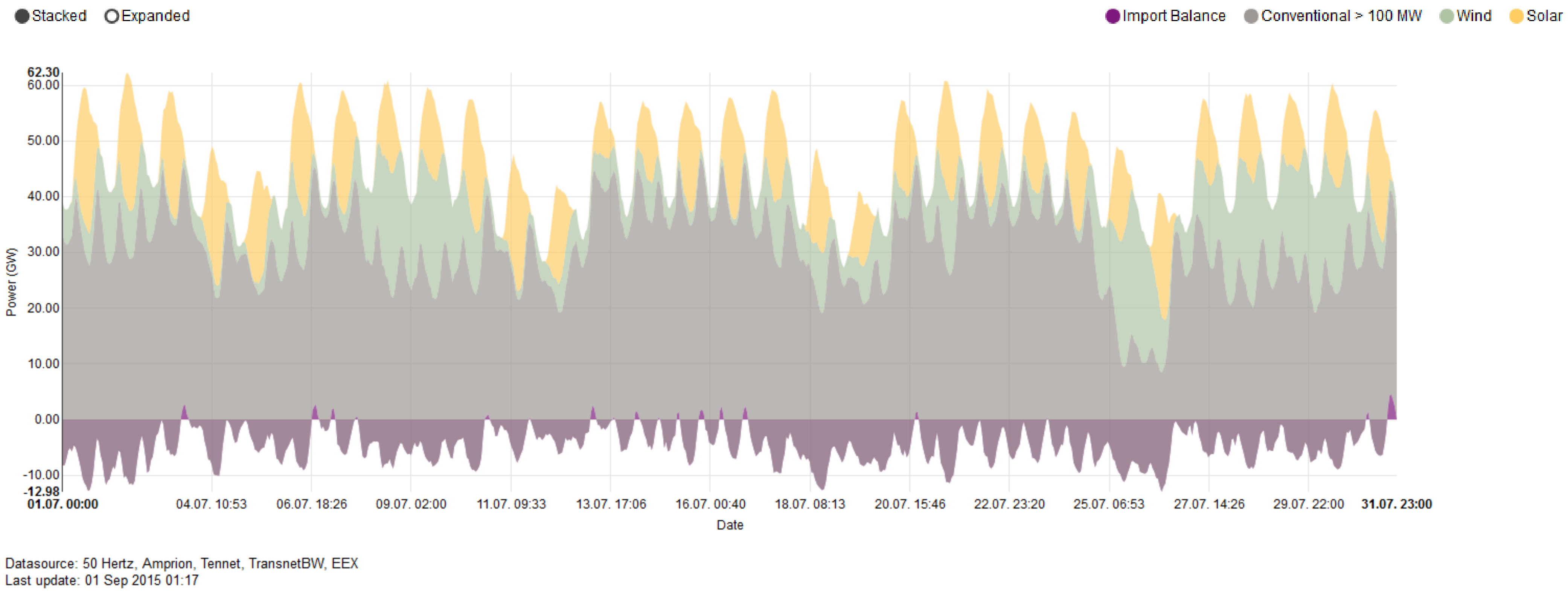
- New technical requirements

Contribution of inertia or synthetic inertia: converter-based VRE generators do not provide inertia.

Black-start capability: ability to start a generation plant without any externally provided electricity. Would usually include a conventional generator or storage system capable of fast balancing.

Damping power system oscillations: Studies are being conducted to investigate whether or how the increasing share of VRE generation changes the oscillatory behaviour of large transmission systems.

