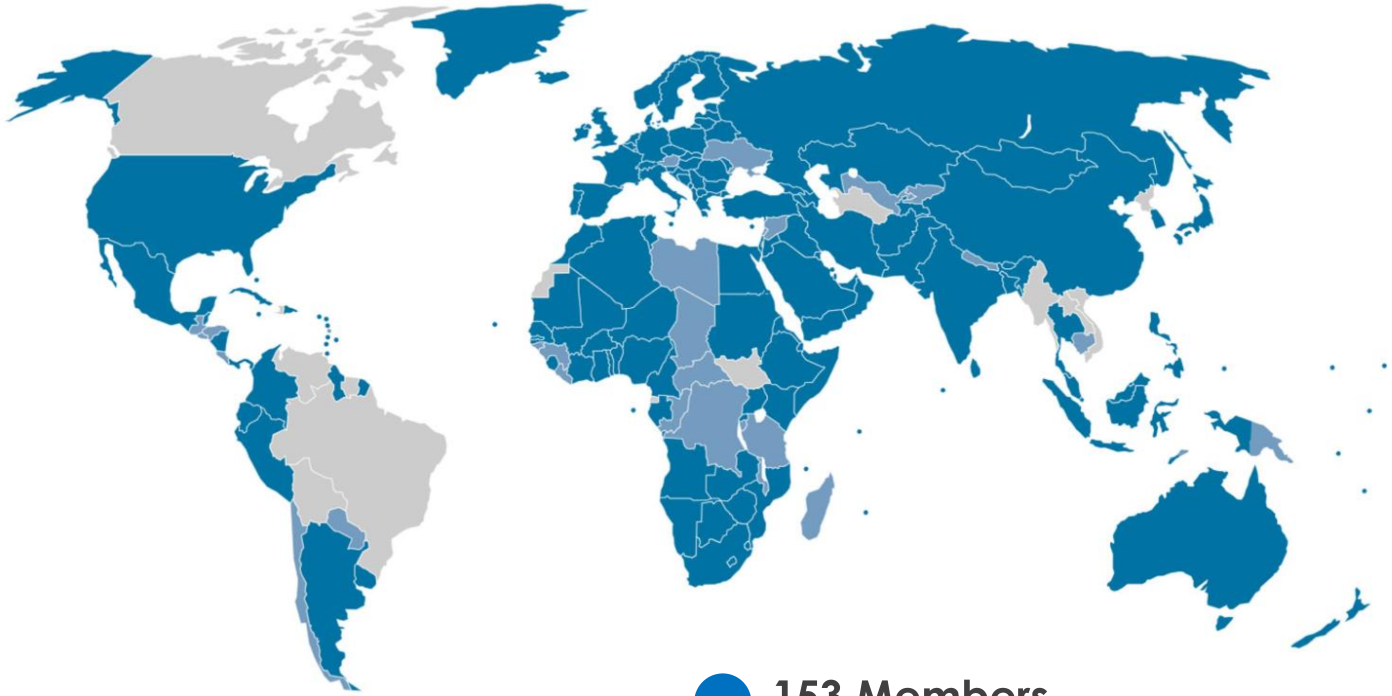
International Renewable Energy Agency

Innovation Driving the Energy Sector Transformation

Renewable Future – Lecture Series
University of Bonn
Bonn, 7 December 2017

About IRENA

- Inter-governmental agency established in 2011
- Headquarters in Abu Dhabi, UAE
- IRENA Innovation and Technology Centre – Bonn, Germany
- Permanent Observer to the United Nations – New York



153 Members

27 States in Accession

Mandate: Assist countries to accelerate renewable energy deployment

1 The energy transition

Development and welfare for all

UN Sustainable Development Goals (SDGs)

Source: IRENA (2017) Rethinking Energy

We need cleaner, affordable, local and abundant sources of energy

The world has already gone through energy transitions before

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Energy transitions occur not due to scarcity of primary resources, but due to availability of new resources emerging geopolitical debates and economic opportunities enabled by technology development

Image sources:
https://vikasacharya.wordpress.com/2015/10/07/early-man/
https://www.nceagletimes.com/news/2017/05/16/industrial-revolution-changing-western-culture/
https://www.collectionscanada.gc.ca/rock/021018-3000-e.html
http://www.nytimes.com/2011/09/27/business/energy-environment/in-north-dakota-wasted-natural-gas-flickers-against-the-sky.html

Energy accounts for two-thirds of total greenhouse gas emissions

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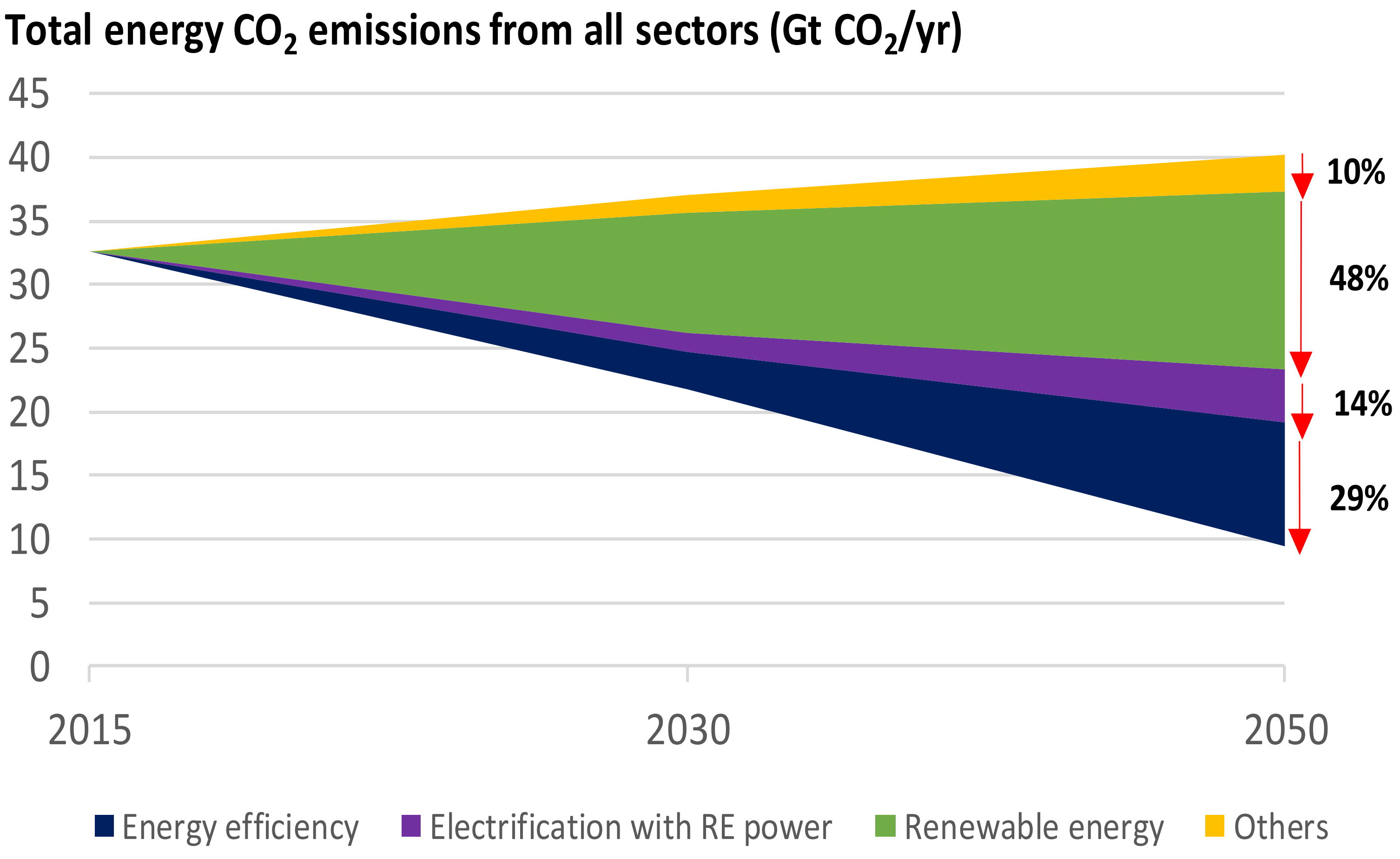
To meet 2°C climate target set at COP 23 in Paris 2015



- Carbon intensity of energy:
  - needs to fall by 85% in 2015-2050
- Energy-emission budget:
  - 790 Gt CO_2 from 2015 till 2100
  - *At current emissions rate, carbon budget would be consumed by 2040*
  - RE and EE can achieve 90% of emission reductions needed by 2050

Source: IEA/IRENA (2017) Perspectives for the Energy Transition

2016 - A record year for renewable power

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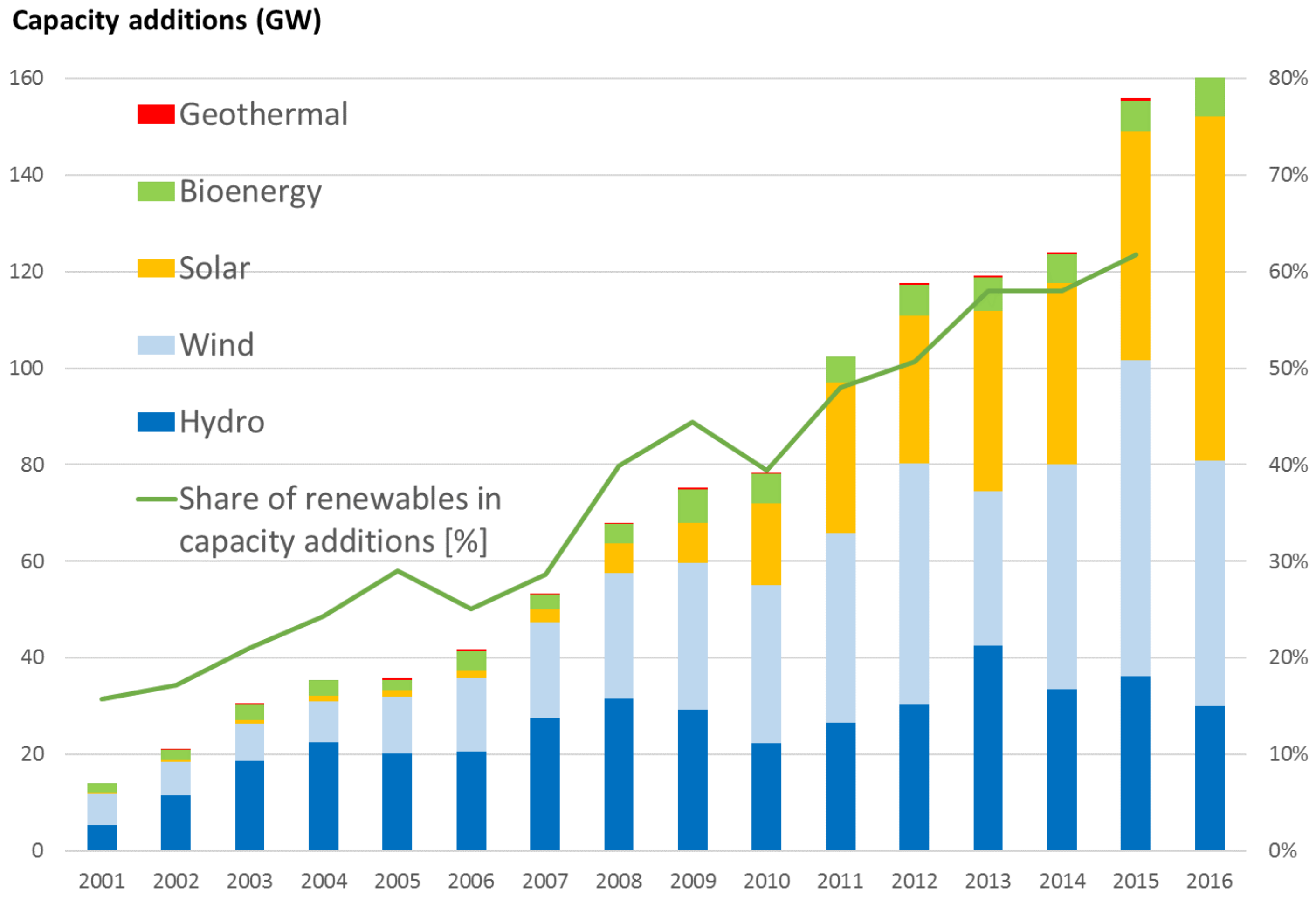
- 162 GW of RE installed – *71 GW solar, 51 GW wind, 30 GW hydro, 9 GW bioenergy, 1 GW geothermal*
- RE cumulative capacity > 2,000 GW
  - Despite low oil prices
- 164 countries with RE policies in place



Source: IRENA (2017) Statistics handbook

Investments in renewable power have surpassed the ones in fossil fuels

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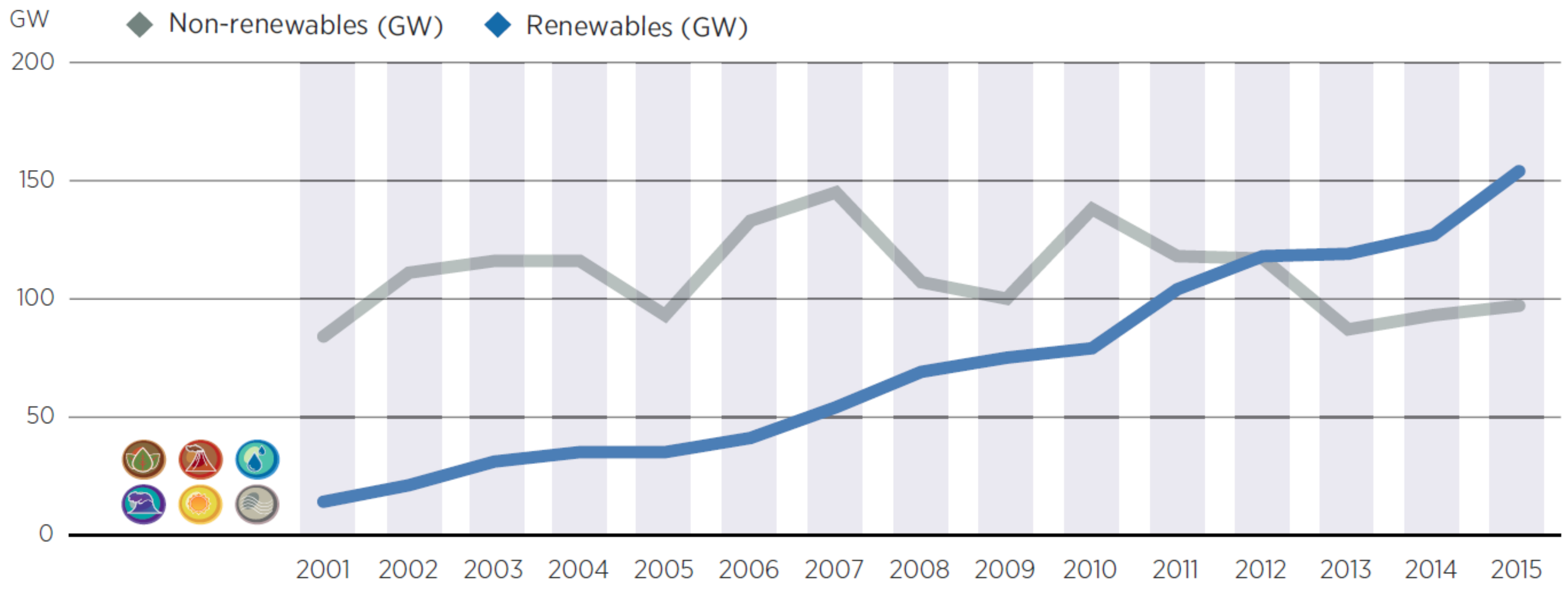
RE represents 60% of the total new capacity investments in the last two years



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Renewables (GW)	14	21	31	35	35	41	54	69	75	79	104	118	119	127	154
Non-renewables (GW)	84	111	116	116	93	133	145	107	100	138	118	117	87	93	97

