Seminar on Energy and Climate Change

Renewables

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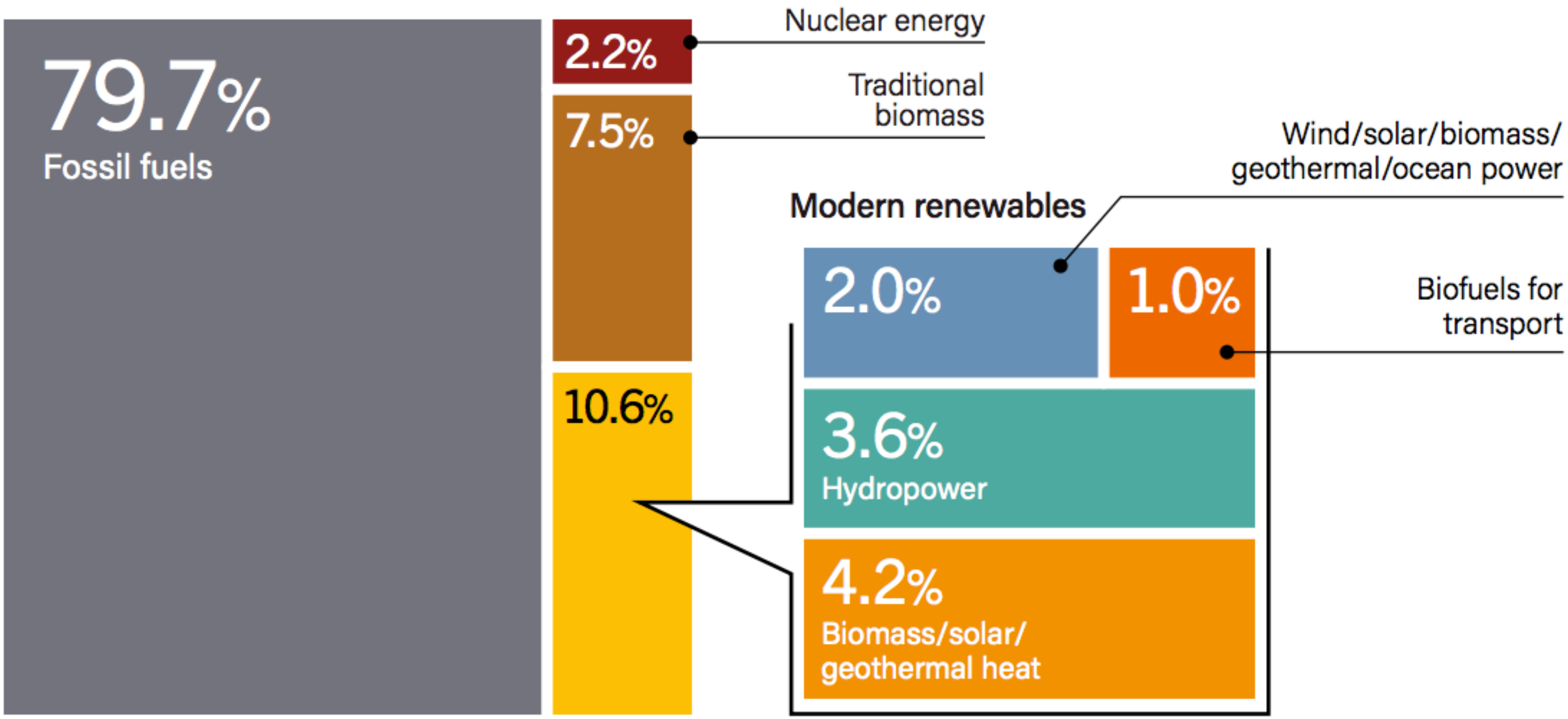
INNOVATIVE RENEWABLES