Time-dependent availability
Example: Generation in Germany



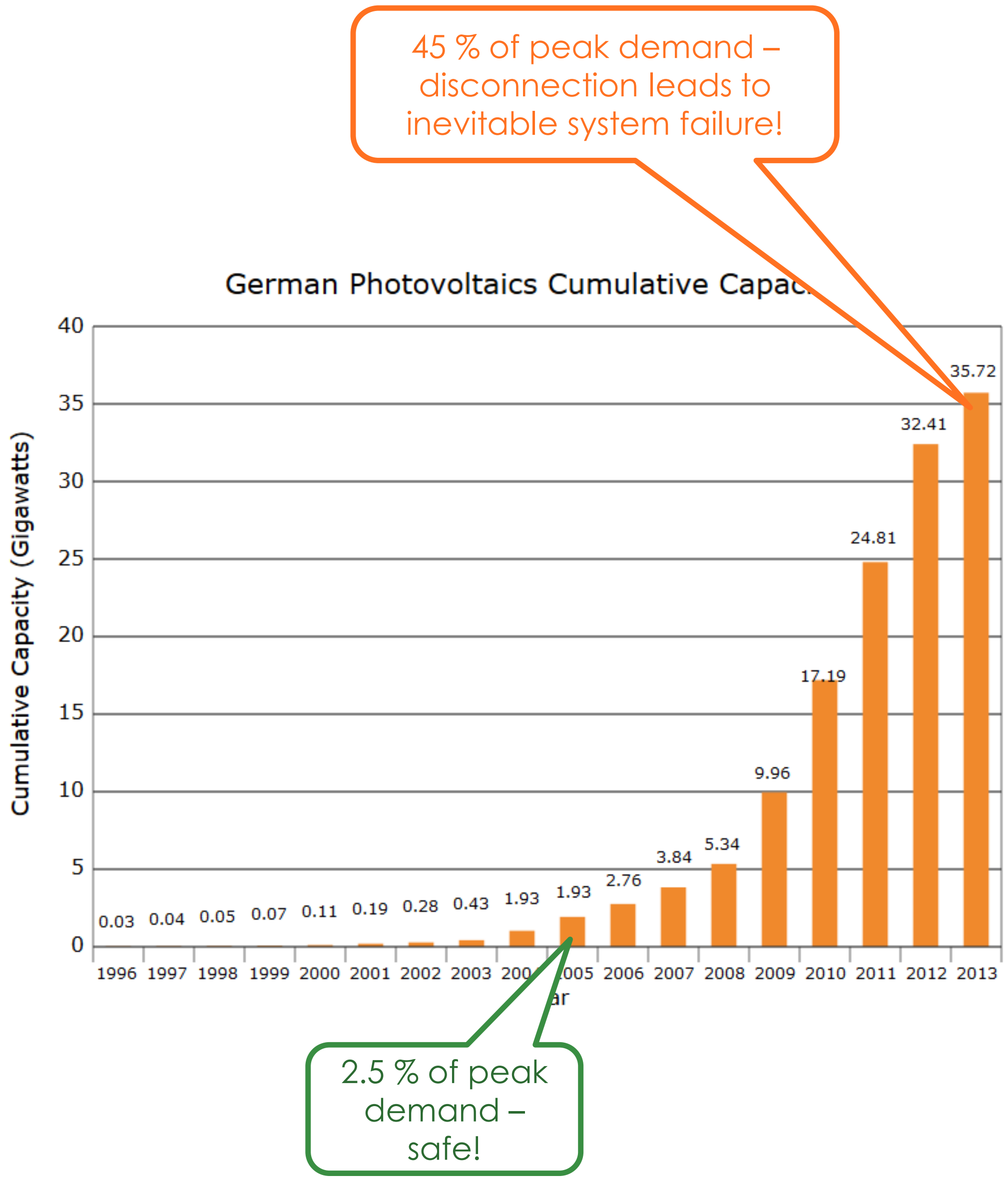
Source: energy-charts.com, Fraunhofer ISE, July 2015. VRE and conventional generation in Germany in July 2015.

Time-dependent variability of VRE generation requires more flexibility from conventional generators. Grid codes can govern the interaction between the different generators.

Grid Codes and their Relation to Energy Policy (II)