Source: IRENA (2017) Rethinking Energy

2016: **242 USD billion.** Solar PV and wind leading

Today's strong business case for renewable power

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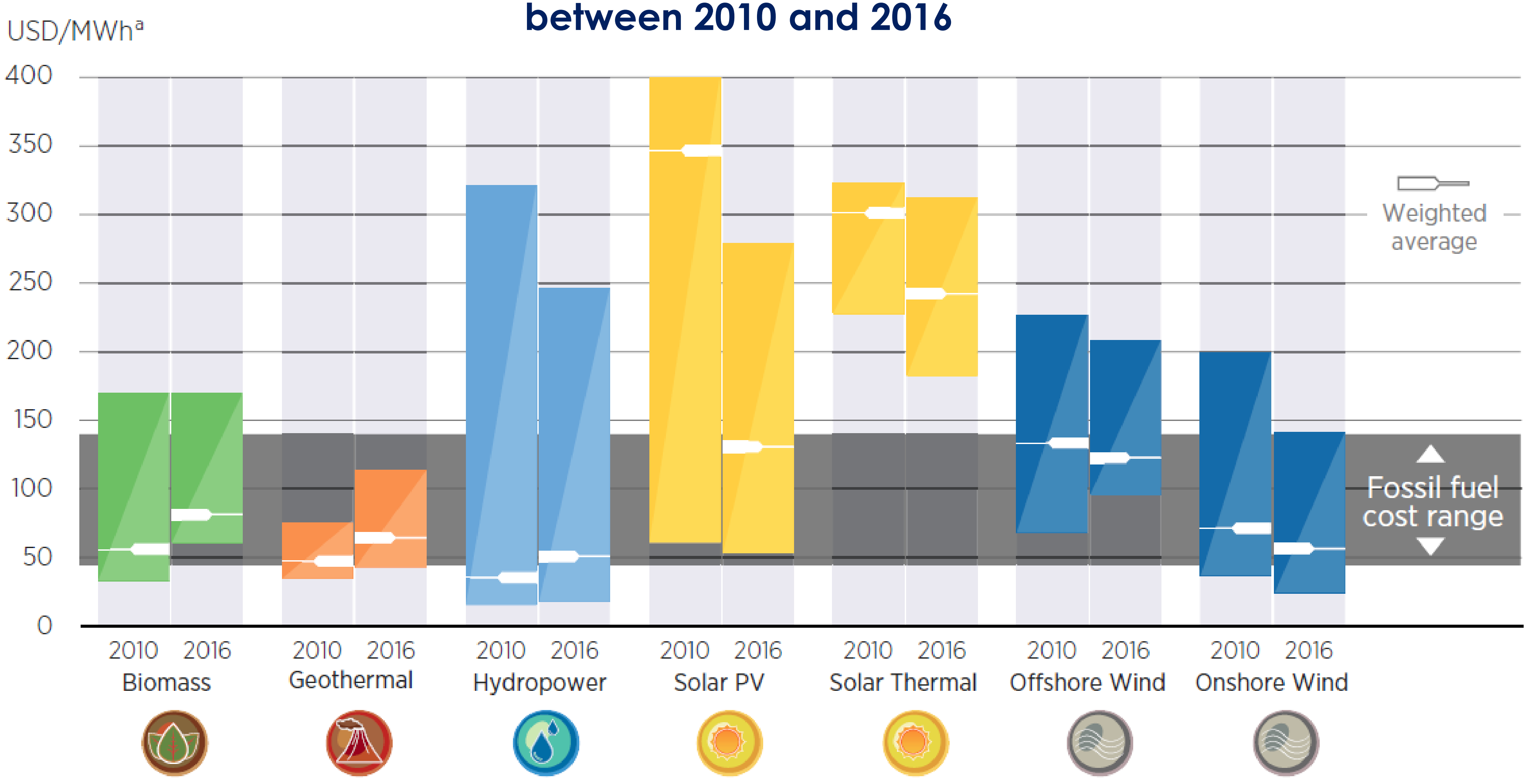
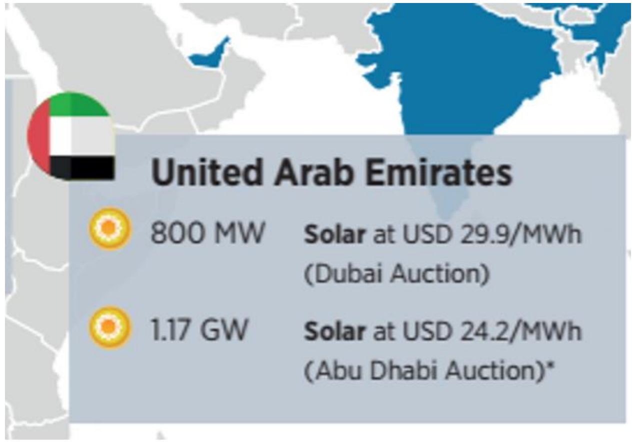
Levelised cost of electricity (LCOE) for renewable power between 2010 and 2016



Note: a) MWh: megawatt-hour
b) All costs are in 2016 USD. Weighted Average Cost of Capital is 7.5% for OECD and China and 10% for Rest of World

Recent auction prices for PV



Saudi Arabia: 300 MW – USD 17.9/MWh

Source: IRENA (2017) Rethinking Energy

Rapid cost reduction – *PV: 80% reduction in the last 6 years*

But energy continues to be a fossil fuels based sector

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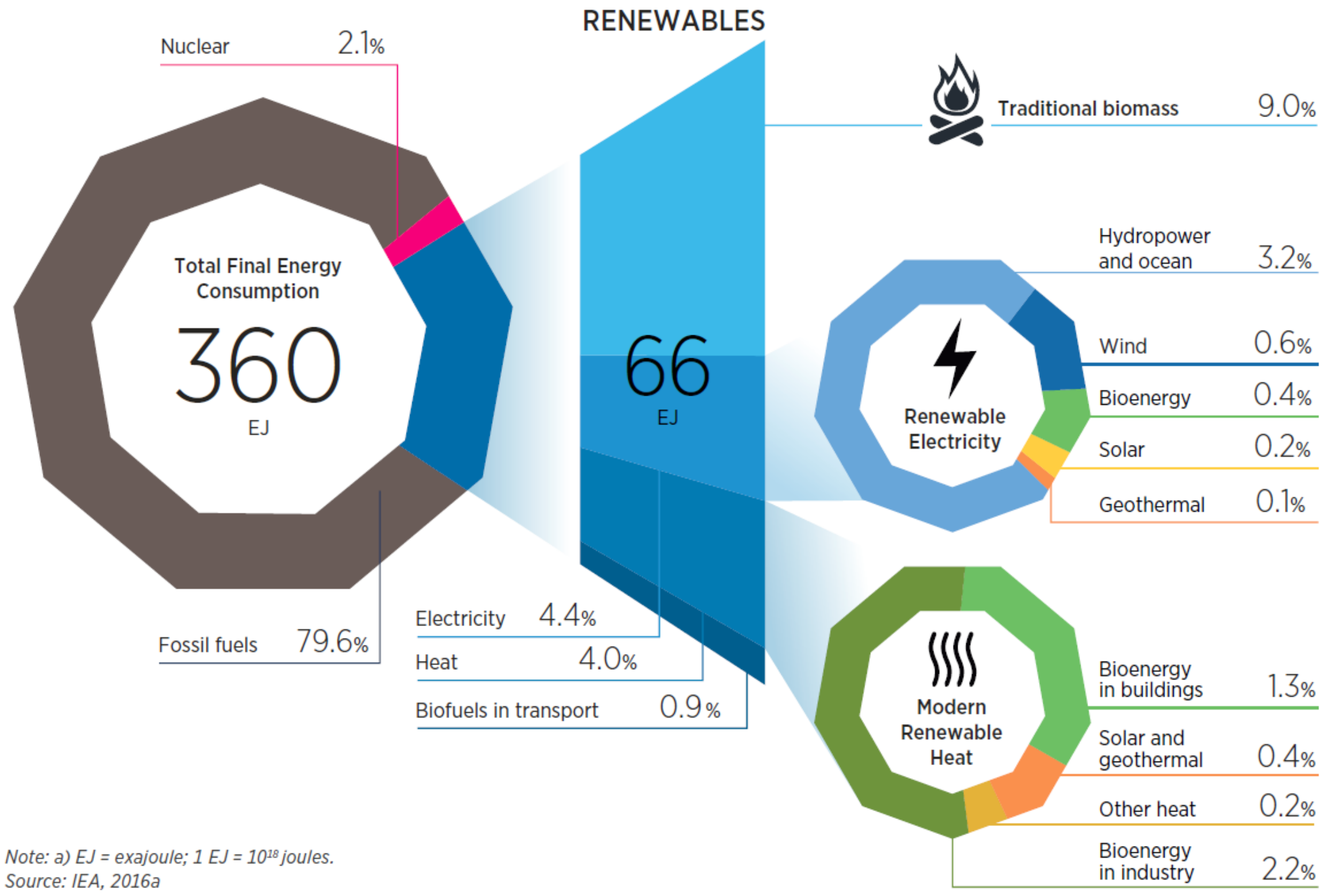
The growth rate in terms of **renewable share per year will need to increase seven-fold** over past rates

Total final energy consumption (EJ) and renewable shares in 2014



Note: a) EJ = exajoule; 1 EJ = 10^{18} joules.
Source: IEA, 2016a

Source: IRENA (2017) Rethinking Energy

2

The role of innovation

Innovation needs

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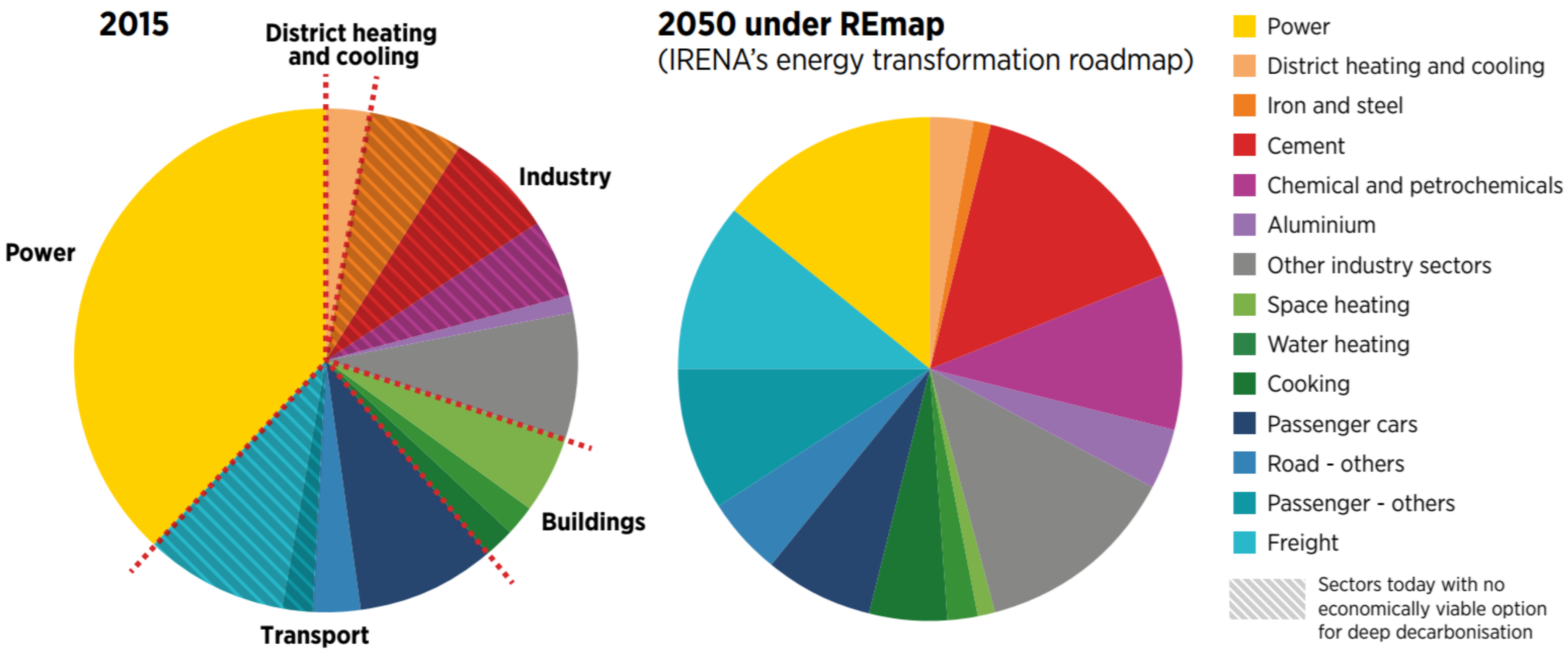
Needed emission reductions per sector in 2050

1. Continue improving available RE technologies – cost & performance
2. For power sector we need focus on systems integration
3. Breakthroughs in industry and transport sectors

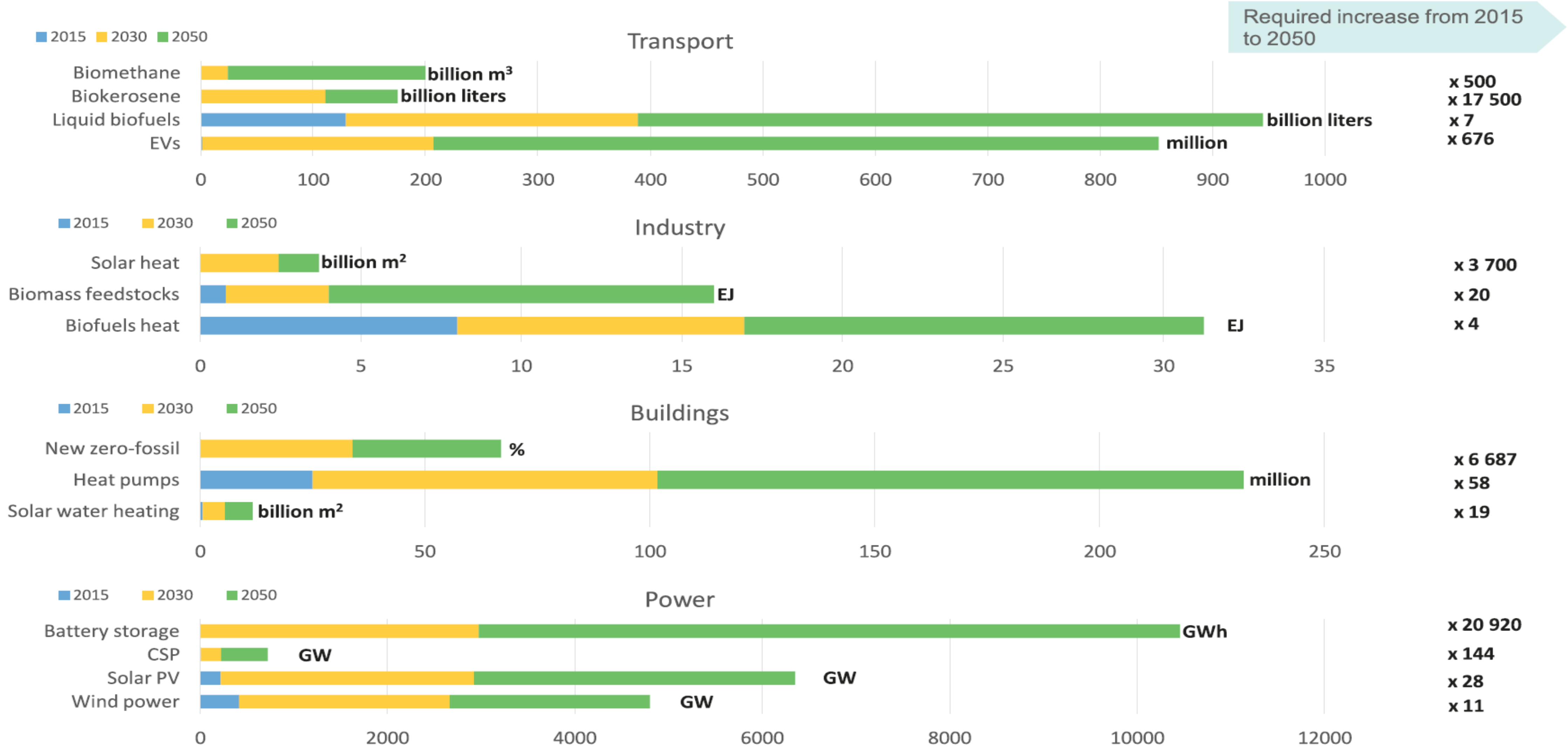


Source: IRENA (2017) Renewable energy innovation: accelerating research for a low-carbon future

Around one third of energy-related emissions in the Reference Case in 2050 currently have no economically viable options for decarbonisation

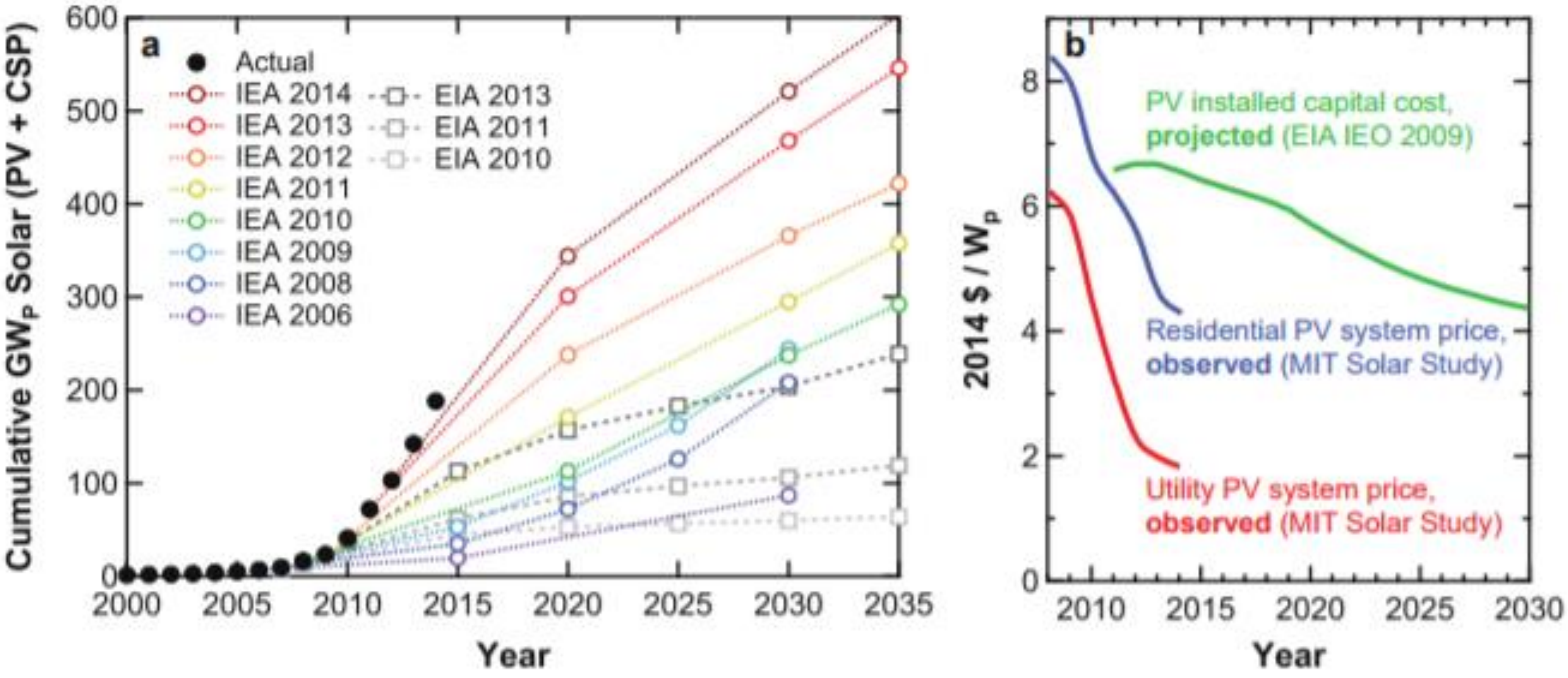
Innovation to scale-up RE deployment

Physical growth needs in energy sectors



Disruption!

