Interreg Sudoe TR@NSENER
European Regional Development Fund

Integration of renewable energy sources into the electrical grid
High Level Conference, **SEVILLE**

Challenges & Technologies for Renewables Integration: the Spanish experience

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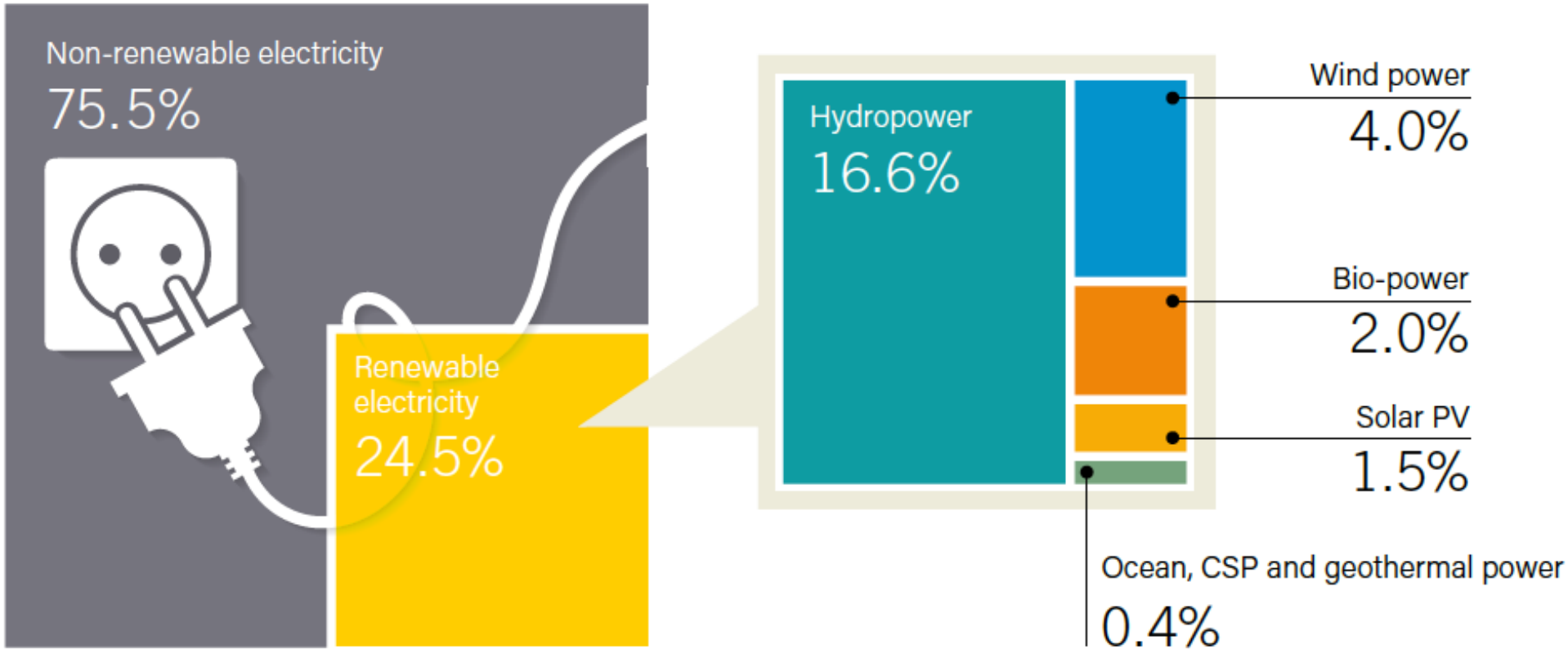
Contents

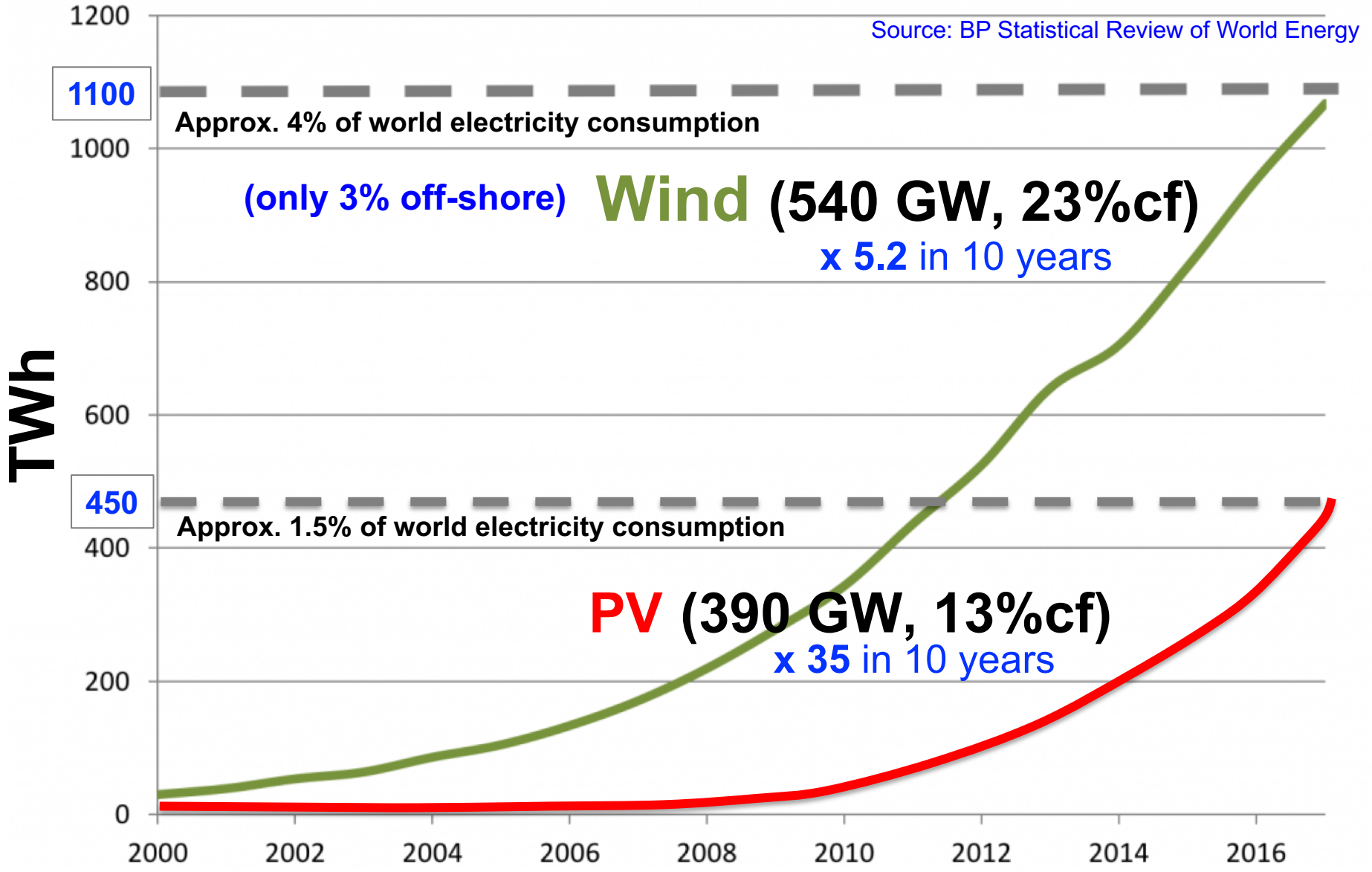
- Renewables deployment: current status & prospect
- Economic & technical challenges
- Enabling technologies: smart grids & storage
- The Spanish (bittersweet) experience