IRENA
International Renewable Energy Agency

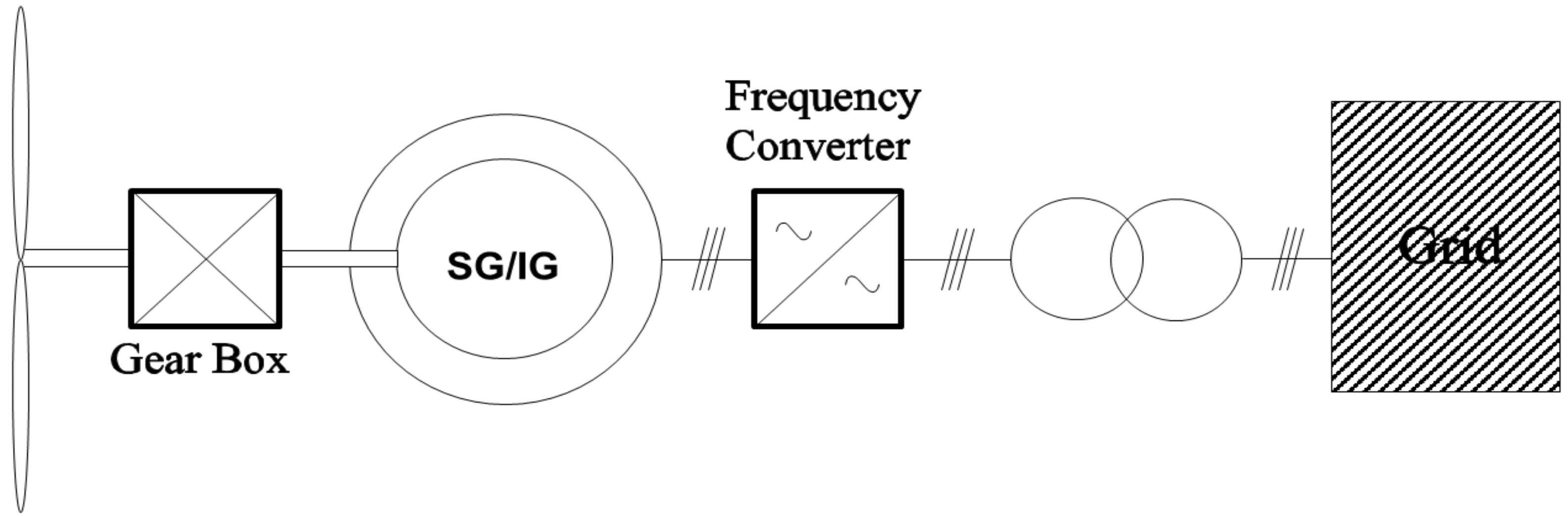
- **Too onerous requirements can prevent reaching energy policy targets.**
- **Too lax requirements can cause reliability or stability issues if renewable installations surpass expectations.**
- **Well-structured Grid Code revision processes are crucial.**
- **Anticipate the needs of a changed system!**



Example: German 50.2 Hz problem

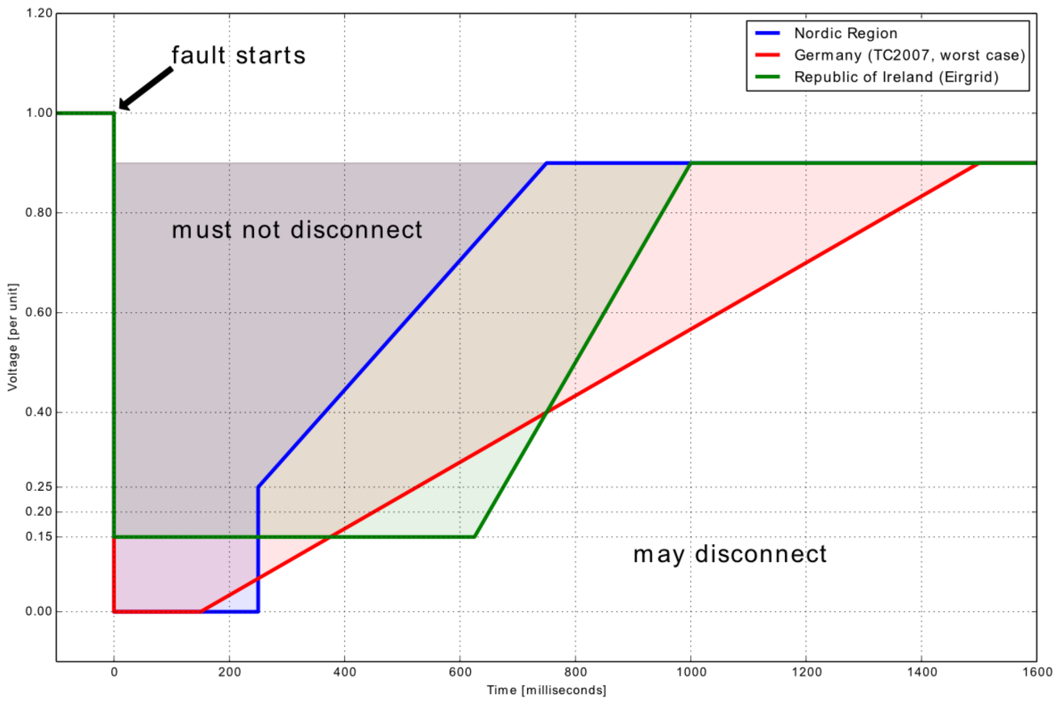
- All PV generators were required to disconnect from the grid if the frequency exceeded 50.2 Hz
- Increase in PV installations exceeded all expectations
- Disconnection of all PV generators at the same time can now lead to the loss of too much generation
- Grid code had to be revised, installations needed to be retrofitted