Solar Capacity Growth and Costs Compared to Projections



Between 2007 and 2016:

- X 30 growth (~ 300 GW)
- CAGR: ~ 47%
- 2030: x 220 (64 000 GW)

Source: MIT (2015) The Future of Solar Energy

Holistic innovation approach for the energy transition

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- Accelerated innovation requires a combination of various policy instruments across the whole technology lifecycle, from R&D to market scale-up
- A systematic approach is required, encompassing technical, policy, business model and regulatory considerations
- Concentrating all efforts solely on a narrow suite of measures, such as R&D spending or market signals, will not bring the expected results.

Innovation across the complete technology lifecycle

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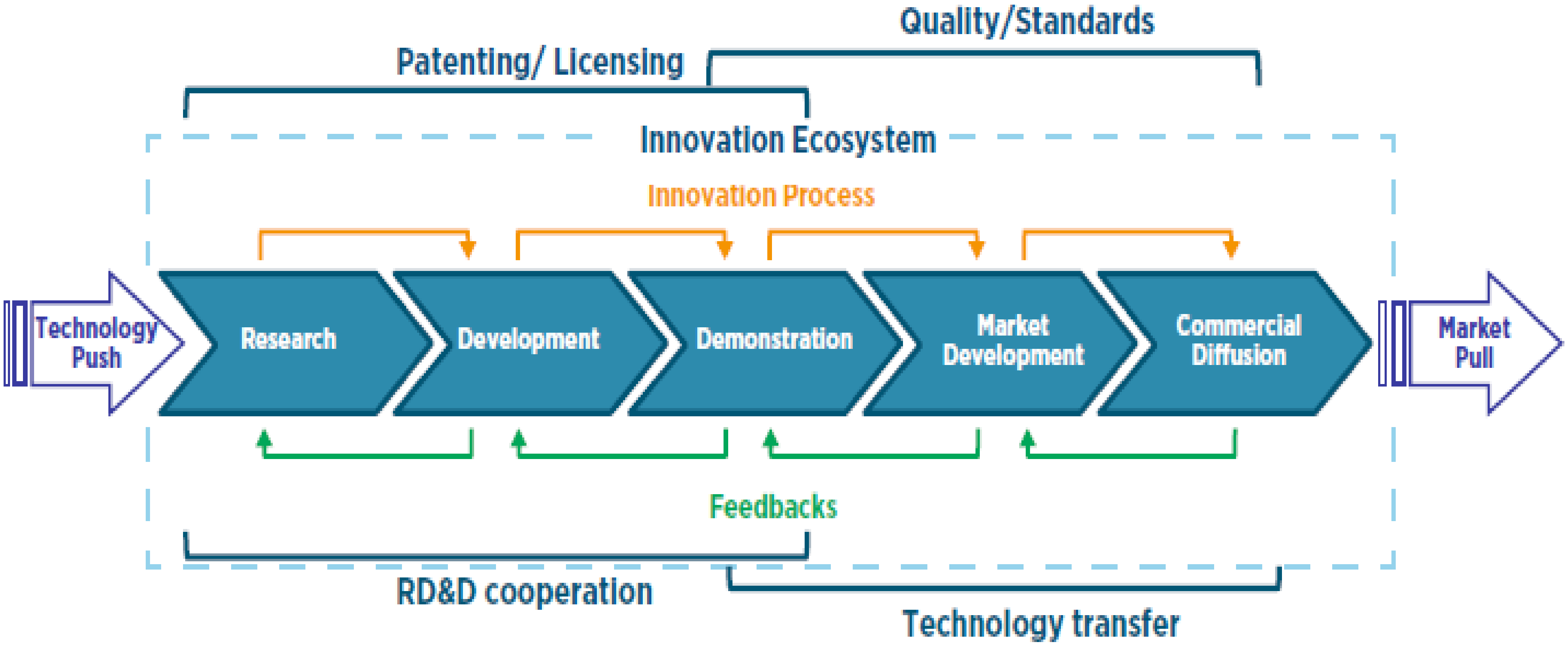

Source: IRENA (2015) Renewable Energy Technology Innovation Policy: A process development guide

3 Research, Development & Demonstration

Technology Development

Drivers?

Vestas V164-9.5 MW
- Rotor diameter: 164m
- Rated power: 9 500 kW

Brush's Wind Turbine
- Rotor diameter: 17m
- Rated power: 12 kW

KEMA Energy Island
- Inverse Offshore Pump AccumulationStation

Learned?

Learning Paths – takes time!

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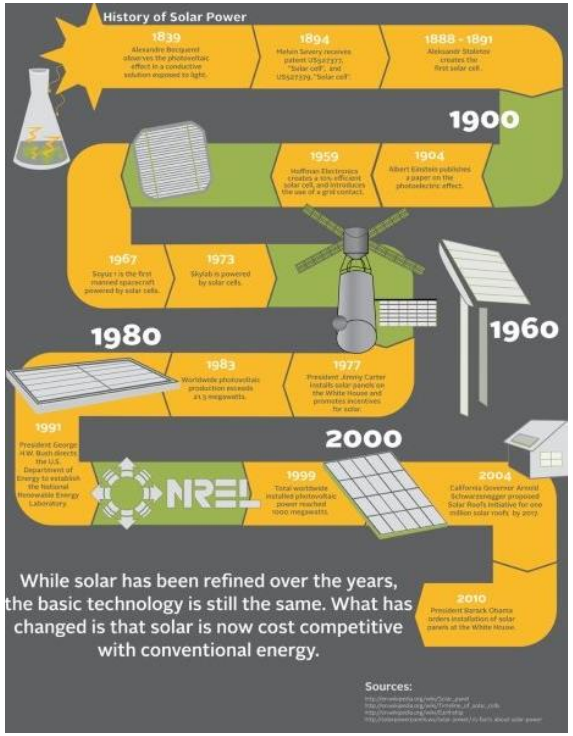

Source: SunRun

PV

Learning by:

- **Searching:** making improvements due to the experiences and results of R&D
- **Doing:** improvements of a technology due to the repetitive manufacturing of a product
- **Using:** compiling the feedback from use experiments into the designing processes
- **Interacting:** reaching improvements due to the network interactions

(Kamp, 2004)

Vestas V100 – 2MW

Source: www.vestas.com

NIBE B – 630 kW (1978)

Source: Gipe, 1995

Juul's – 200 kW (1957)

Source: Gipe, 1995

Wind Evolution in Denmark

R&D spending on renewable energy 2004-2015

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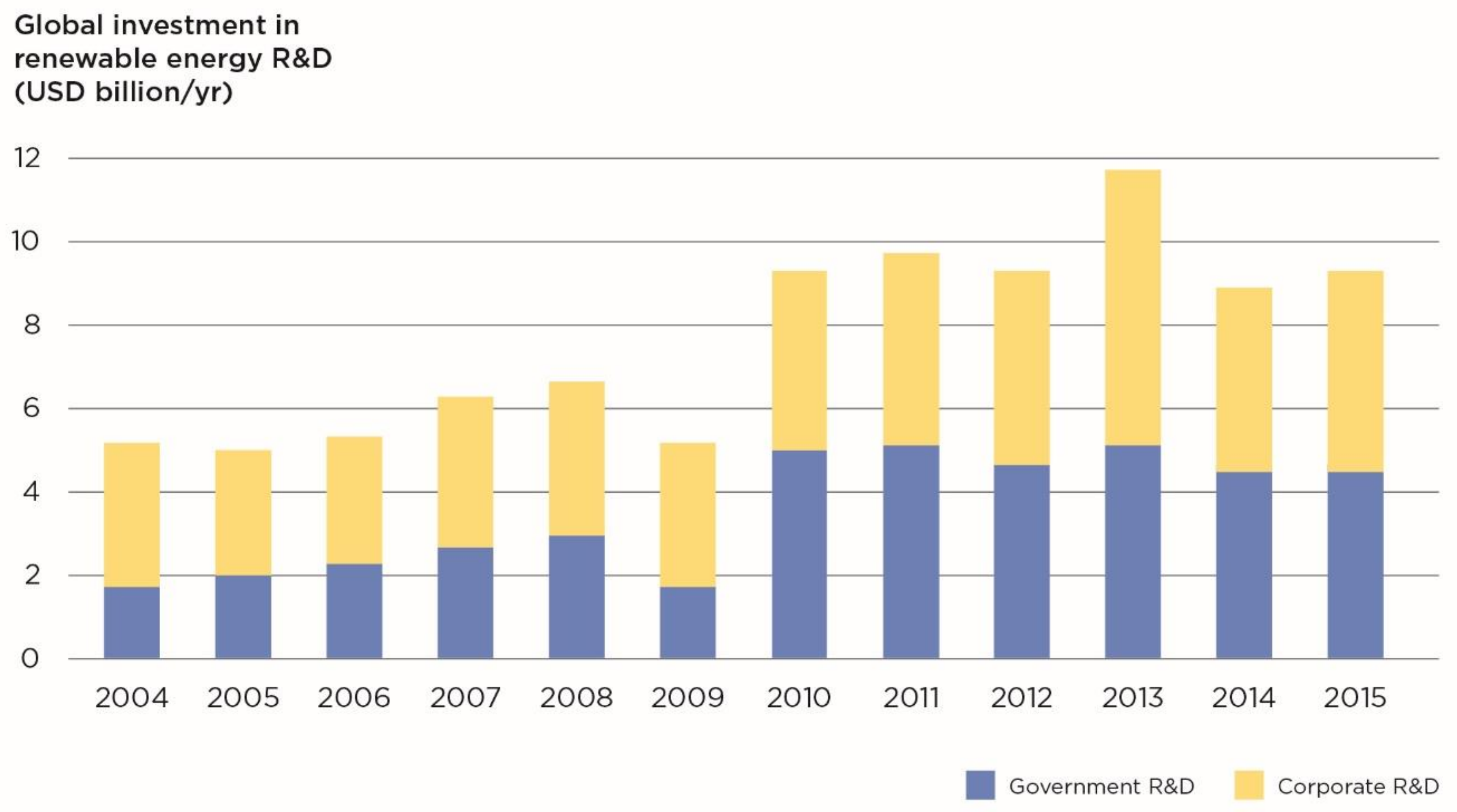
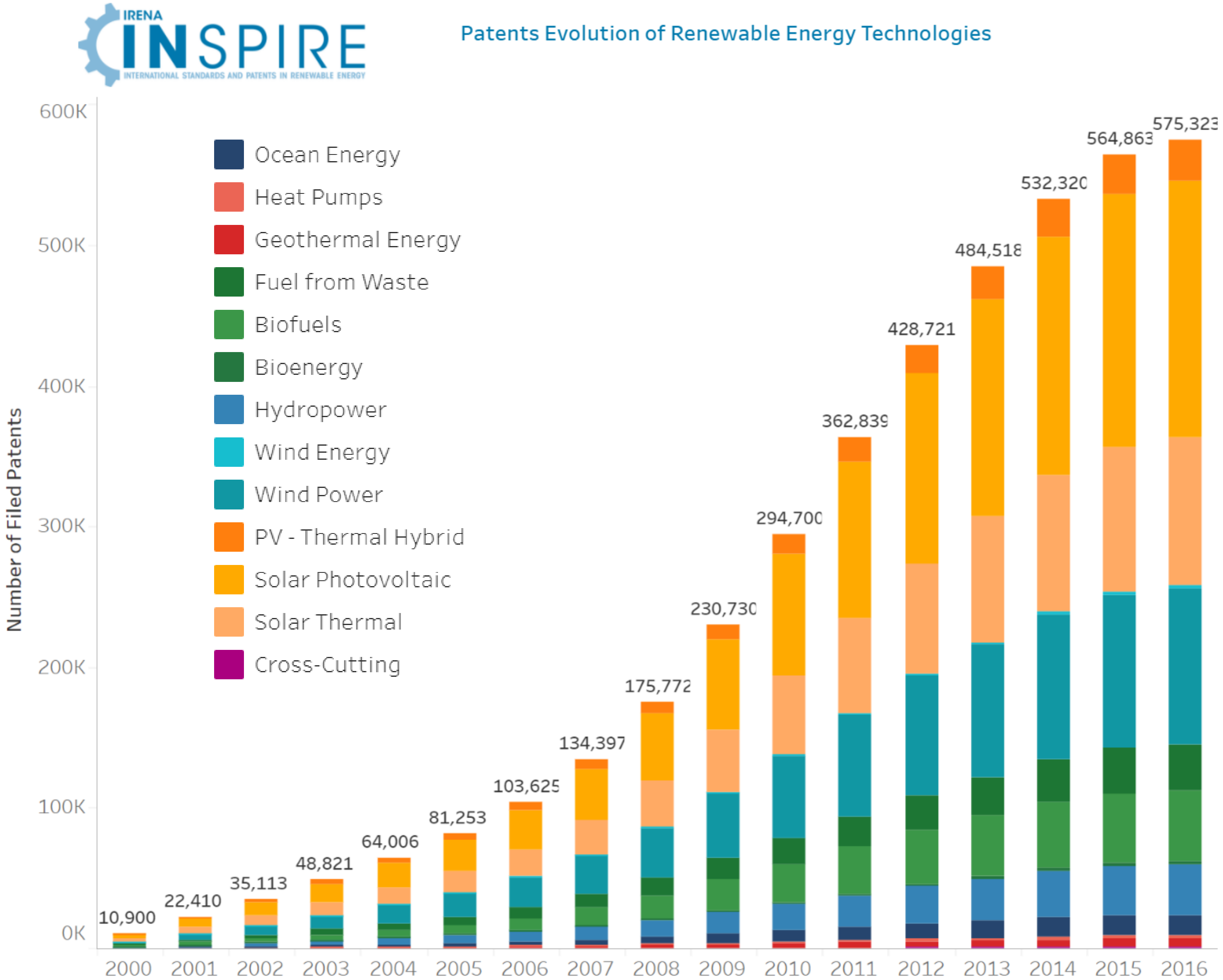
- There is an urgent need to increase R&D investment
- R&D for renewables is not currently growing
- Most R&D investments directed to the power sector - end-use sectors overlooked
- Monitoring mechanisms on R&D investments' impact are missing



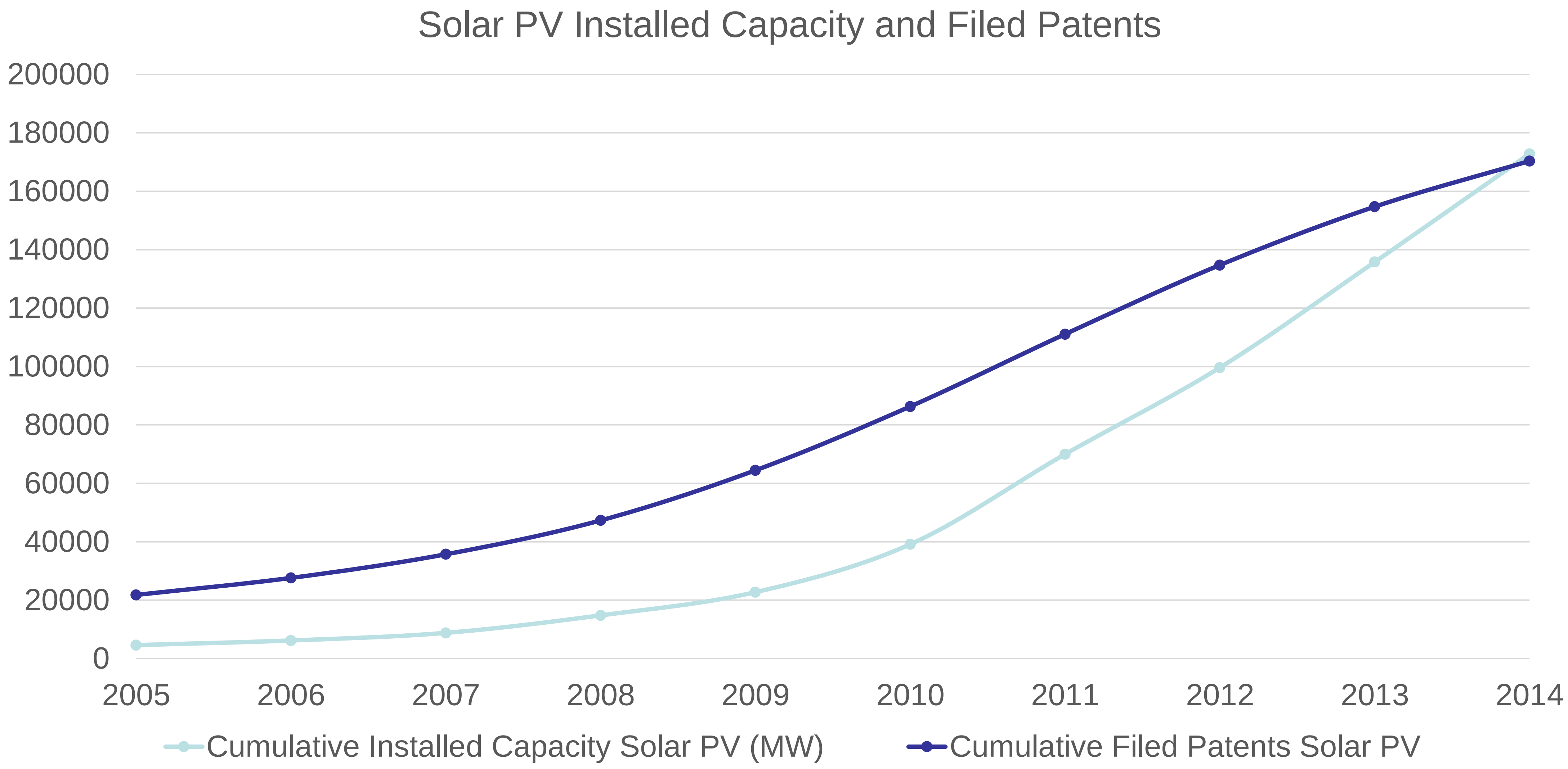
Patent Development in Renewables

- Close to **600 000** patents in RE today
- A compound annual growth rate of **17%**
- Solar, Wind and Bioenergy accounts for **90%** of the patents in renewable Energy
- Solar is the leading technology with **55%** of patents in 2016
- All the renewable energy technologies have **at least tripled** the quantity of patents in comparison to 2006