Global share of renewable electricity in 2016



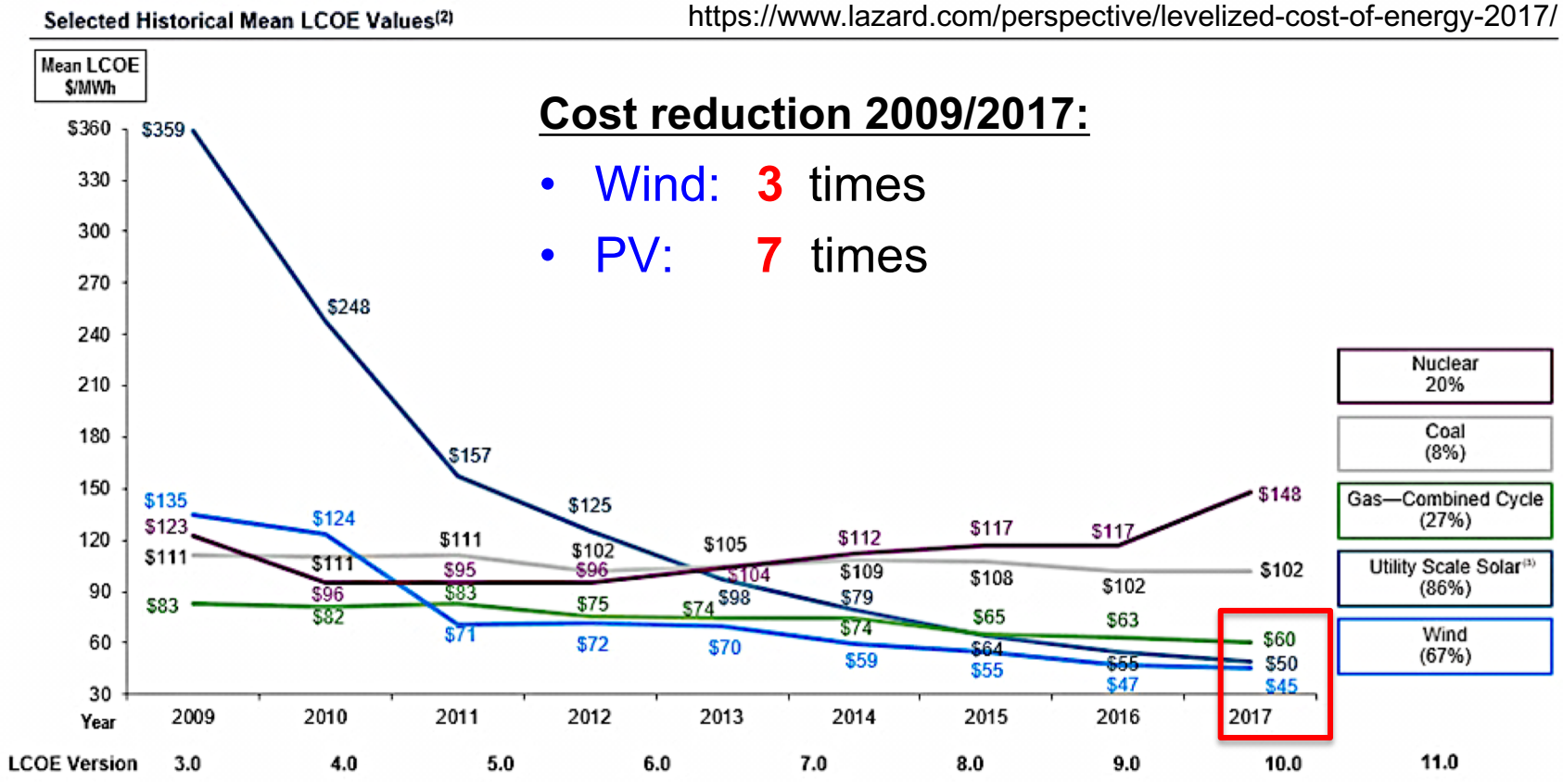
Source: REN21 Global Status Report 2017

Global capacity and generation: **wind and PV**



Drastic cost reduction (LCOE)

LCOE in USA (no subsidies) **Source: Lazard 2017**



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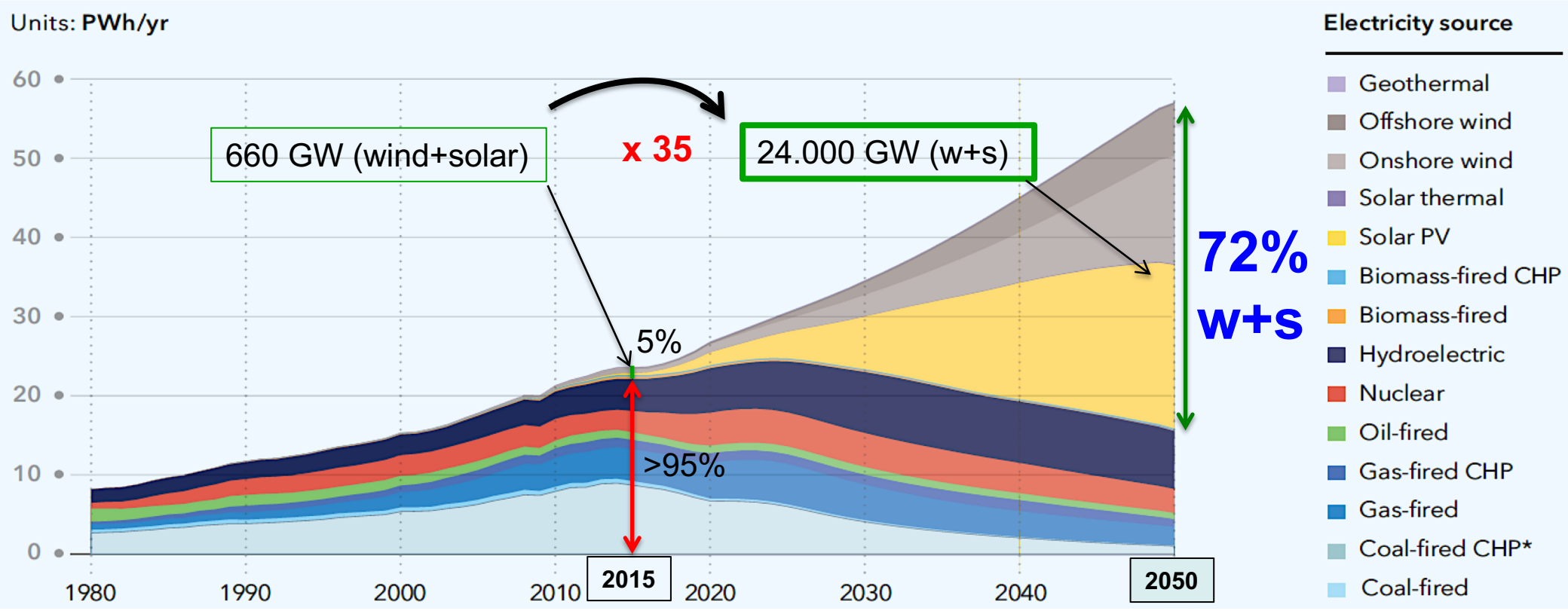
Huge investments ahead (CAPEX)