VRE generation technology example



Synchronous generators possess inherently grid-stabilizing properties, such as rotational inertia, while VRE are mostly connected to the grid by **power electronics**. These can be used to stabilize the grid as well, but features need to be **implemented electronically**.

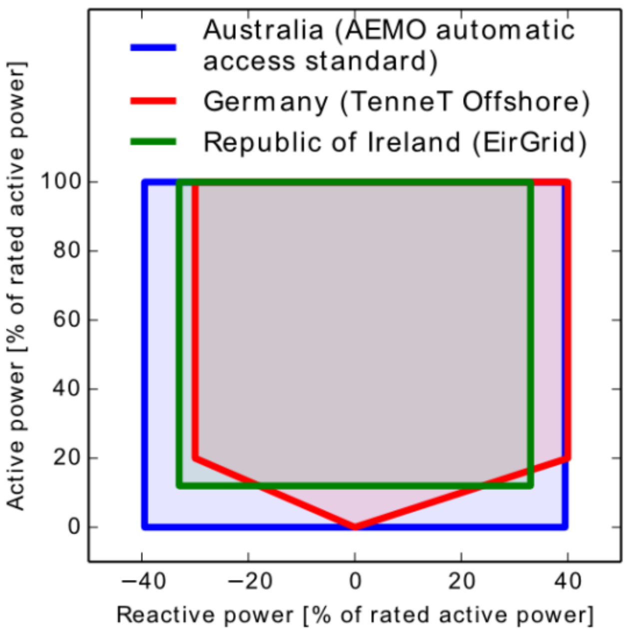
Requirement Example: LVRT



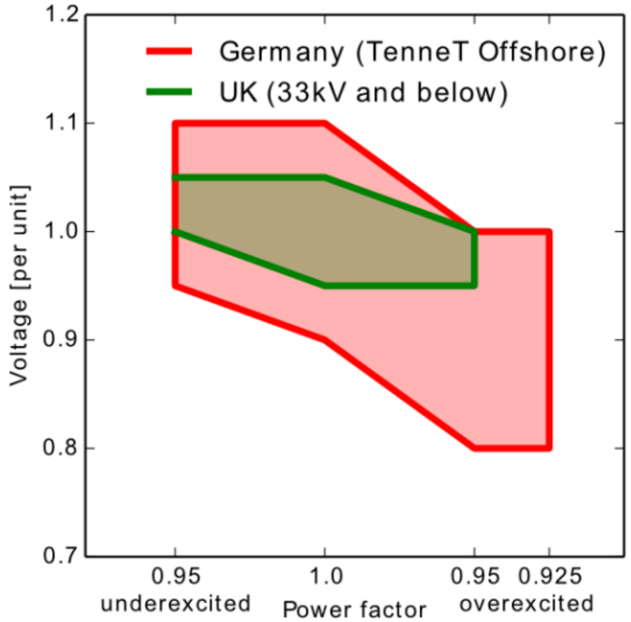
LVRT requirements from different grid codes

In fault cases that cause a voltage drop, such as short circuits, VRE must support the grid for a certain time without disconnecting.