Source: inspire.irena.org

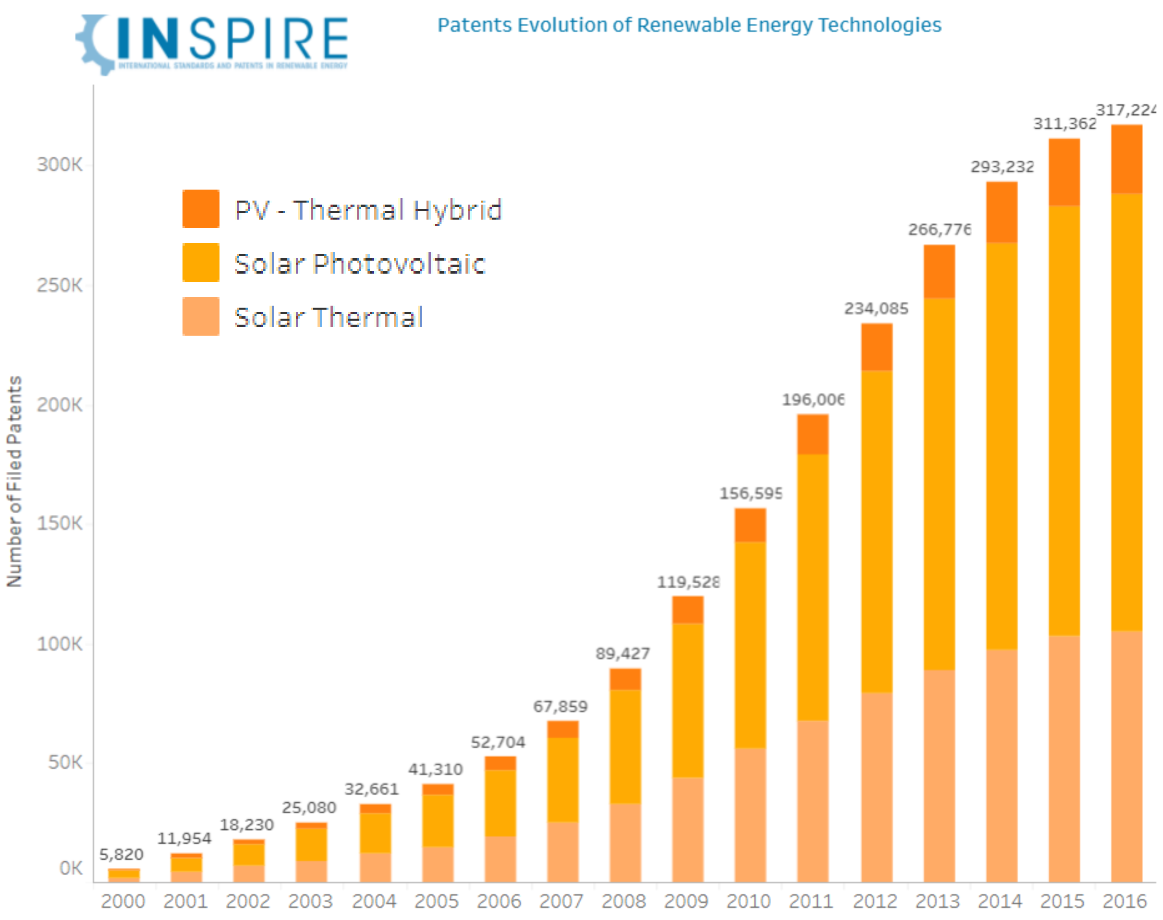
Correlation between Patent Activity and Deployment



Source: inspire.irena.org

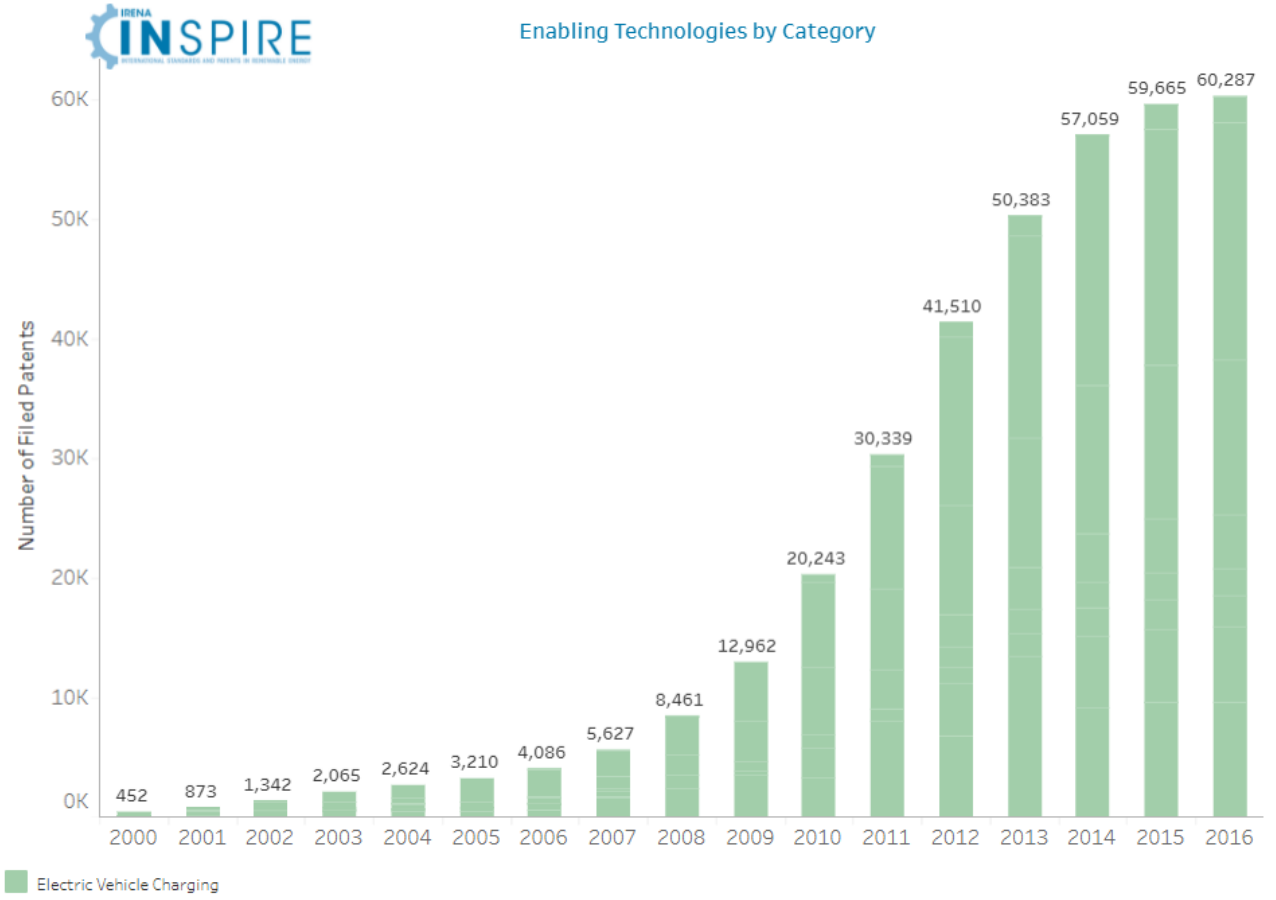
Innovation is now moving into enabling technologies

Patents in Renewable Energy



✓ 6 fold growth in the last ten years

Patents in Enabling Technologies



✓ EV charging has grown 16 times

Source: INSPIRE. IRENA. (2016)

Early stages - ocean energy technologies

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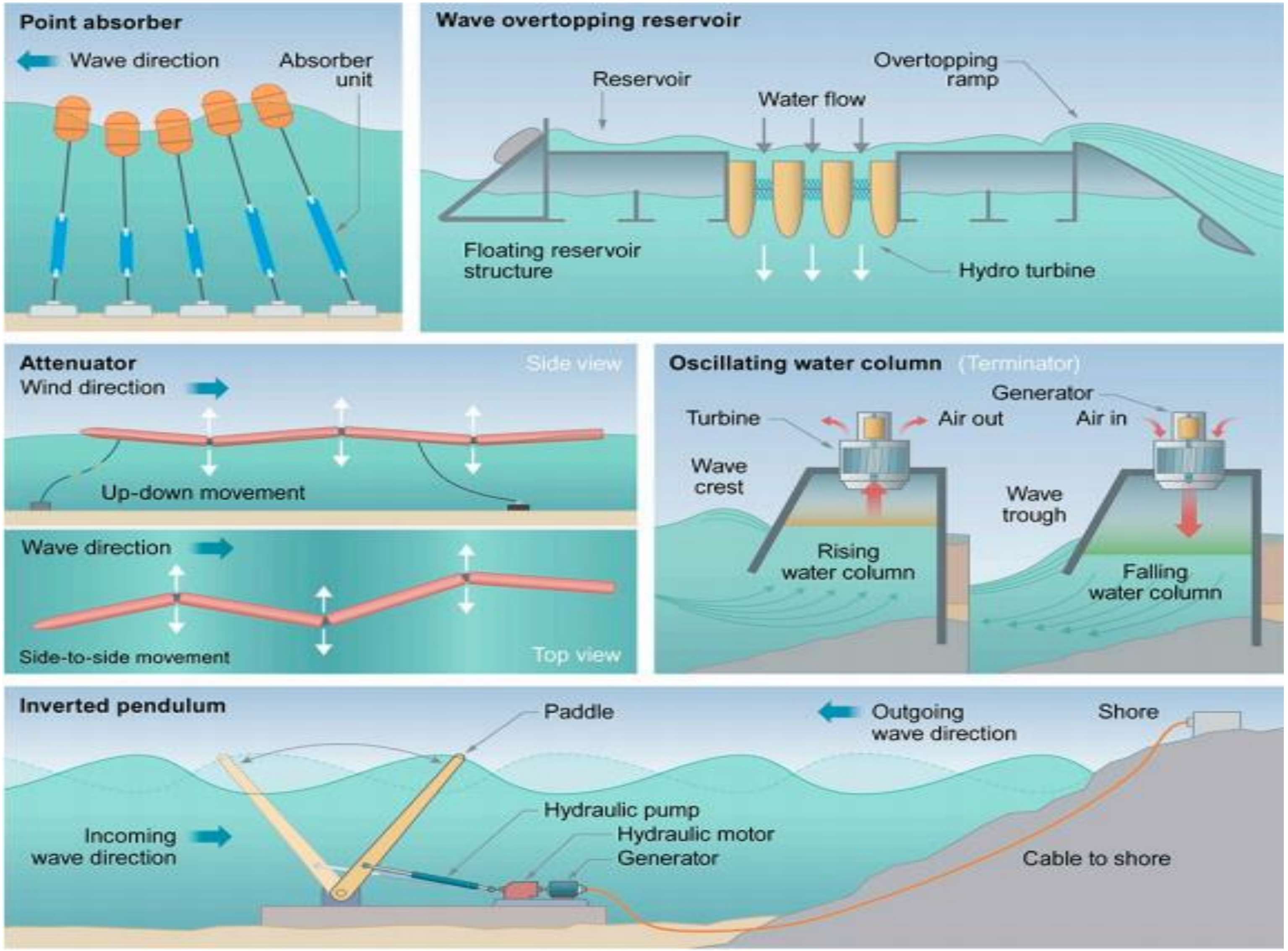

Capital cost [EUR/kW]

- 4,800 – 9,680

O&M Cost [EUR/kW/yr]

- 48 – 97

Availability [%]

- 75 – 85

LCOE [EUR/MWh]

- 330 – 630

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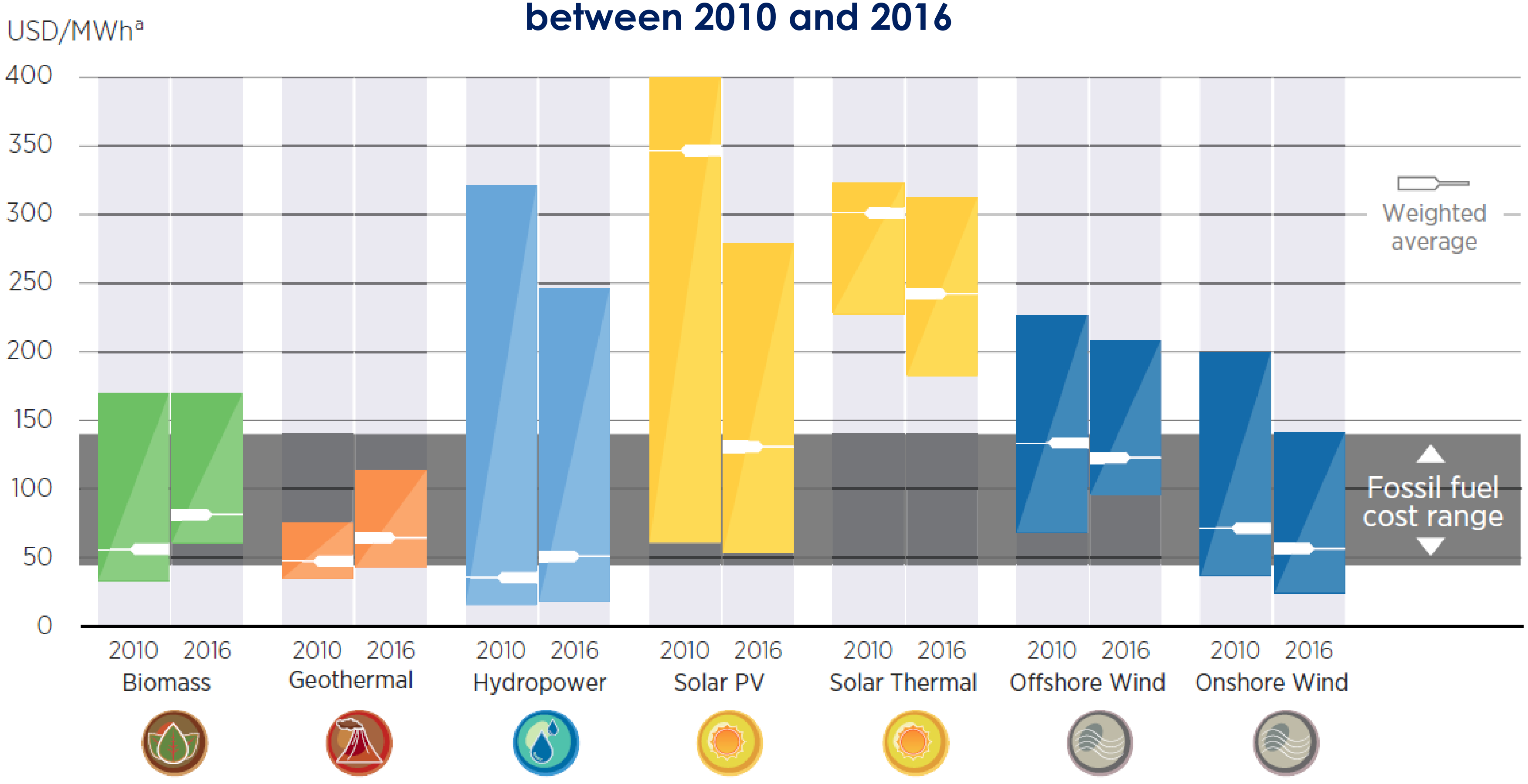

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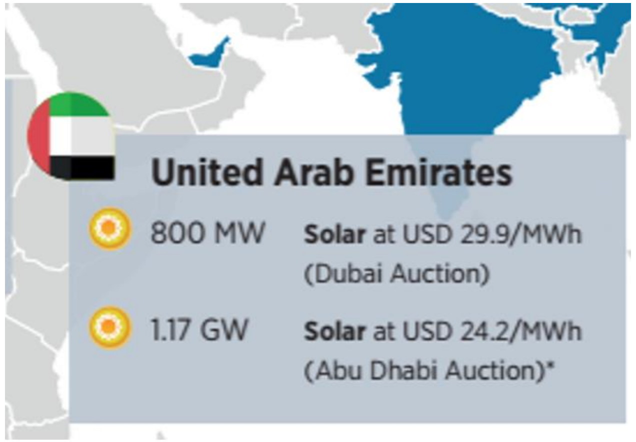