Source: DNV-GL Energy Transition Outlook 2017

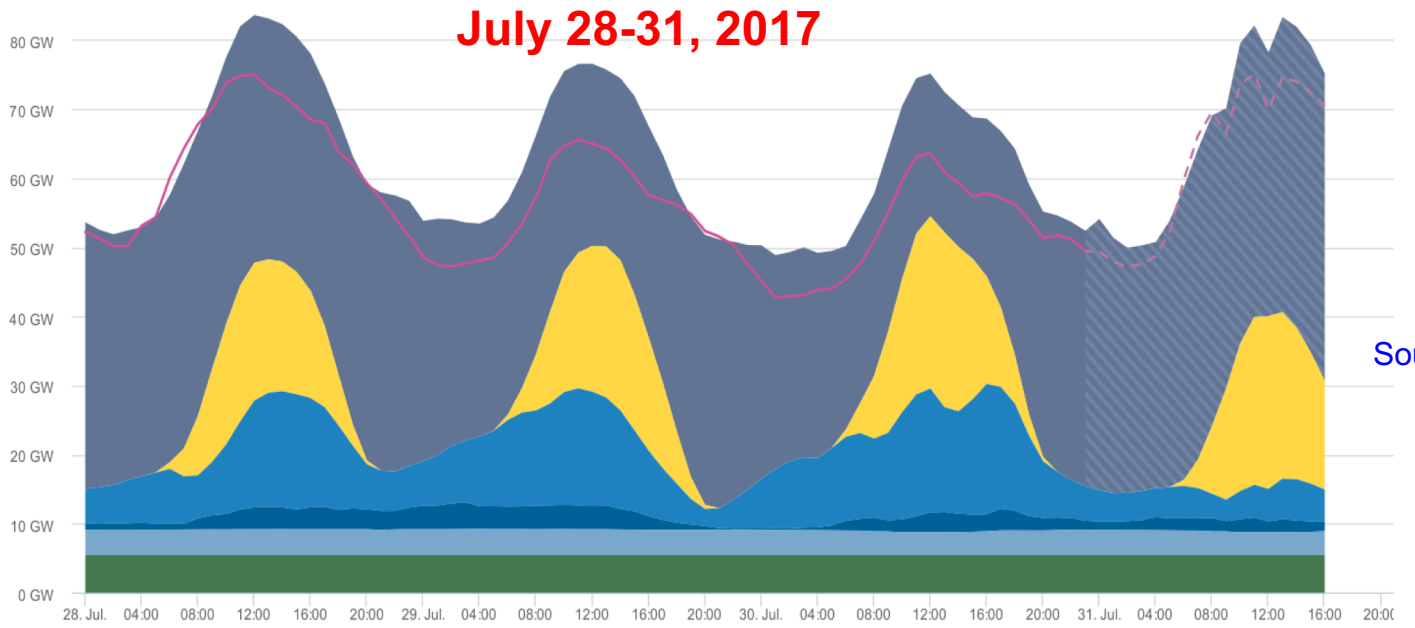


Wind+solar average growth rate needed:

650 GW/year (~1,000 billion€/year)

Intermittent nature of renewables

Germany (installed power end of 2016)
- PV 40 GW (6.9% energy share)
- Wind 46 GW (14.2% energy share)



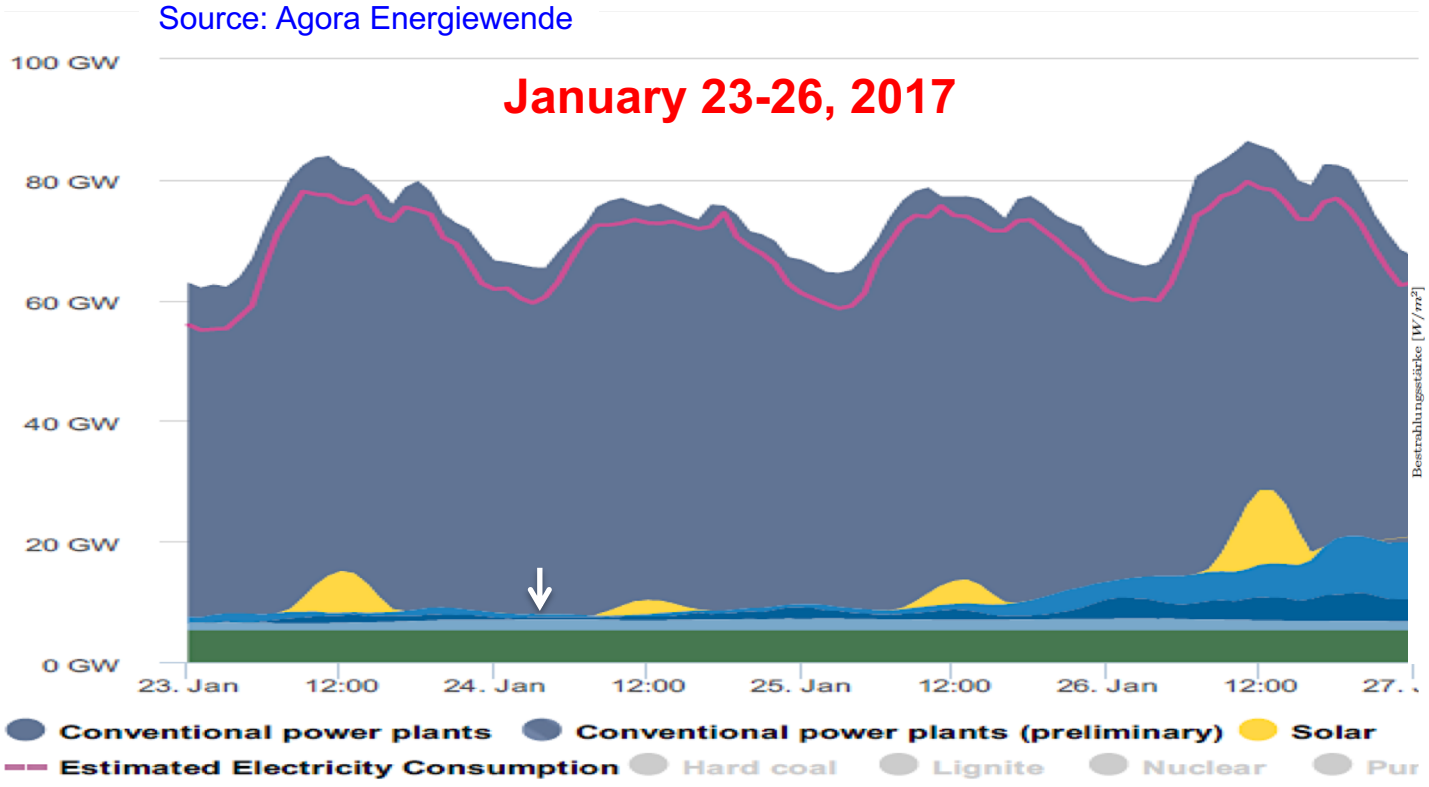
Source: Agora Energiewende

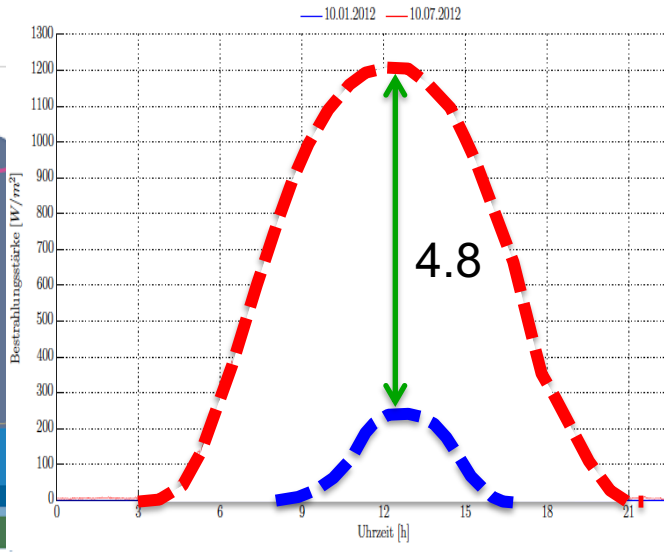
- **Real time (short-term):** frequency regulation
  - Low or null inertia, no synchronizing power
  - Limited P regulation (decrease only)
- **Daily horizon:** energy balance
  - More and deeper net demand gradients