Requirement example: Reactive power



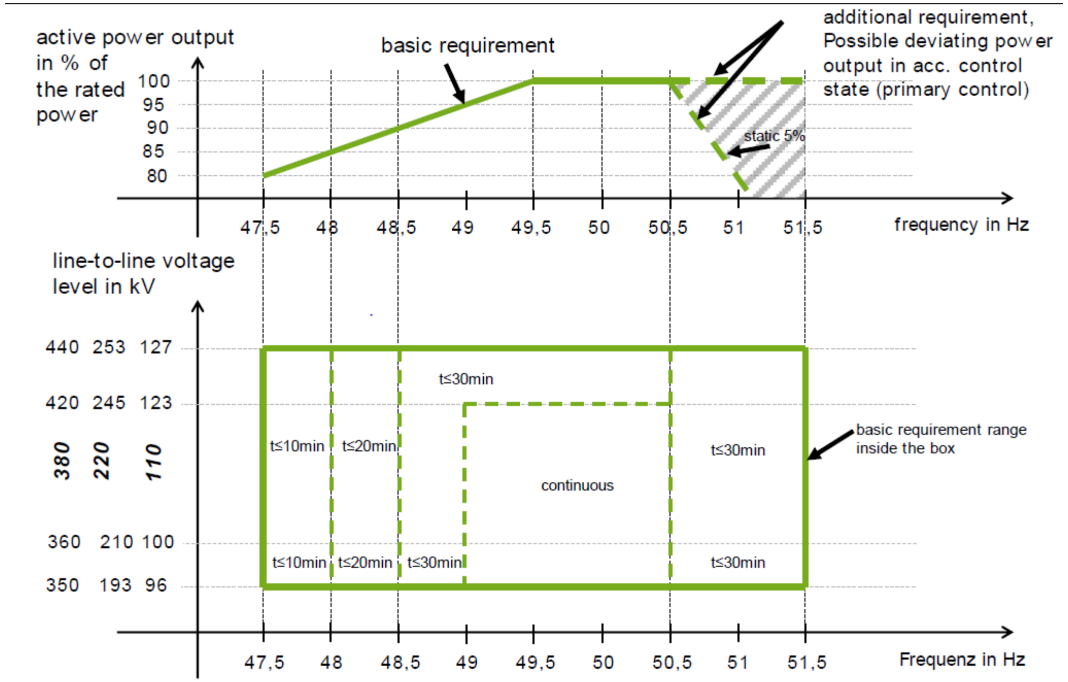
Required reactive power characteristics for wind turbines from different grid codes



Reactive power operational ranges for offshore wind parks in Germany and the UK

VRE units must provide reactive power for voltage control.

Requirement Example: Operation Ranges



Required operation ranges for VRE connected to the transmission grid in Germany.

VRE generators may not immediately disconnect during frequency or voltage deviations to avoid cascading failures.

Regional and National Grid Codes

Many requirements can be harmonised between countries, enabling countries to pool their resources in areas such as certification and to make it easier for manufacturers to access more markets, **resulting in lower costs for consumers**.

The development of regional VRE grid codes do not replace national grid codes, but instead provide a common framework for minimum requirements that all national grid codes should meet. Example of those are:

- The **ENTSO-E Network Codes** are intended to harmonise and standardise the technical requirements of European Grid Codes.

- The **Nordic Grid Code** is used by all Scandinavian TSOs, primarily to facilitate exchanges of energy and ancillary services.

Regional and National Grid Codes

IRENA
International Renewable Energy Agency

Grid Codes with overlapping scopes or areas of application (such as TSO- or province-specific requirements in a national setting) must be consistent and the precedence of the Grid Codes must be made clear.

The use of international standards in the preparation of VRE grid codes is another relevant instrument for the harmonisation of requirements, as well as a valuable platform for experts to exchange international experiences and document good practices.

Study cases – Key Findings

Overall, there is a **correlation between power system characteristics, such as VRE share, and the stringency of the grid code requirements**

- Barbados has currently a low share of VRE, and its grid code requirements are relatively easy to fulfil.
- Ireland has a relatively high share of VRE, and at the same time is part of an island system with Northern Ireland, thus the island of Ireland must regulate its own frequency. For this reason its grid code contemplates:
  - A focus on frequency control requirements,
  - Restricted ramping rates,
  - The ability to curtail wind power plants, given worries about frequency stability with high levels of non-synchronous generation.

Study cases – Key Findings

There are **many similarities** between the grid codes and often they **differ only in how the grid code requirements are parameterized**, rather than differing substantially in the types of requirements made.

This is due to the fact that **network operators** have been able to **share experience** in the requirements for VRE generators, and **avoid the mistakes** made by early-adopters of VRE technology.