Saudi Arabia: 300 MW – USD 17.9/MWh

Source: IRENA (2017) Rethinking Energy

Rapid cost reduction – *PV: 80% reduction in the last 6 years*

4 Market formation and Commercialisation

Learning Curves – the case of PV

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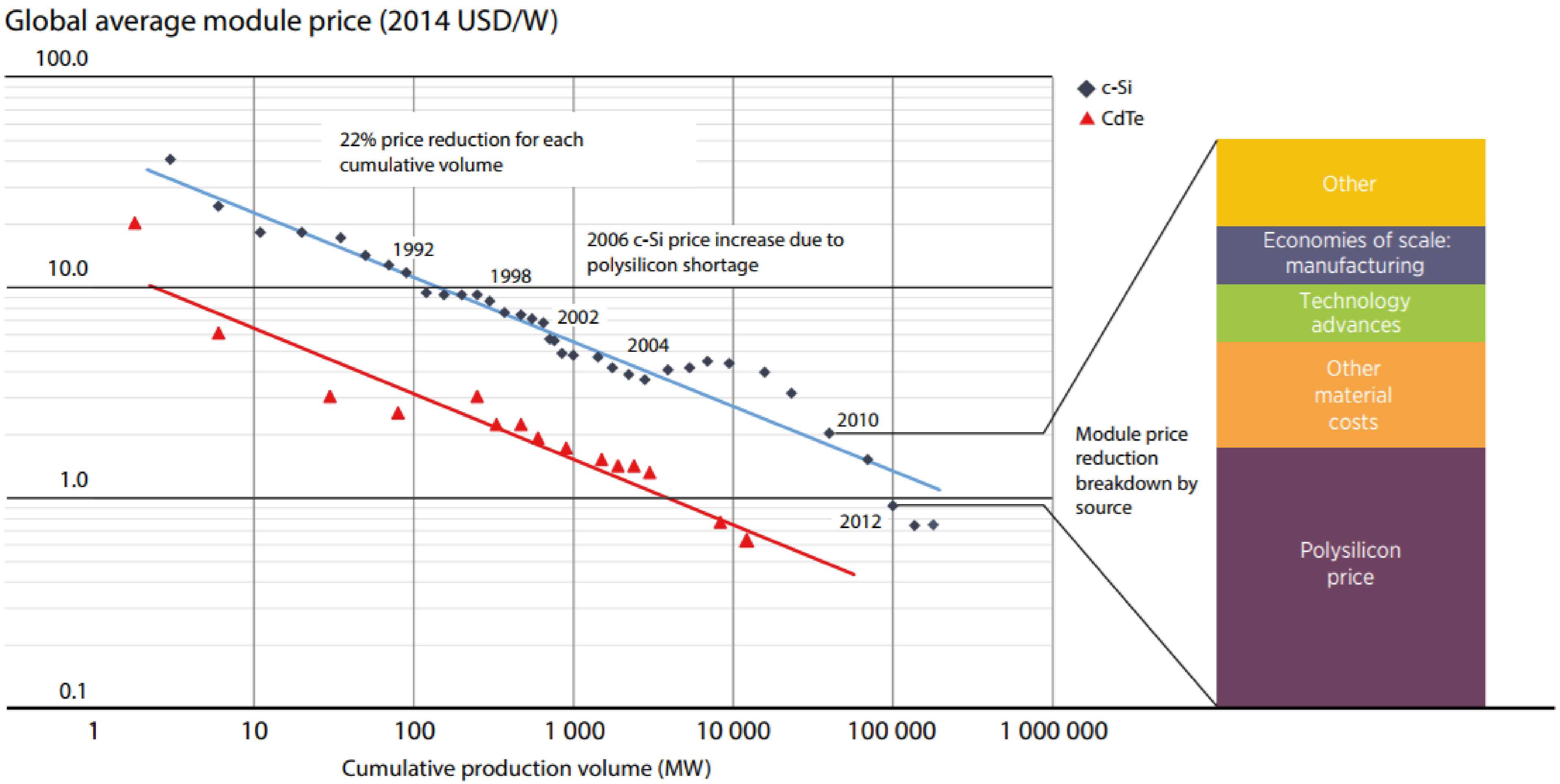
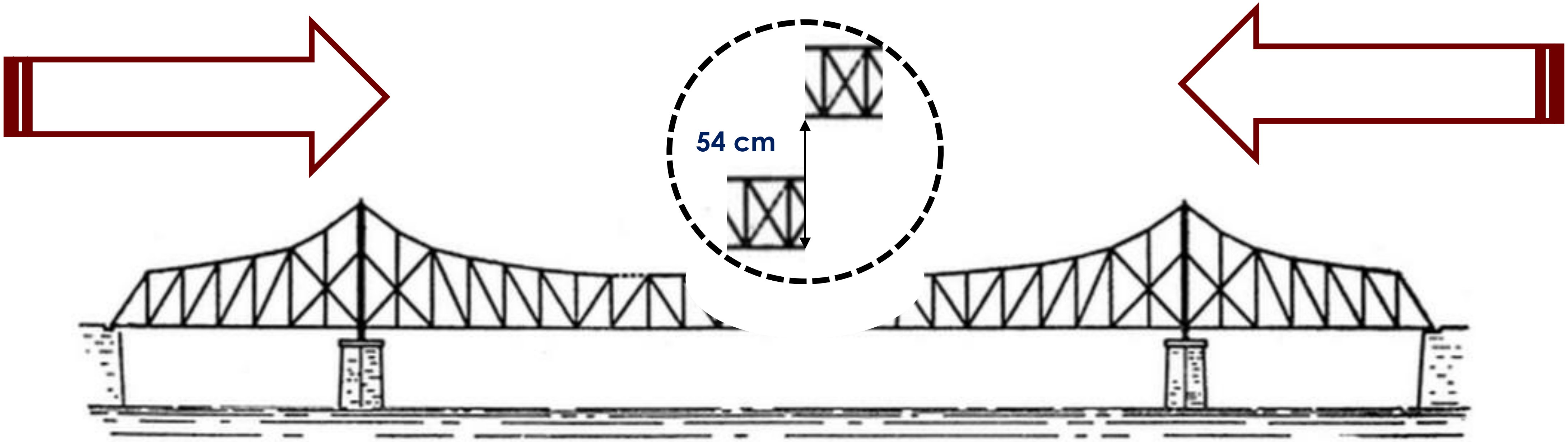


Market pull policies are needed – *who pays for the learning?*

Standards – harmonisation facilitating trading

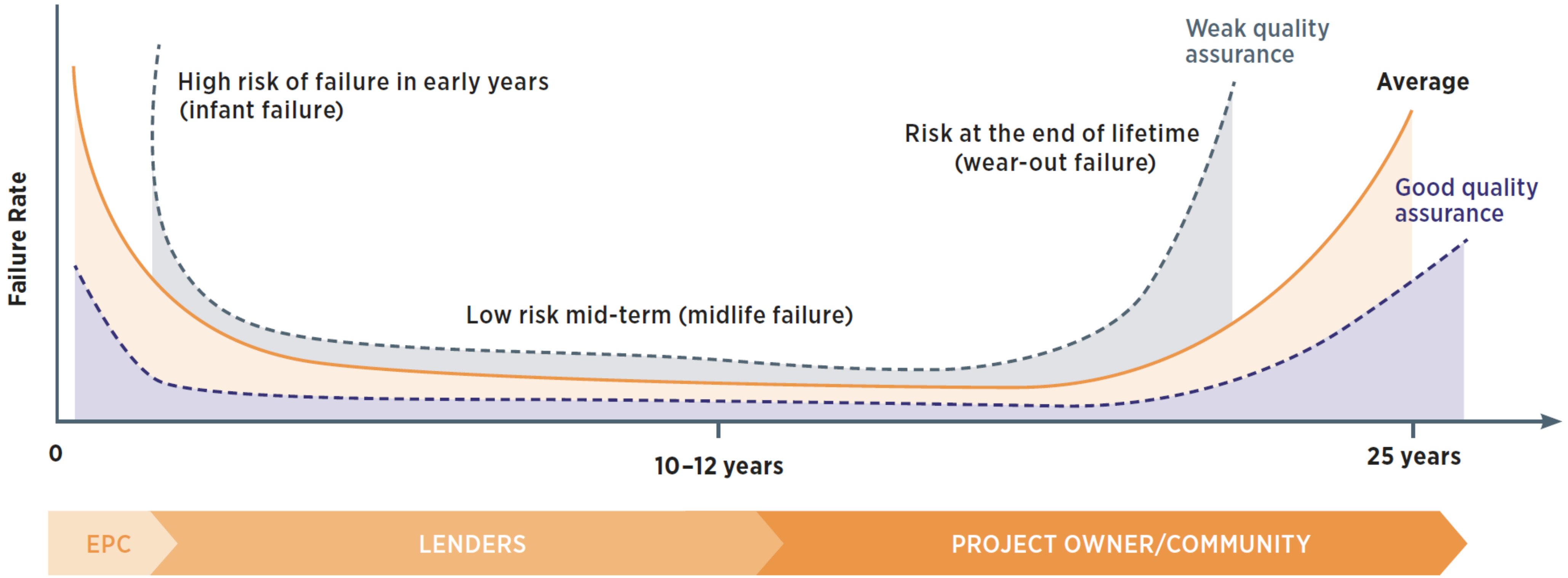


Laufenburg bridge between Germany and Switzerland

See level reference:

- Standard used by Germany – North see
- Standards used by Switzerland – Mediterranean see

The role of standards and quality control – risk mitigation



Lenders' perspective: revenues only important during first 10-15 years

- Risk of infant failures are passed to EPC
- Bankability assessments further minimize risks of midlife failure
    - ✓ Valid renown certifications
    - ✓ Track record of company and modules
    - ✓ Quality of manufacturing facility
    - ✓ Warranty conditions

Innovation Outlook: Advanced liquid biofuels

TECHNOLOGY DEVELOPMENT

- Hydrolysis fermentation reached commercialisation (DuPont, Beta Renewables)
- Gasification route ready for commercialisation
- Pyrolysis and hydrothermal routes require more development.
- Economics – challenging in a low oil-price context

SUPPORT TO MARKET FORMATION

- Support to commercial-scale demonstration plants is crucial
- Bio-refineries – business models including co-products
- Policy incentives, targets or mandates
- Internalisation of carbon cost is essential
- Public procurement
- Niche markets (expectations on aviation and shipping) to create critical mass

SUPPORT ENTERPRISE FORMATION

- Support start-ups
- Sharing successful business models
- Harness potential socio-economic benefits -

DuPont Lignocellulosic Ethanol plant in Nevada
(Source: www.dupont.com)

Innovation Outlook: Offshore wind

TECHNOLOGY DEVELOPMENT

- The most significant innovations will be next-generation turbines with larger rotors and advances in electrical transmission under-sea
- Other non-technology innovations — risk mitigation and business models to reduced the WACC
- A potential game changer are floating foundations (several prototypes tested in Japan, Portugal, North sea)

IMPACT OF INNOVATION

- Offshore wind going into waters deeper than 50 m
- Expand its geographic range and reduce costs by more than half over the next three decades
- Decrease in the global average LCOE from USD 170/MWh in 2015, to USD 95/MWh by 2030 and USD 74/MWh by 2045
- Growth in installed capacity from close to 13 GW in 2015 to 100 GW by 2030 and 400 GW by 2045

Hywind Floating Wind Farm – Oct 2017
(Source: Statoil)

Expected reduction in LCOE for Offshore Wind

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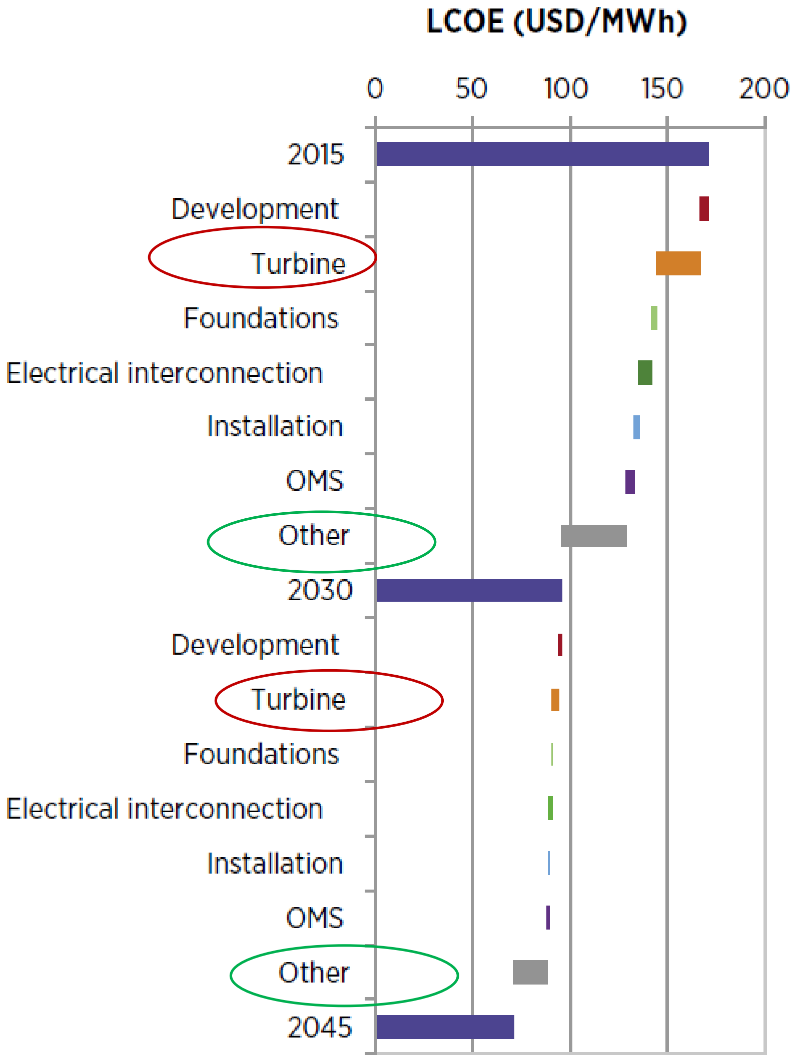
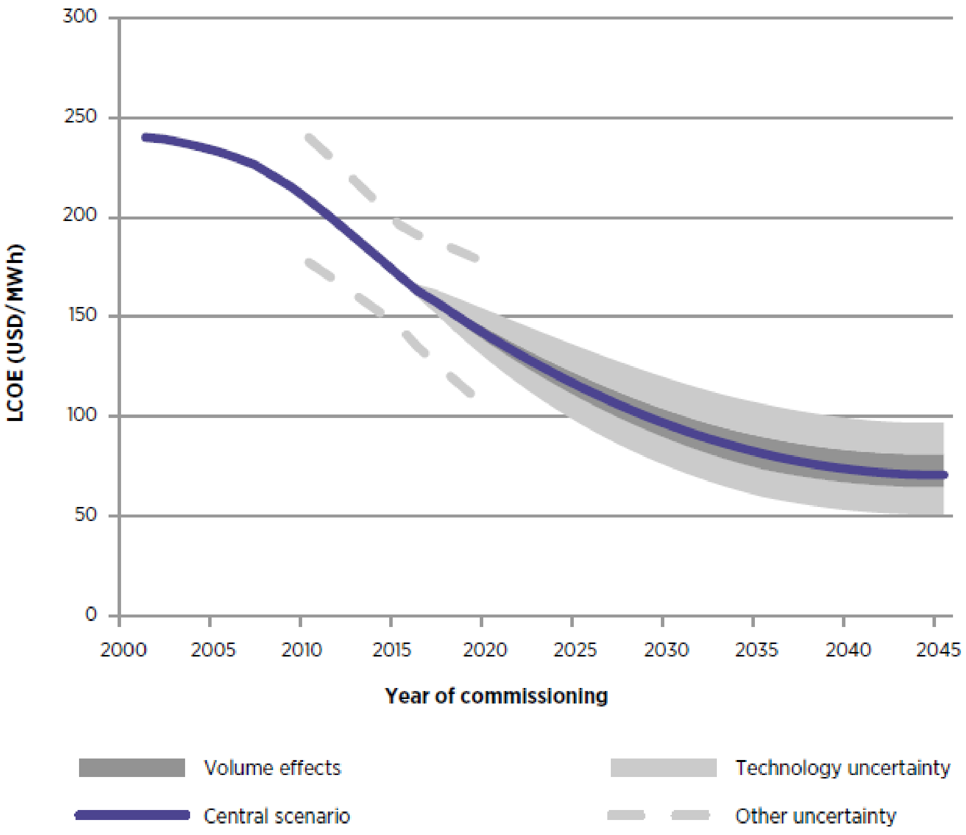
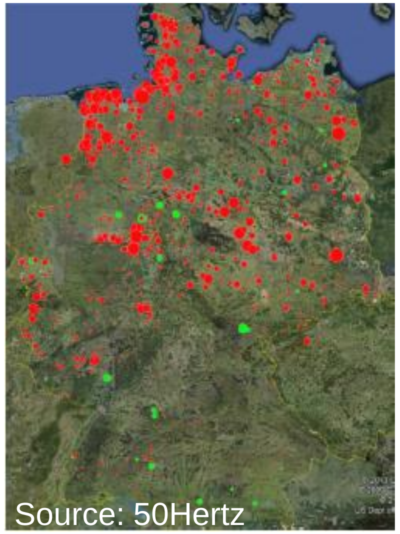


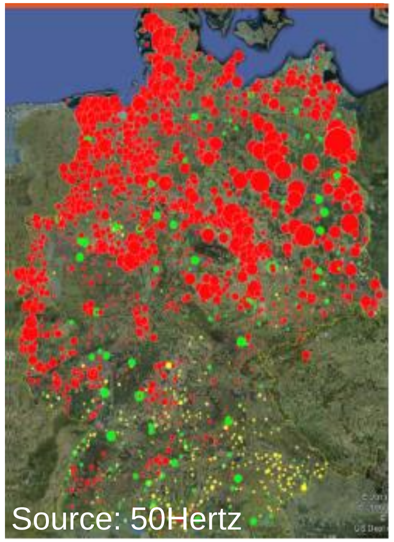


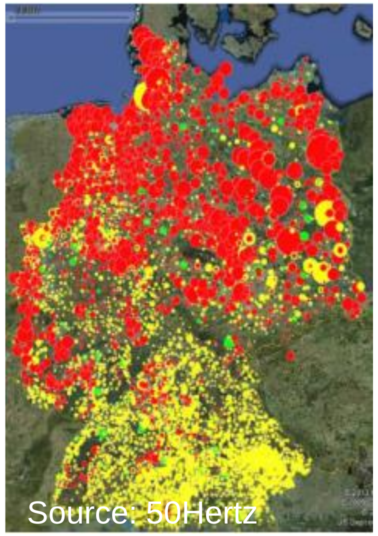
- 2030: **105 – 145** USD/MWh
- 2045: **70 – 120** USD/MWh