Seasonal imbalance

Long-term storage is mandatory

Source: Agora Energiewende



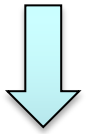


Solar radiation in January and July (Germany)

Even **4-5 times** current PV production would be insufficient in winter

Technical challenges: transmission

- **Longer distances between generation and load hubs**
- **Network congestions** (loop flows)
  - Limitations of conventional AC grids
- **System stability threatened:**
  - Less synchronizing and damping power
  - Sudden disconnections (voltage dips, strong winds, clouds)
  - Limited Q-V control capability



Ancillary services (flexibility)
Higher costs

Technical challenges: distribution

DG and EV:

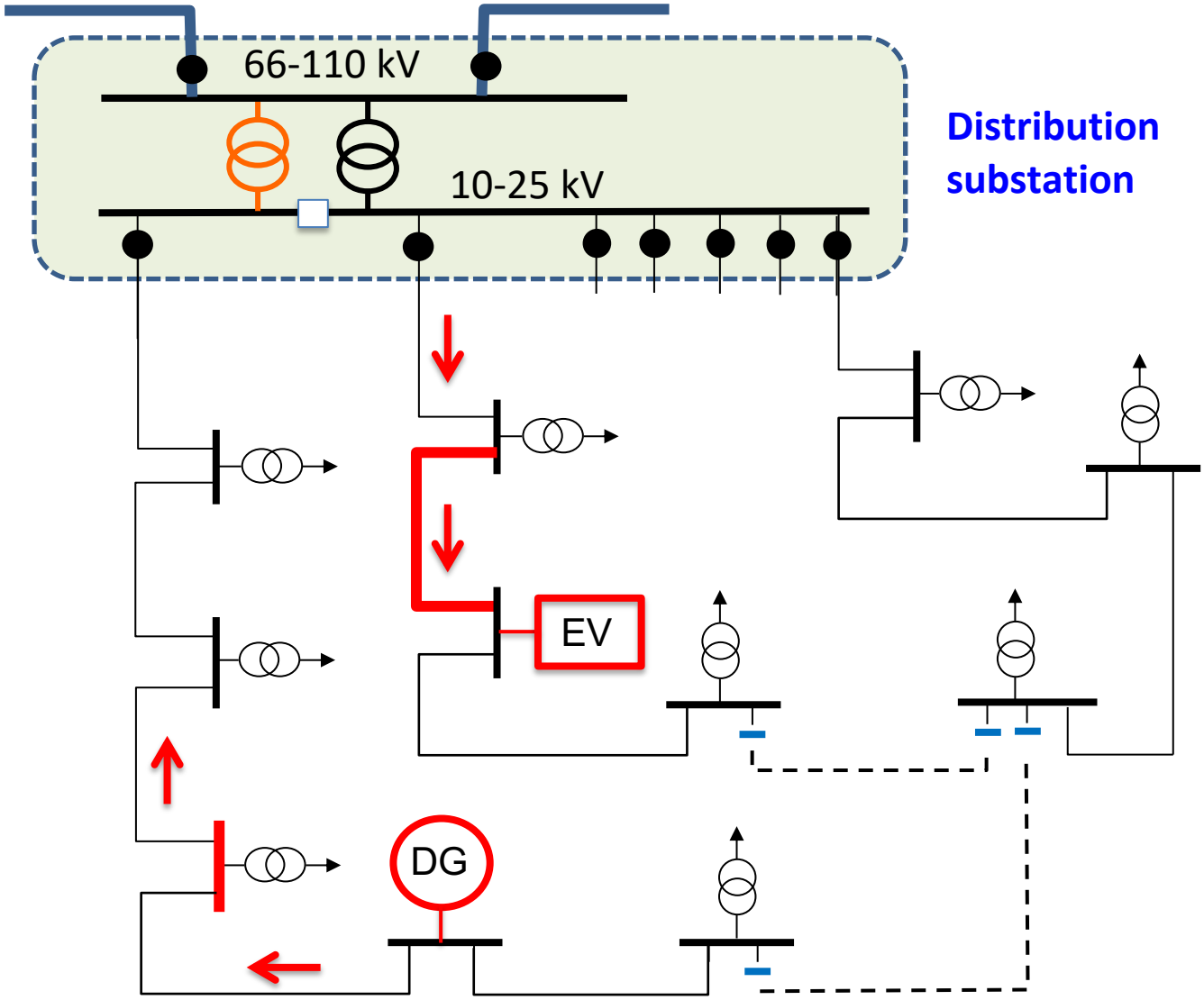
- Bidirectional flows
- **Much higher simultaneity coefficients**

Congestions:

- Ampacity
- Voltage violations
- Primary transformer

Short circuit levels

Protections, islanding



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Smarter RES interfaces

- **Contribution of renewables to ancillary services**
  - Voltage and frequency regulation
  - Emulation of synchronism: **VSC**'s
  - Black-start and grid-forming capability (microgrids)
- **Need for ubiquitous short- and long-term storage**
  - Renewables built-in storage (daily balancing)
  - Autonomous seasonal storage (**new agent?**)

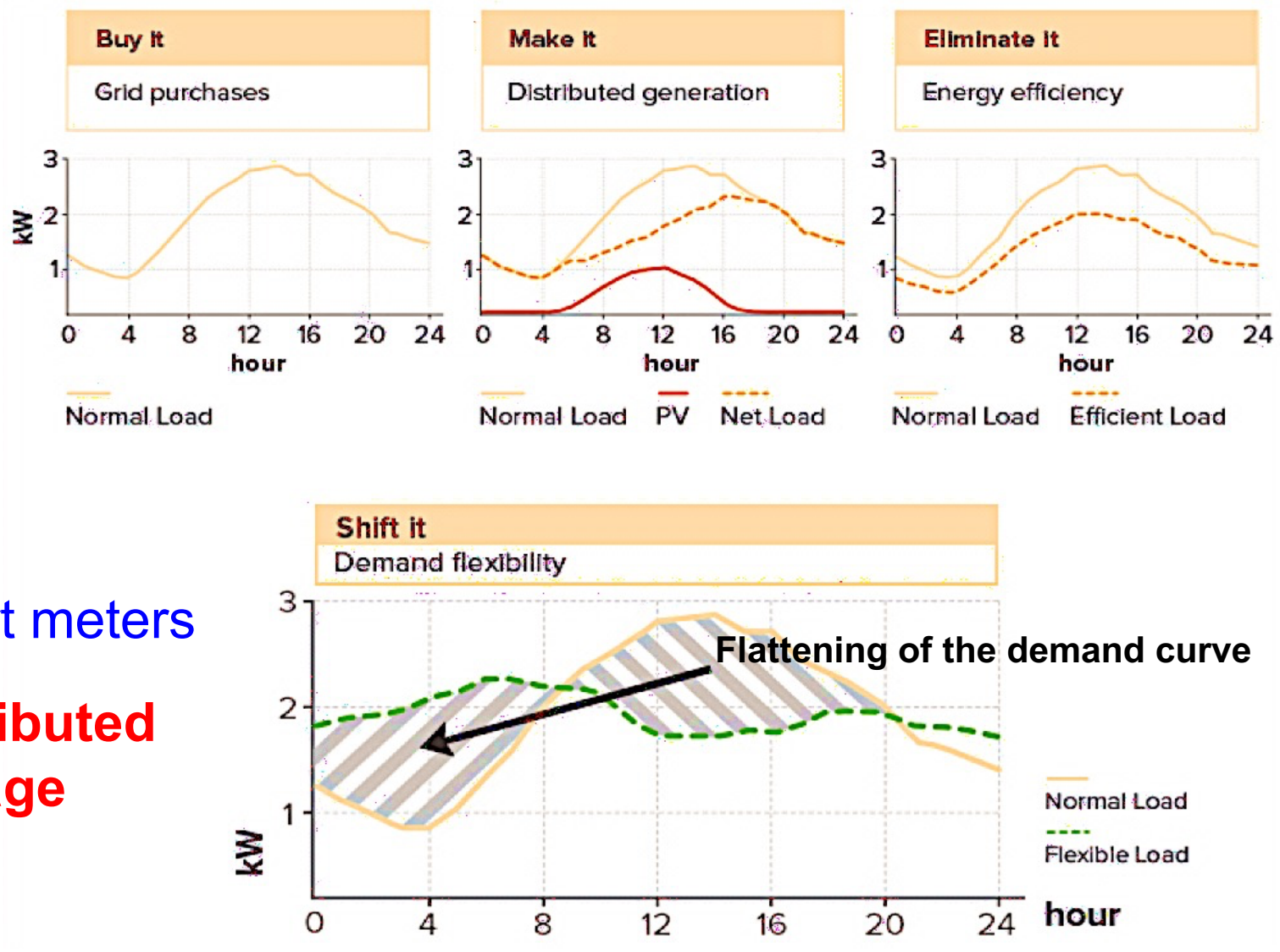
Smarter transmission grids

- **FACTS devices** and phase shifters
- **VSC-HVDC lines** (multiterminal, meshed?)
- **Supergrids:** UHV-AC & UHV-DC (overlay grids)
- **Grid codes** (standarization)
- **More advanced EMS**
    - Regional (multi-area) systems and markets
    - PMU-based WAM/WAC
- **Storage systems for ancillary services**

Smarter distribution grids: a true DSO?

- **Power electronics:** D-FACTS, tap changers
- **Distribution automation**
  - *Self-healing*, dynamic feeder reconfiguration
- **Information & communication systems**
  - Smart meters, big data
- **More advanced DMS**
  - Feeder monitoring (state estimation), var & V control, losses, …
- **Demand management:** Prosumers (DG, EV), aggregators
- **Microgrids, cogeneration, local markets:** Efficiency
- **Distributed storage systems**
  - Owned by DSO or by third-parties

Smarter consumer (prosumer)



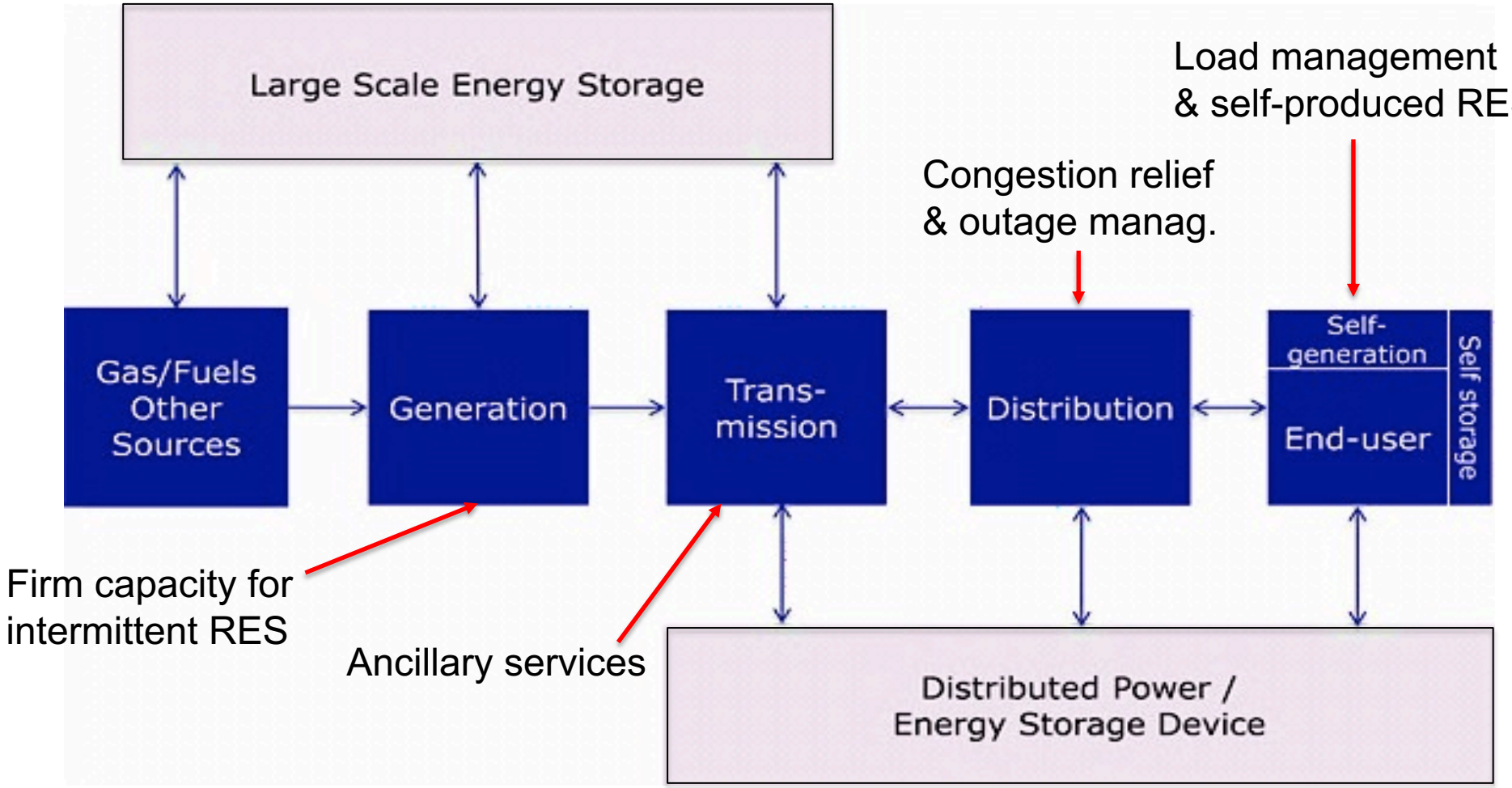
Smart meters

Distributed storage

Source: RMI - "The Economics of Demand Flexibility"