4 Power Sector Transformation

Example in Germany







around 30.000 plants | around 220.000 plants | around 1.500.000 plants

2000 | 2006 | 2014

Wind | Photovoltaics | Biomass

Source: 50Hertz

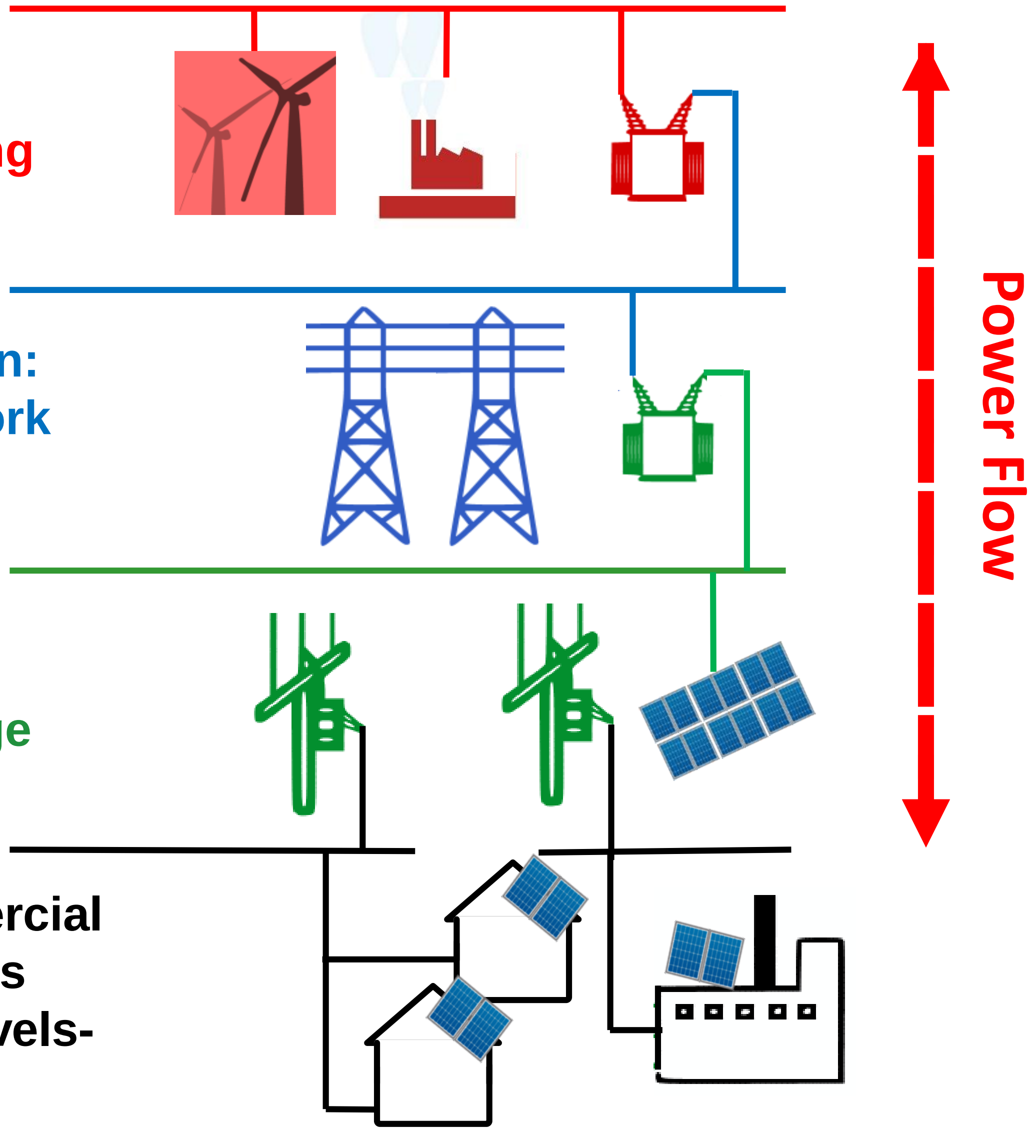
The transformation of the power system

Centralised Power Generation including large scale VRE

Power Transmission: High Voltage Network – Long distance transport of large blocks of power

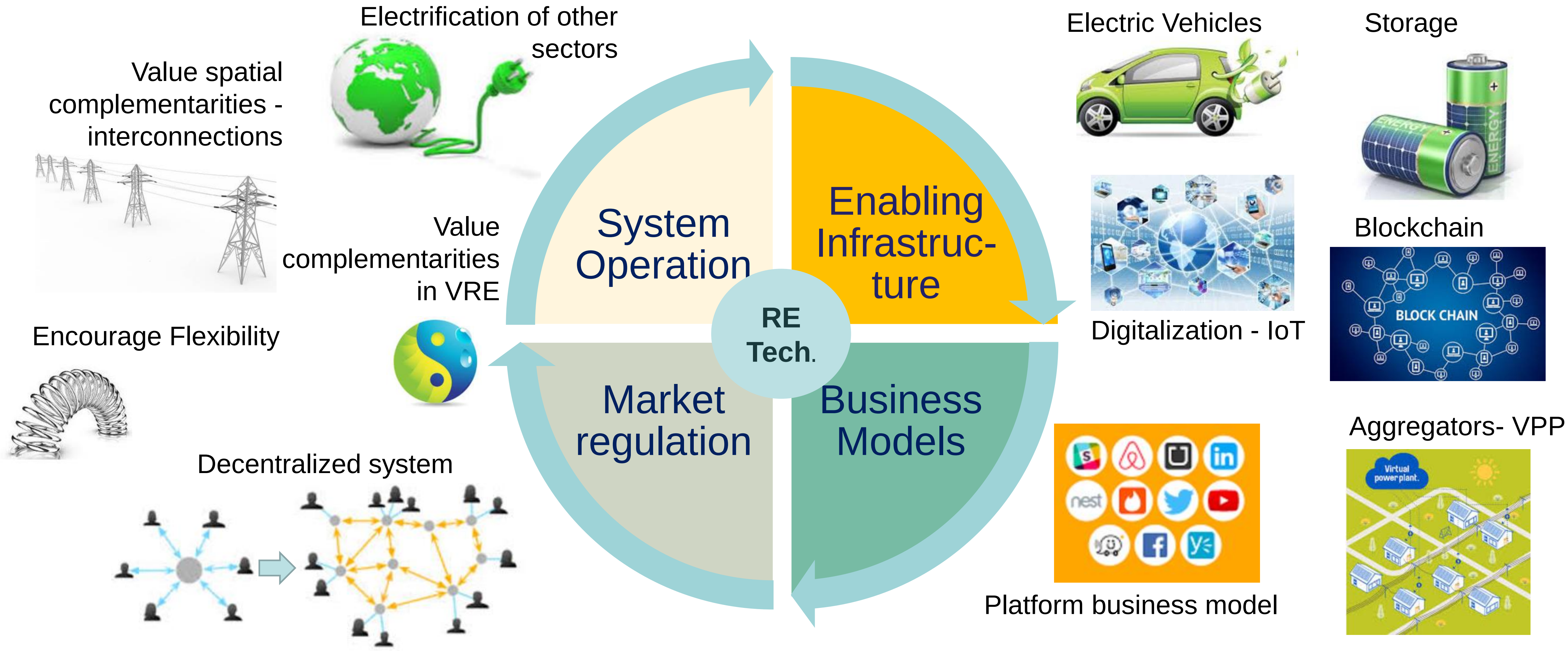
Power Distribution Medium/Low Voltage power delivery including VRE

Residential, commercial industrial customers
Different voltage levels-
Distributed VRE



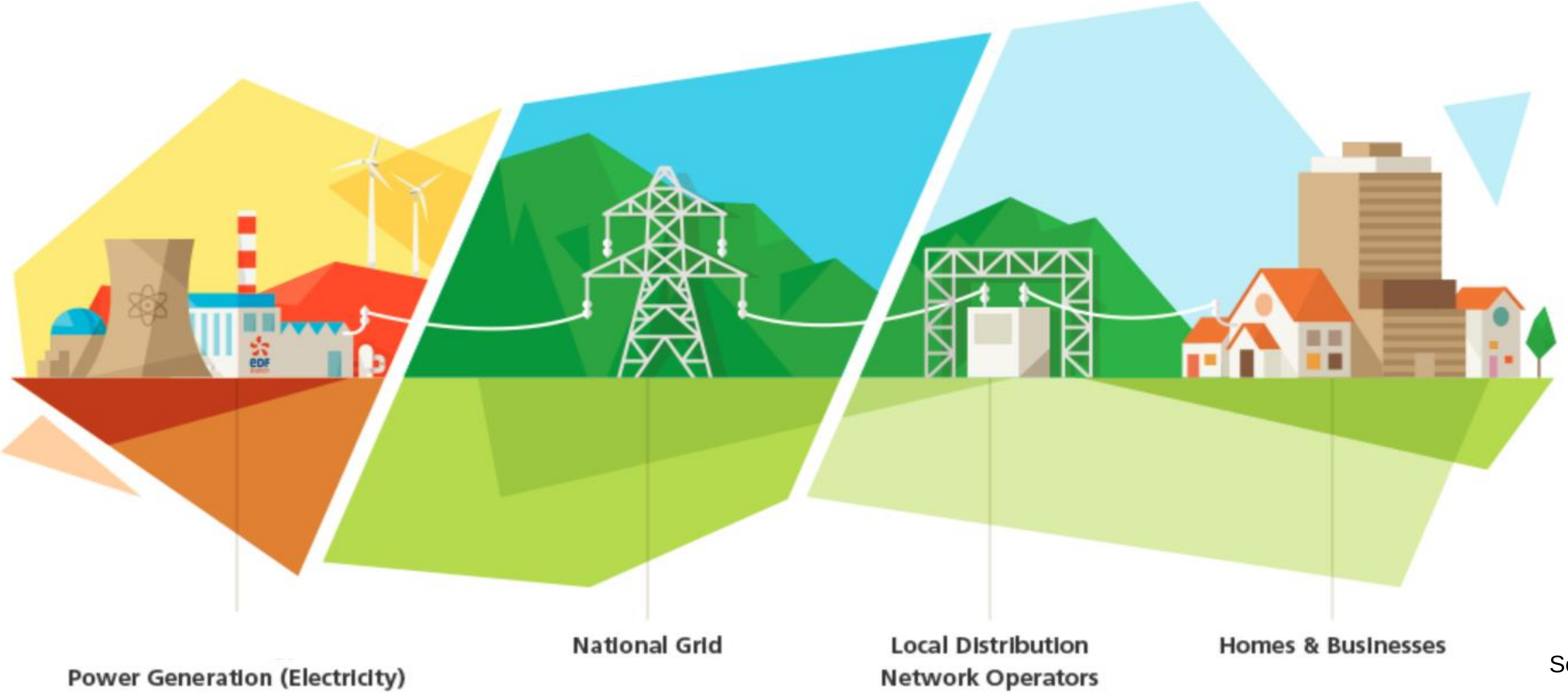
Vision for the Power Sector Transformation

Report on Systemic Innovation for the Renewable Power Sector



Technology Innovation: BATTERY STORAGE

From electricity to a commodity, as any other



Source: EDP

Storage provides more stability and flexibility to the system

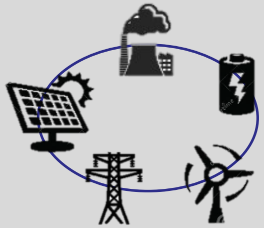
Energy Storage System Services

Small scale storage

Behind the meter

- Residential / commercial self supply
- Peak shaving
- Synergies with the PV on the roof

Decentralized generation – mini grids



- Grid upgrade deferral
- Remote areas access (off-grid)

Large scale storage

>> Support Variable RE Integration

- Avoid RE curtailment
- Energy arbitrage (time shifting)
- Connect next to a wind farm to provide controllable generation to the grid

Key factors to enable deployment

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- **Decrease costs**
- **Increase familiarity** with storage technology among utilities, regulators and financiers
- **Capacity building** to address the need for highly skilled and experienced technicians to maintain and operate systems correctly
- **Regulations** allowing storage to be **remunerated** for all the services they can provide
- Clear **regulations** regarding the **ownership** model of the large storage battery system

Batteries on wheals: ELECTRIC VEHICLES

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There is a potential to increase electric passenger cars from 1.25 million in 2015 to160 million in 2030 (REMap 2030).
This total would represent 10% of the total passenger cars fleet

The potential for electric two and three wheelers is also significant. In 2016 there were 200 million, and by 2030 their number could reach 900 million.

Electric buses have the potential to electrify the public transportation. 300 000 electric buses are in service around the world, mostly in China

(IEA,2016)

Coupling between transport and RE power sectors

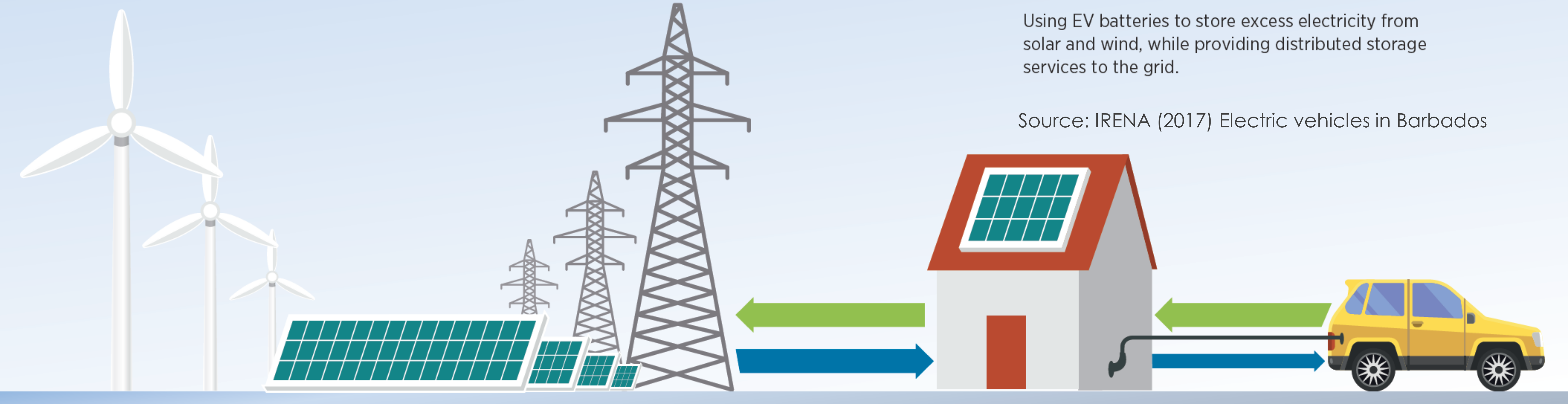
Decarbonisation:

- EVs require a clean energy supply source
- Variable renewable power integration require system flexibility

Vehicle-to-grid:

Using EV batteries to store excess electricity from solar and wind, while providing distributed storage services to the grid.

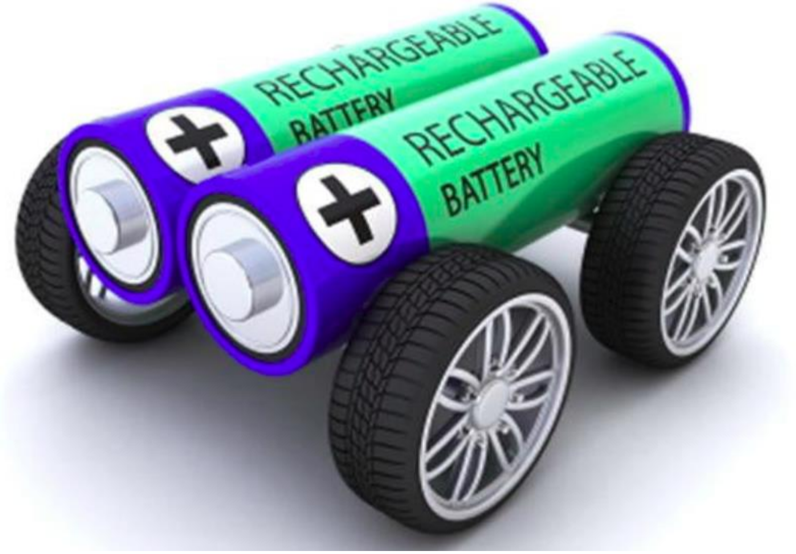
Source: IRENA (2017) Electric vehicles in Barbados



Coupling between transport and RE power sectors

How everybody sees Electric Vehicles?

How power sector sees Electric Vehicles?



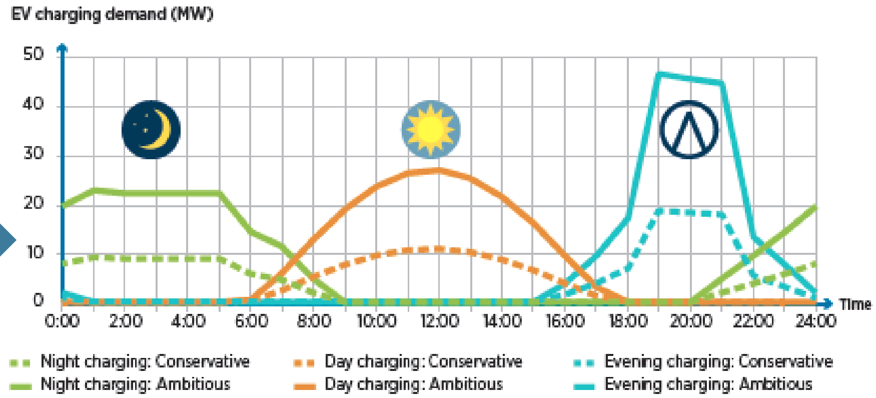
EVs as enabler for integration of VRE…

….a smart charging approach is critical

Load management

Charge the EV when wind or sun energy available, when demand is low.

Understand customer behaviour and create awareness of the possibilities to use load management



EVENING PEAK

- EVs charged at home as people return from work
- Likely charging pattern with no policy intervention
- Reduces system reliability by adding to existing evening peak demand
- Should be discouraged with time of use pricing and availability of public charging stations

NIGHTTIME

- Requires pricing signals and smart grid technologies to delay / prolong charging away from evening peak
- Better option for home charging
- Opportunity for vehicle-to-grid in the future, with EVs providing remunerated services to the grid

DAYTIME

- Maximizes RE share in EV charging: 58-76%
- Significantly reduces RE curtailment from 14.5% to 9.3%
- Supports deployment of additional 12 MW of PV
- Requires investment in public charging infrastructure

EV as decentralised storage

- Grid-connected battery electric vehicles can provide additional flexibility to the power system by suppling power back to the grid (V2G).