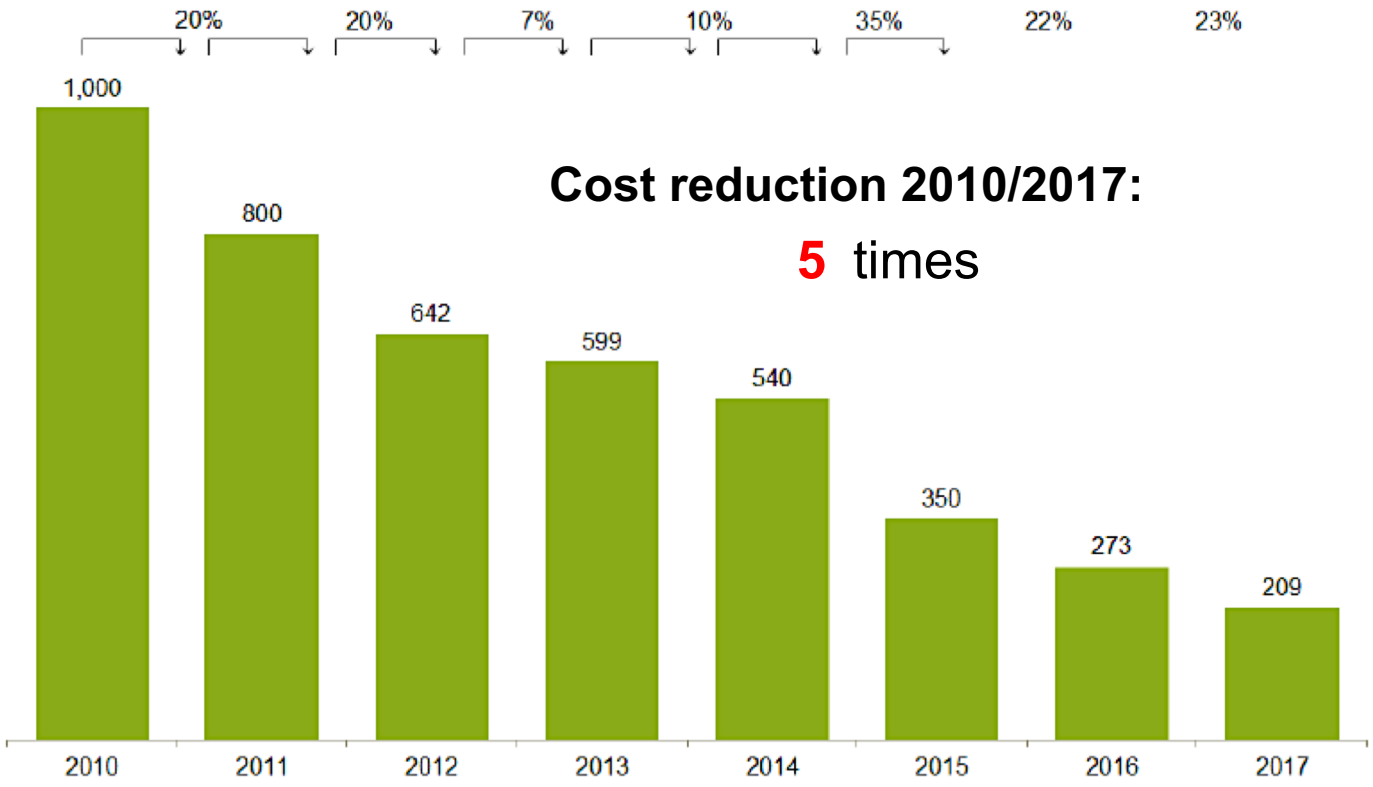
Energy storage: the “Holy Grail”

How, when, where? Who is to invest? Which incentives?



Li-ion battery pack: cost reduction

FIGURE 26. LITHIUM-ION BATTERY PACK PRICE, GLOBAL AVERAGE, $ PER KWH



Source: UN Environment, Bloomberg New Energy Finance

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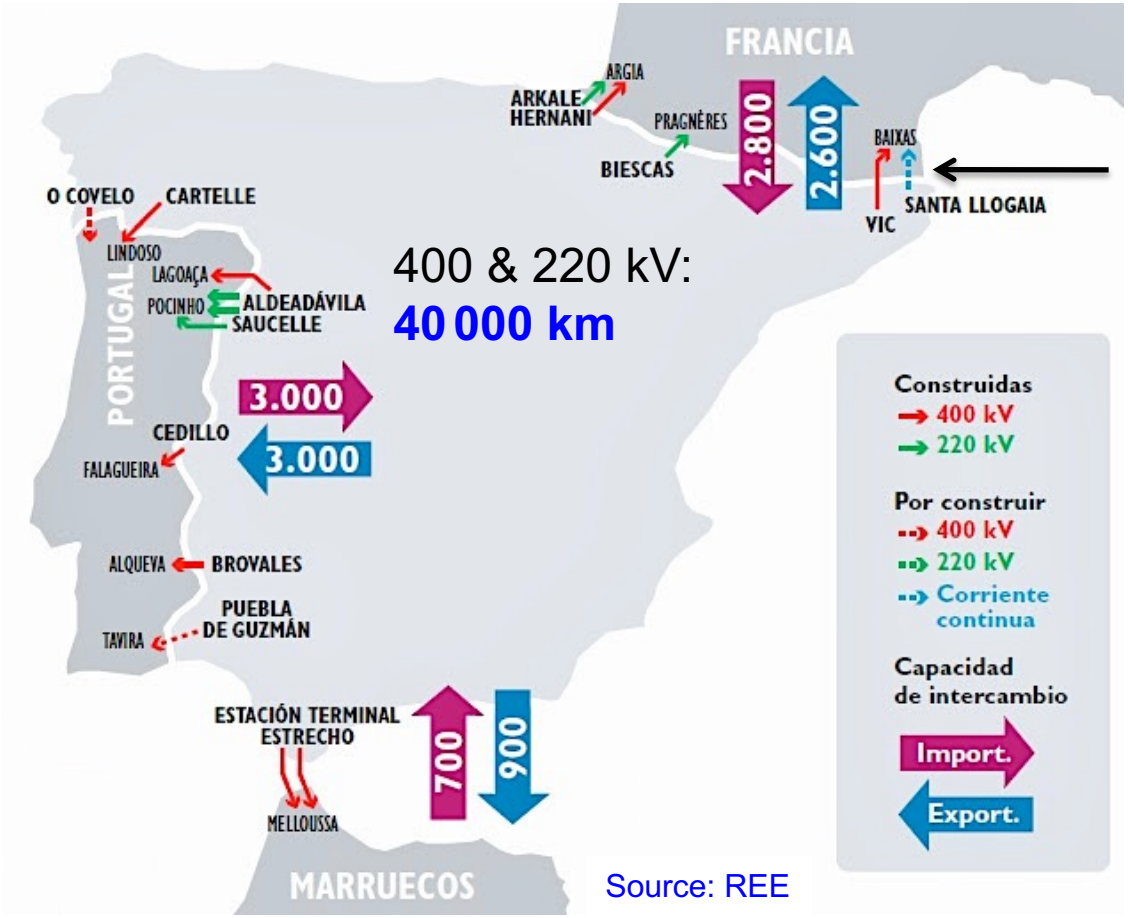
The Iberian electrical “island”



Source: REE

2015: New VSC-HVDC line doubled the capacity
(still **<7%** of peak demand)

Less than British islands

REE created in 1984
(15 years before deregulation)

- Iberian (Spain+Portugal) day-ahead market since 2007
- Integrated in European wholesale market (PCR) in 2013

Solar resource and infrastructure

- Spain is a privileged country for solar energy

PV installed power and annual production (2014)

	MWp	TWh/year	Cap. Factor (%)
Spain	4 787	8.2	**19.6**
Portugal	423	0.6	16.9
Italy	18 622	22.3	13.7
France	5 954	5.9	11.3
Germany	38 301	35.1	10.5
UK	5 379	4.1	**8.6**

- Smart meters to be fully deployed by 2018: mandatory **hourly billing** since 2015: indexed to wholesale prices