EVs & Smart charging – Policies to stimulate EV demand and support charging infrastructure

Country	Targets	EV purchase incentives	Infrastructure support
China	7 million electric cars on the roads annually by 2025; 200 000 Electric buses by 2020 and around 4000 charging stations	Subsidies to manufacturers	Incentives to city governments to build charging
Japan	EV market share reaches 50% in total vehicle sales by 2020	Subsidy based on price difference between an EV and a comparable gasoline car (with max 7800 USD)	Government invested in charging infrastructure, public-private partnership with car retailers
US	State level targets	Tax credits; purchase incentives at states level	Utilities invested in infrastructure
UK	1.7 million EV by 2020	Premium based on purchasing price for vehicles emitting less than 75 g/km	~44 Mil Euro allocated to charging infrastructure; financing up to 75% EV home chargers
Netherlands	phase out all petroleum based cars by 2025	Exemption from registration tax	Tax incentives
Norway	phase out all petroleum based cars by 2025	Exemption from purchase tax, VAT, toll road charges, registration tax and annual circulation tax	1.200 EUR subsidy for every EV charging station in Oslo
France	2 million EV by 2020	Purchase incentives (6300 Euro for EV) and supplementary bonus (10 000 Euro) for scrapping diesel vehicles	50 Mil Euro allocated to cover 50% of the costs; all newly built residential buildings and workspaces include EV charging points
India	produce and sell only EV by 2030	Long term scheme (FAME- India)	Pilot project of solar charging points

The new CONSUMER

The increasing role of consumer

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The new consumer is also producing, storing, trading energy and managing own load

Distributed generation

Behind the meter storage

Electric vehicles

Smart meters

Digitalisation - Internet of things

Artificial intelligence

IoT and Artificial Intelligence will support the consumer's participation in the energy market

New technologies empower the consumer

IoT and smart houses and Artificial Intelligence

- Thermostats, lighting and energy monitoring and controls are increasingly enabled with smart devices that connect with the Internet and can be controlled remotely by smart phones. Adding communication capabilities and remote controls to existing sensors and diagnostics can turn them into an energy management system.
- Artificial intelligence identifies patterns and controls the load, the same way humans would do

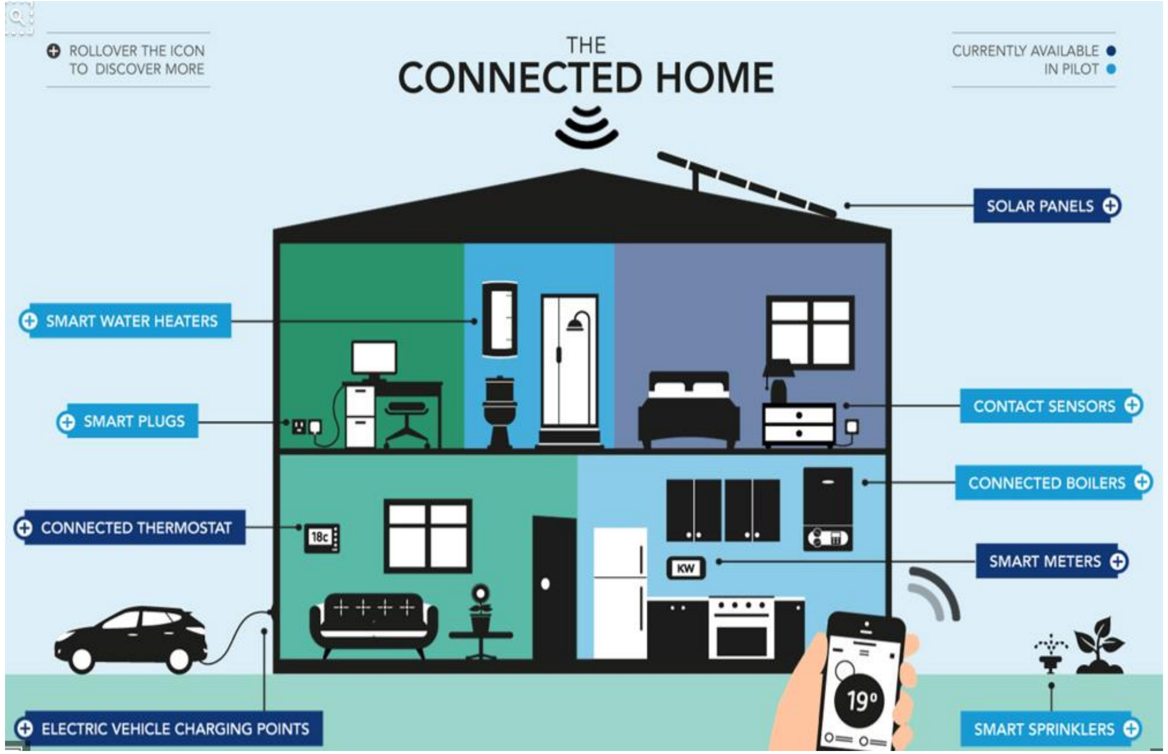


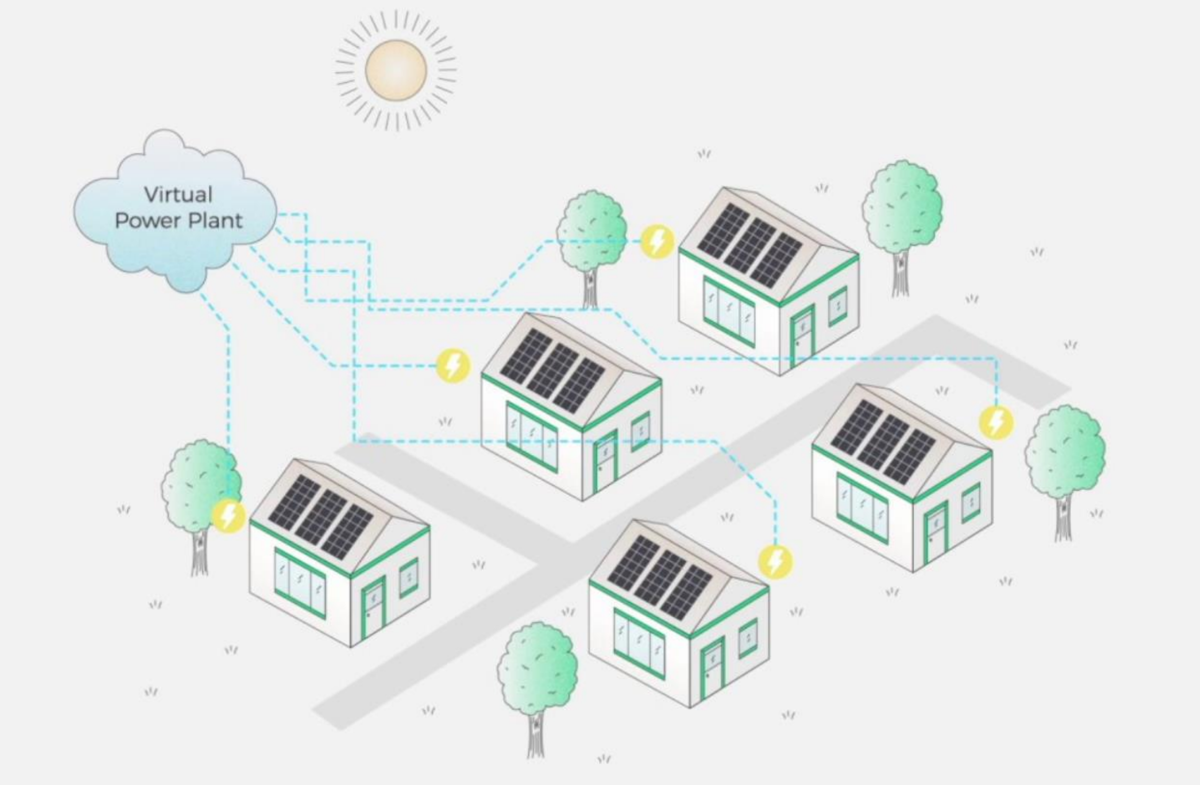
Photo source: https://www.centrica.com/

IoT and AI enable demand side management, decreasing consumers' costs by improving energy efficiency and preventing energy waste

New business models empower the consumer

RE aggregator: Virtual Power Plant (VPP)

- VPPs supports distributed RE sources to leverage on the synergies between them and maximize their remuneration
- Virtual power plants allow coordinating previously uncoordinated renewable generation sources. It can provide the much needed flexibility in the system



Aggregators enable distributed technologies (RE plants, storage) to participate in the energy market

Examples: Next Kraftwerke (Germany, Belgium), CrowdNett project (Eneco Netherlands)

New business models empower the consumer

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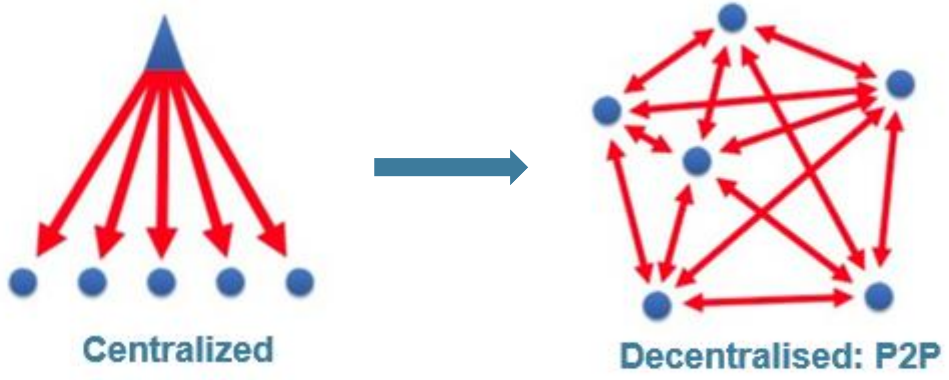
International Renewable Energy Agency

Peer to peer trading

- Also known as Uber or Airbnb of energy, the platform allows local generators of distributed energy to sell their excess energy at the desired price.
- With increasing number of smart devices, digitalization and increasing distributed generation, platform based models should see a huge potential in terms of market size and demand in the near future.



Platform based model promote Peer to Peer trading, offering a market place for distributed generation

Examples: PowerPeers (Vattenfall in Netherlands), Solar Coin, E.On Cloud Storage

Some take aways

There are many innovations supporting the energy transition towards 100% RE

Storing electricity will unlock many opportunities, integrating more RE in the grid, decarbonizing transport sector etc

Consumers’ role is increasing: their behaviour is key!

4 INSPIRE

Big question

How to measure or track innovation?

How to measure or track innovation?

R&D Investments, budget

R&D Initiatives

Start ups

Think tanks

Number of projects in the innovation pipeline

Intellectual Property: Patent Activities

Venture Capital

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INTERNATIONAL STANDARDS AND PATENTS IN RENEWABLE ENERGY

Which are the latest trends in RE development?

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Information on standards development and project application

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Networking and more

Get in contact with developers and find reports on the topics

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News and Events

Extending the Frontier of PV Reliability IRENA at the World Future Energy

Quality Infrastructure: Develop, Control, Cost and Benefit

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Solar PV

Roof systems for PV cells (Y02B 10/12)

PV hubs (Y02B 10/14)

Photovoltaic [PV] energy (Y02E 10/50)

PV systems with concentrators (Y02E 10/52)

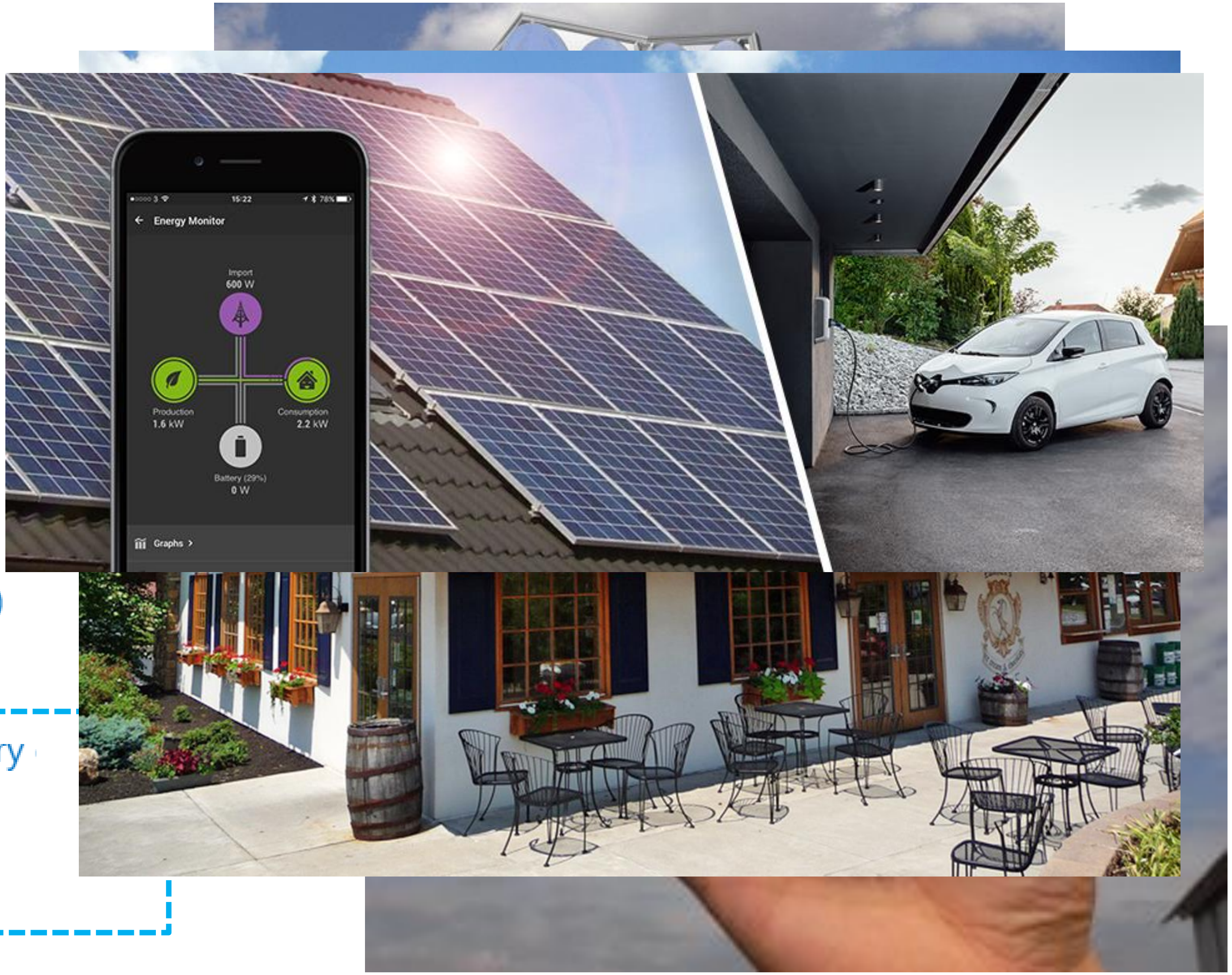
Material technologies (not used; see subgroups) (Y02E

organic PV cells (Y02E 10/549)

Power conversion electric or electronic aspects (Y02E 10/56)

for grid-connected applications (Y02E 10/563)

concerning power management inside the plant , e.g. battery charging/discharging, economical operation, hybridisation with other energy sources (Y02E 10/566)



Reference: IEEE Spectrum, Pubscienc, SRS Energy's Solé Power Tiles, Loxone

Innovative developments - HOT Innovation areas at the moment

Wind

Wind power (Y02B 10/30)

Wind energy (Y02E 10/70)

Wind turbines with rotation axis in wind direction (Y02E 10/72)

Blades or rotors (Y02E 10/721)

Components or gearbox (Y02E 10/722)

Control of turbines (Y02E 10/723)

Generator or configuration (Y02E 10/725)

Nacelles (Y02E 10/726)

Offshore towers (Y02E 10/727)

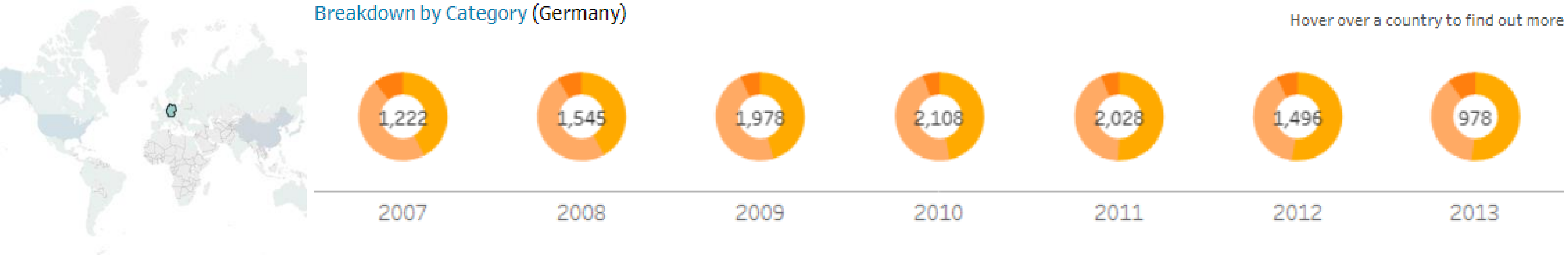
Onshore towers (Y02E 10/728)

Wind turbines with rotation axis perpendicular to the wind direction (Y02E 10/74)

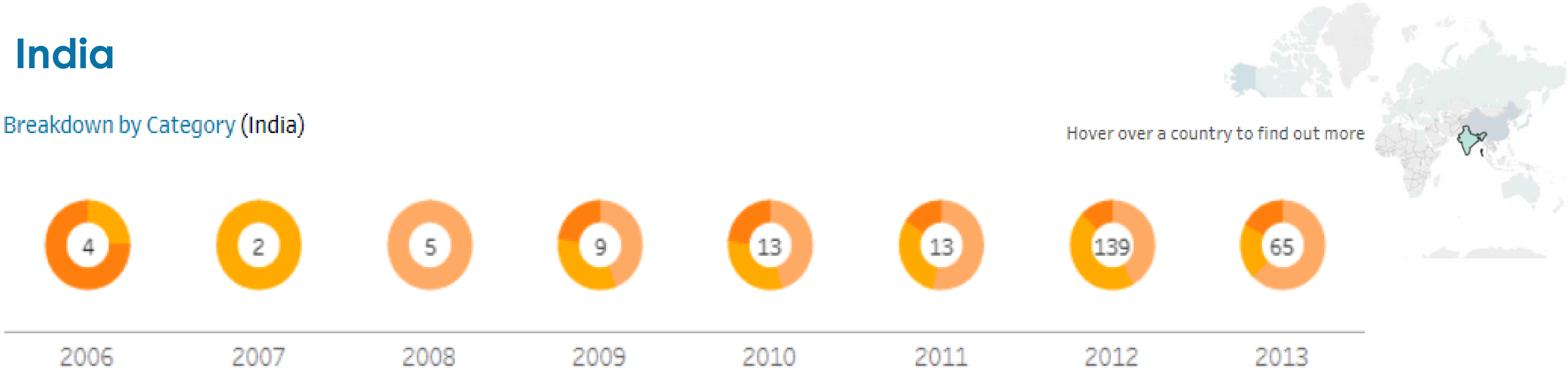
Reference: BAT-Buoyant Airborne Turbine, Atsushi Shimizu, Sandia Natiional Laboratories,Offshorewind.biz