Ready for an aggressive **net metering** policy

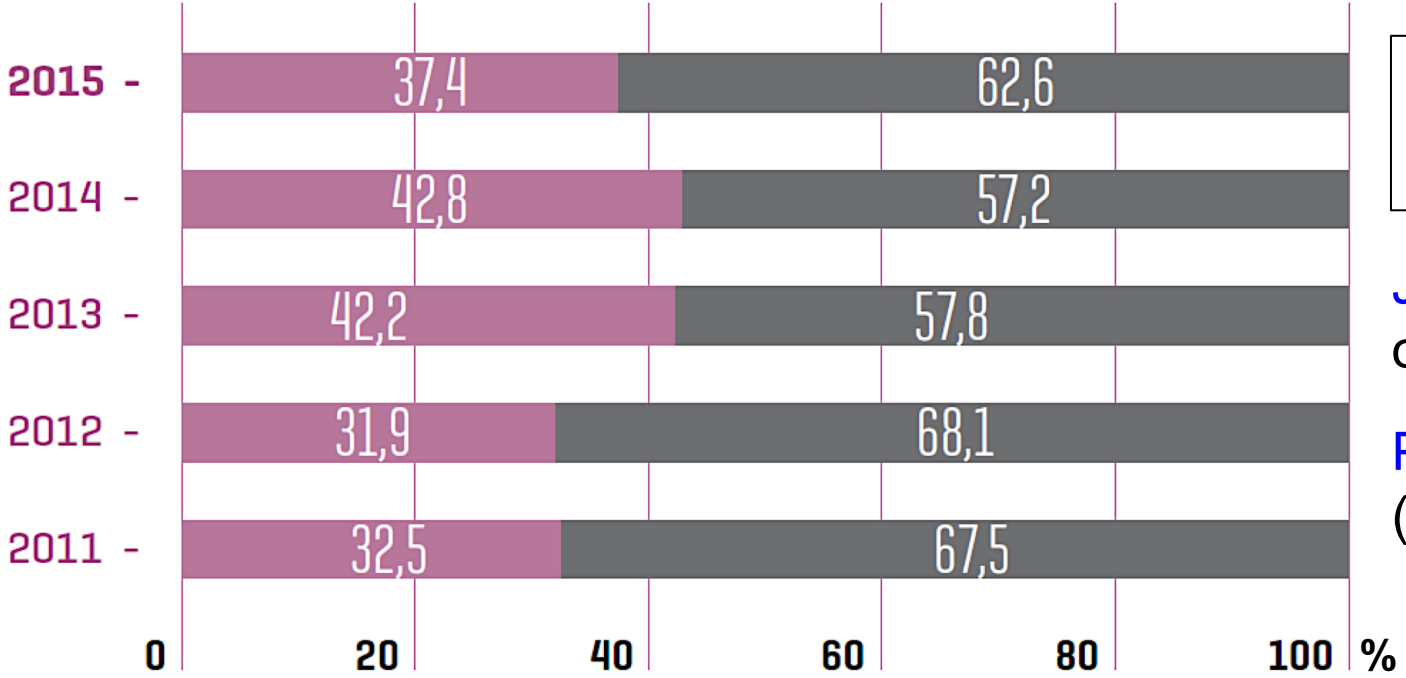
Share of renewables in Spain

Installed power:

55 GW nuclear+fossil

52 GW RES

2.7 GW pumped hydro



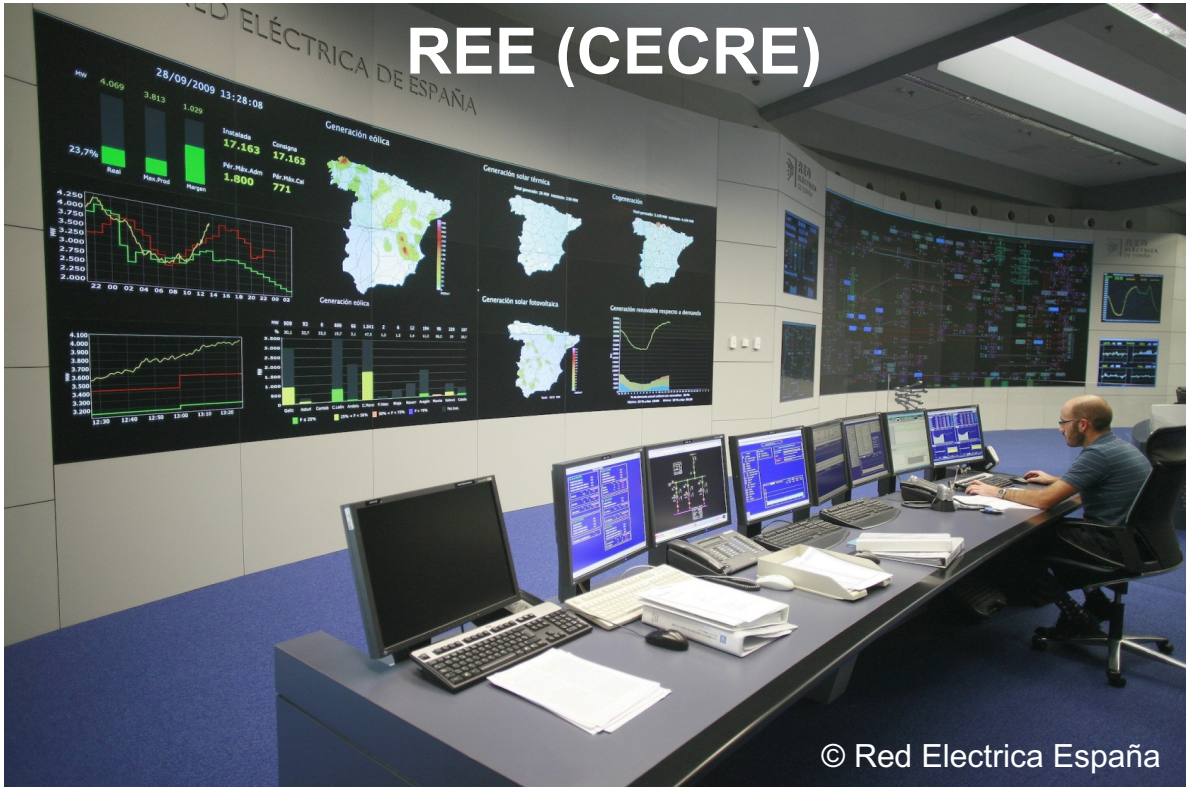
Mean 2011-2017:
37.3%

January-May 2016:
over 50% share

Peak wind record: >70%
(nov. 21, 2015, 4:50am)

Renewables integration in Spain

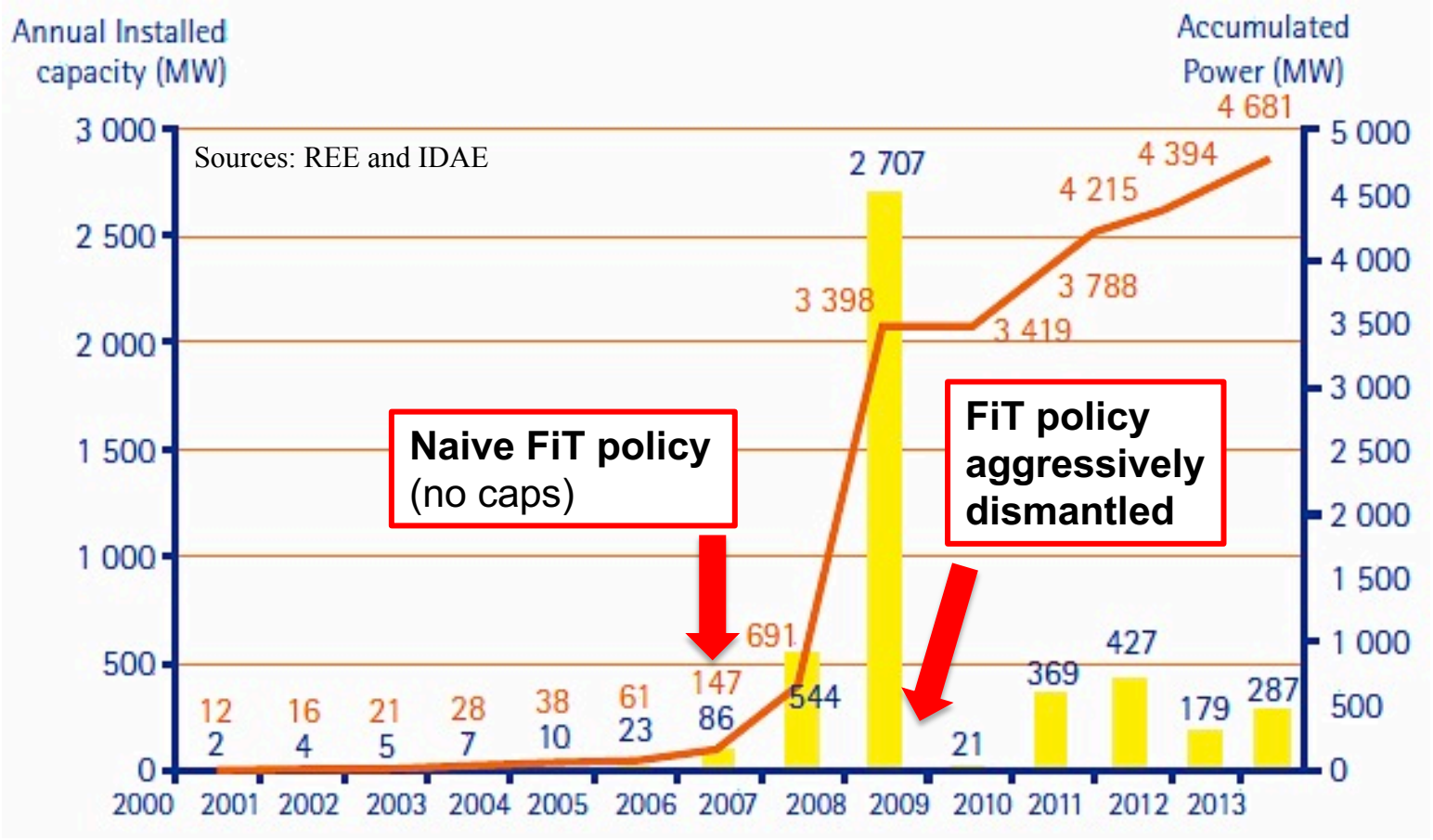
Positive experience from **technical (grid)** point of view



Negative experience from **regulatory & economic** sides

The burst of the PV bubble

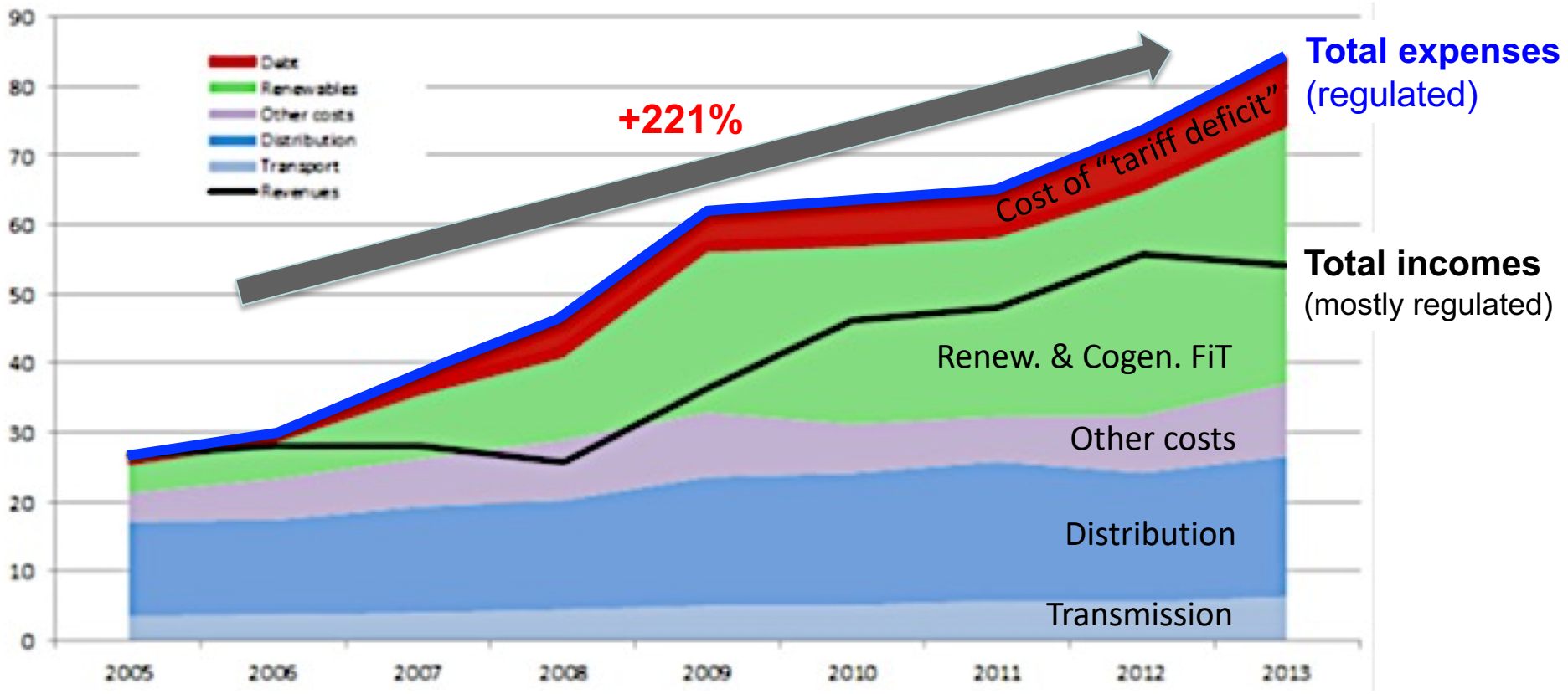
Evolution of installed PV in Spain



What happened in 2008-09? Policy reform suddenly cutting formerly very generous PV feed-in tariffs. **Goal:** keep under control tariff deficit

The electricity “tariff deficit”

Evolution of incomes and costs, **excluding Energy** (€/MWh)



38 625 M€ tariff deficit peak in 2013 (4% GDP)

Hurdles to PV self-production

Spanish policy on PV self-production (RD 900/2015):
For any domestic (type I) installation *connected* to the grid:

- No compensation for energy injected to grid
  (net metering not allowed for residential customers)
- Technical complexity (two separate meters)
- P_{PV} < contracted power
- Tax on self-produced energy (**"tax on Sun"**):

Installed power + produced energy

P < 10 kW: 9 €/kW/year	P < 10 kW: 0 (**??**)
10 kW < P < 15 kW: 15 €/kW/year	10 kW < P < 15 kW: 6 c€/kWh

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SPECIAL ISSUE

Smart Cities

Open-access paper: https://ieeexplore.ieee.org/document/8291073/

City-Friendly Smart Network Technologies and Infrastructures: The Spanish Experience

By Antonio Gómez-Expósito, *Fellow IEEE*, Angel Arcos-Vargas, José M. Maza-Ortega, José A. Rosendo-Macías, *Senior Member IEEE*, Gabriel Alvarez-Cordero, Susana Carillo-Aparicio, Juan González-Lara, Daniel Morales-Wagner, and Tomás González-García