RE Patent Progress in countries

Germany

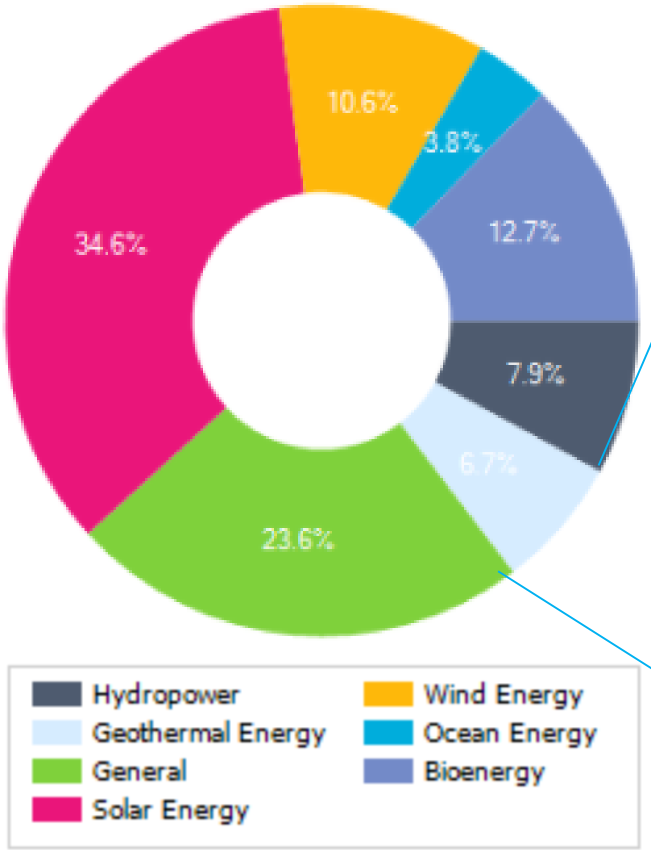


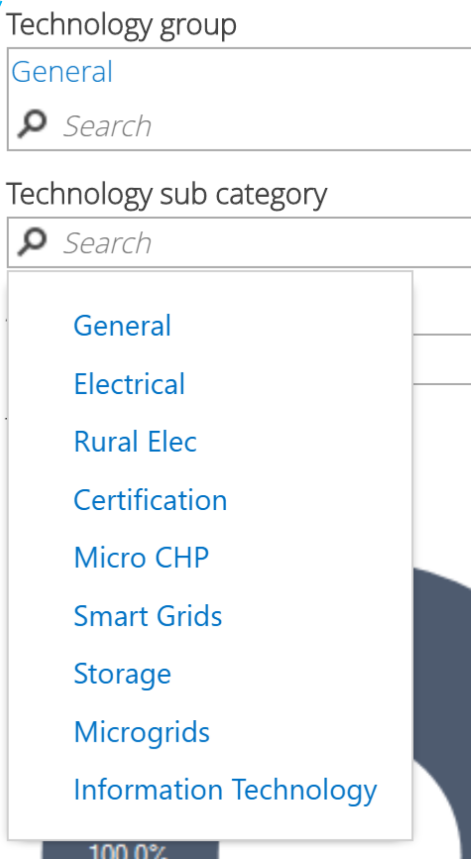
India



Standards follow the pace of Innovation

Technology





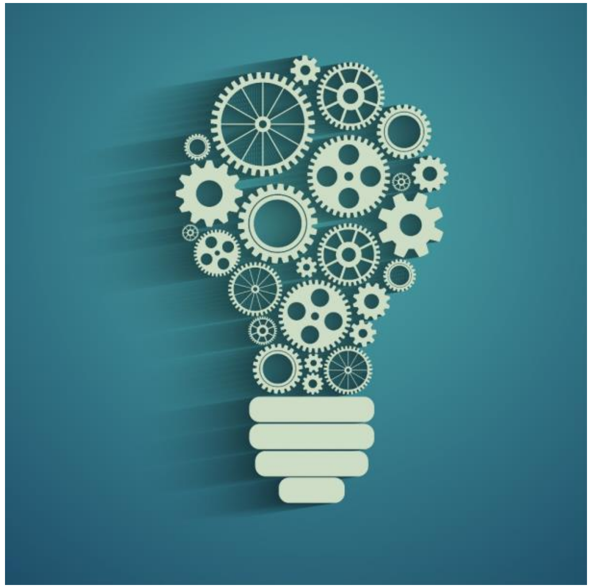
Around 400 RE Standards including close to 100 that enable RE deployment:

- JTC1-SC41-8 : Information technology - Internet of Things (IoT) - Interoperability for **Internet of Things Systems** – Part 2: Network connectivity
- IEC 62660-1 ed1.0 : Secondary lithium-ion cells for **the propulsion of electric road vehicles** - Part 1: Performance testing
- IEC TS 62257-4 ed2.0 : Recommendations for **small renewable energy and hybrid systems for rural electrification**. Part 4:System selection and design

Standards follow the pace of Innovation

Today there are technical committees of standards in: block chain, batteries for ER storage, artificial intelligence, ER integration in the network.

Others have as part of their focus: hydrogen, wind energy with floating structures, Marine Energy (OTEC)



Some take aways

1. Innovation in RE

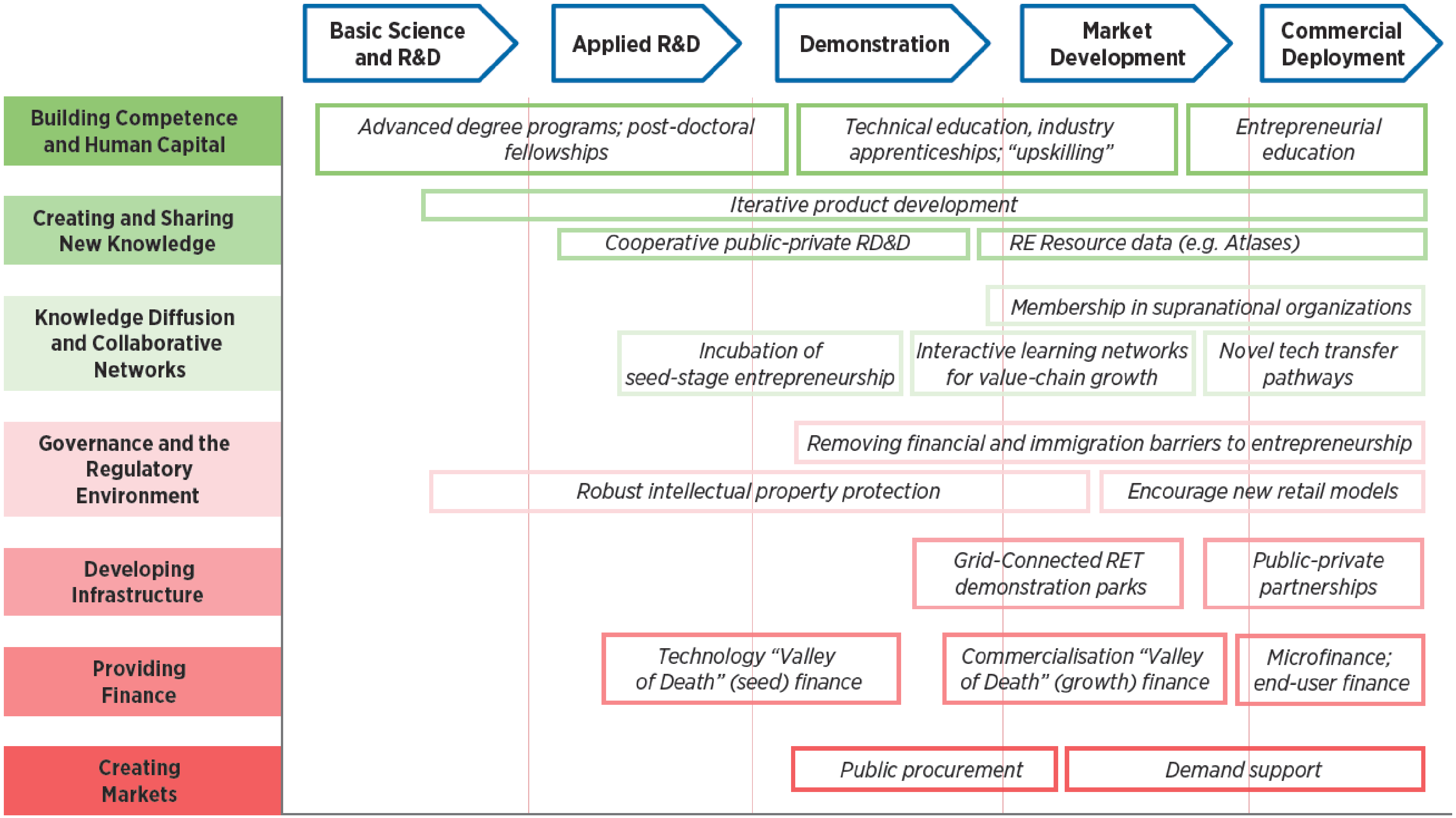
2. Want to know how the technology can perform as expected across its life use?

Use INSPIRE!

"I assume all this playing will lead to innovation."

5 Policy Messages

Innovation policy toolbox



Source: IRENA (2015) Renewable Energy Technology Innovation Policy: A process development guide

Strategy for accelerating the energy transformation

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Accelerating the Energy Trasition

1 Nurture Innovation
This is crucial for the decarbonisation of the energy sector

2 Pursue power system integration
Renewable power already has a strong business case, but materialising its potential requires additional efforts in innovation for systems integration

3 Decarbonise end-use sectors
This requires a combination of electrification, technology breakthroughs and sector-specific global agreements

4 Expand innovation beyond R&D
Innovation efforts encompass the complete technology lifecycle and all aspects or renewable energy integration. Governments play a key role in setting the right framework

Source: IRENA (2017) Accelerating the energy transition through innovation

We invite you to engage!

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INTERNATIONAL RENEWABLE ENERGY AGENCY (IRENA)

THANK YOU

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Back up

Bioenergy

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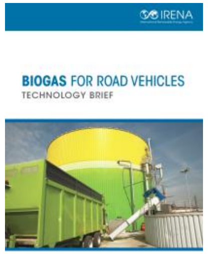

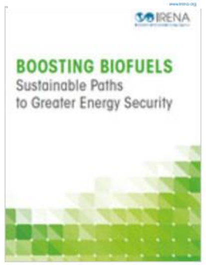

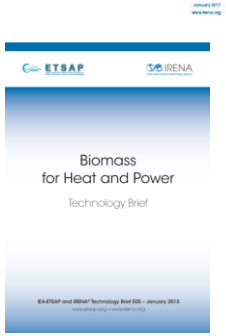

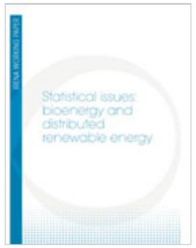

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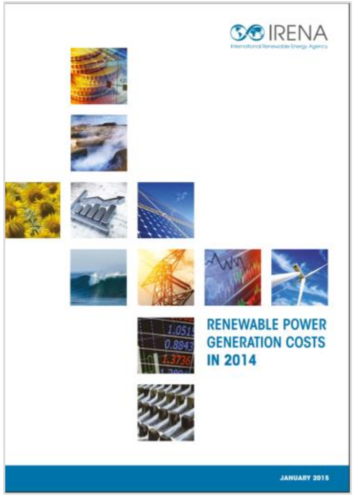

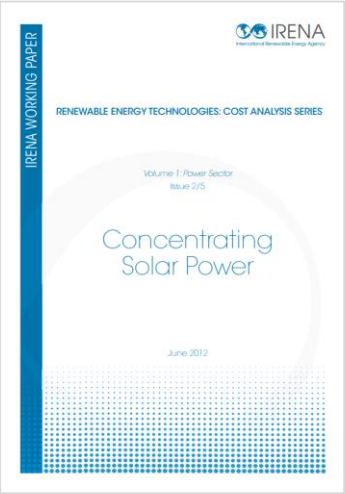

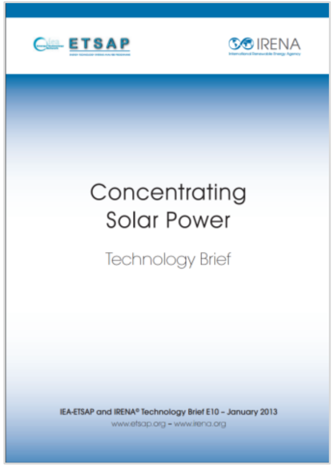

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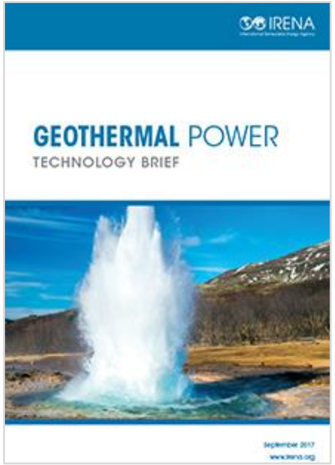

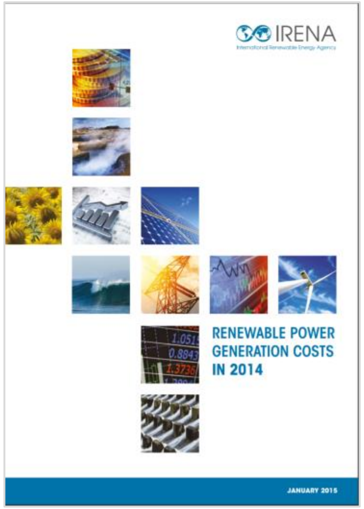

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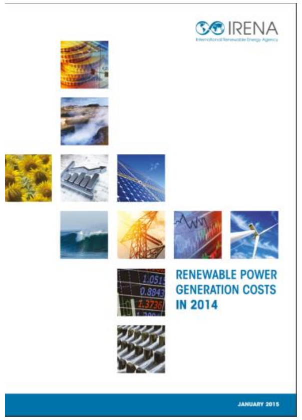

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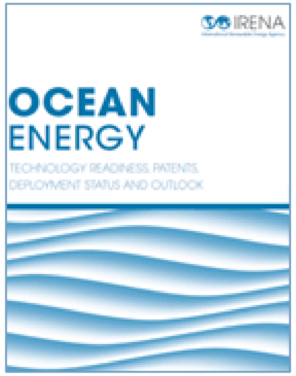

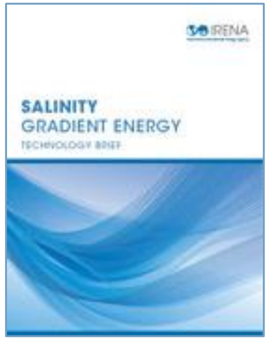

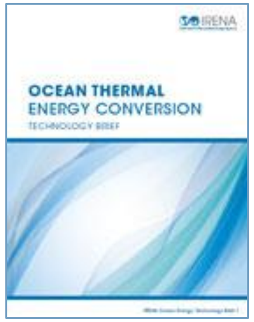

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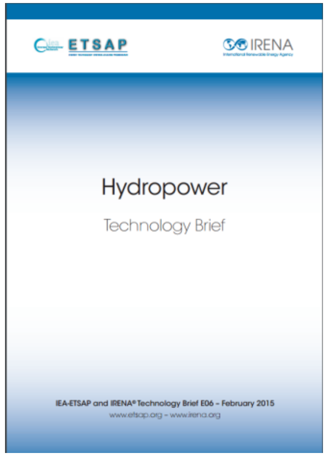

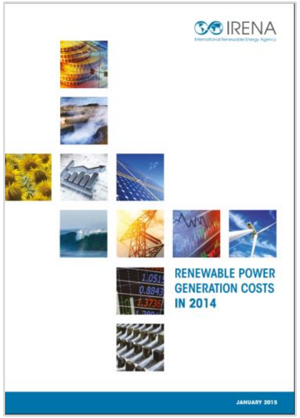

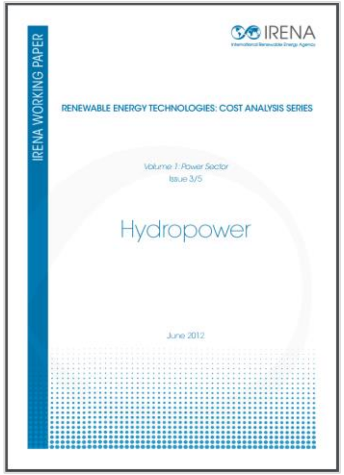

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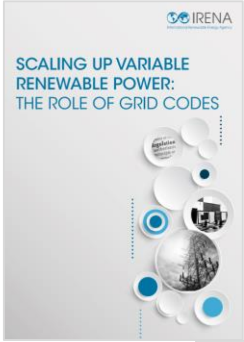

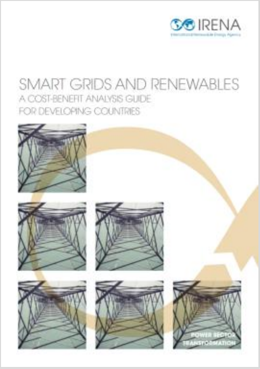

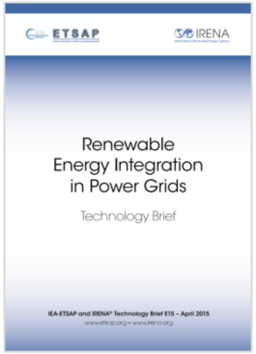

Next Innovation Stage for the Power Sector – System Integration

Systemic approach to Innovation for the Energy Transformation