High altitude wind
Exemple #1: https://www.youtube.com/watch?v=vMTchVXedkk

Renewables represent a very small share of the world energy system

FIGURE 1. Estimated Renewable Share of Total Final Energy Consumption, 2017



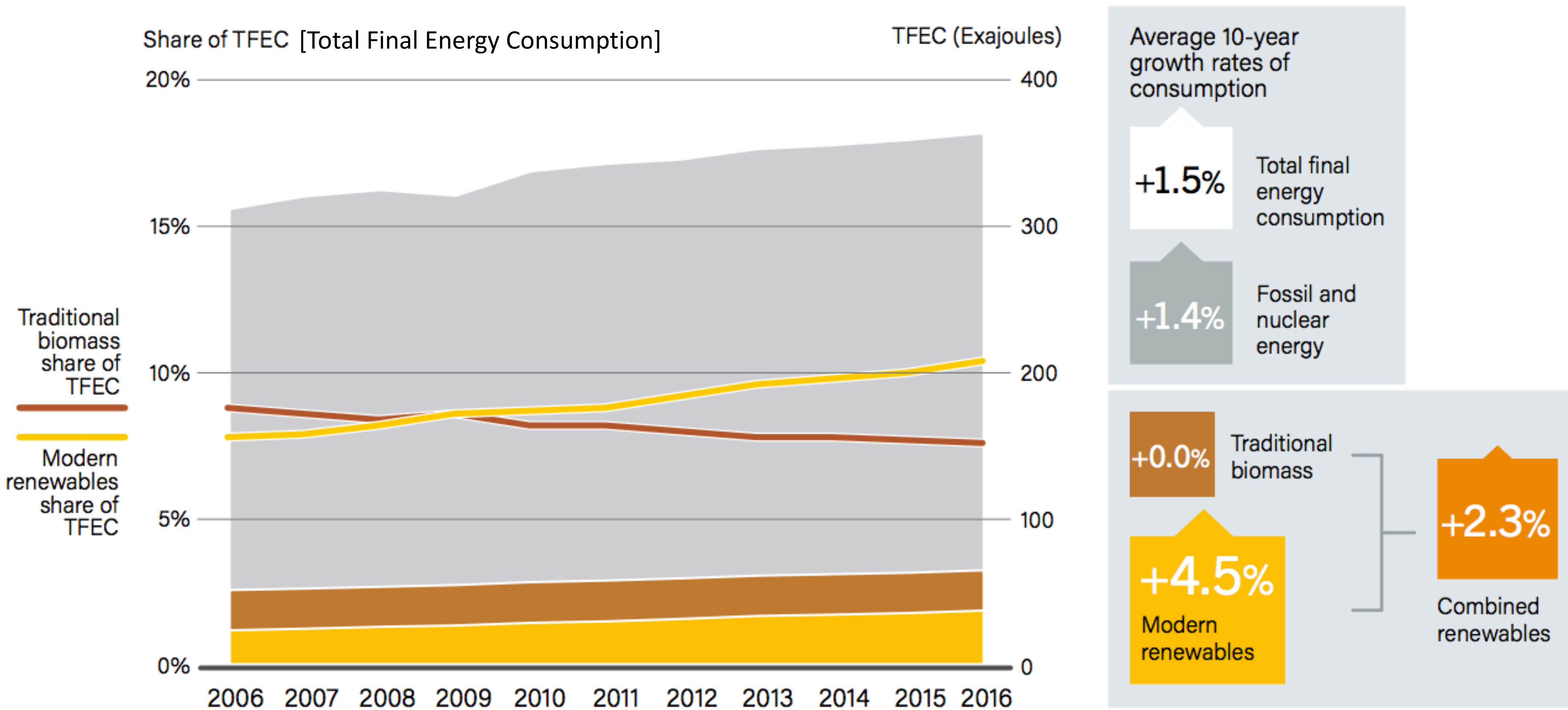
Note: Data should not be compared with previous years because of revisions due to improved or adjusted data or methodology. Totals may not add up due to rounding.

Source: Based on OECD/IEA and IEA SHC. See endnote 54 for this chapter.

https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf

Renewables growth (+2.3%) is higher than (fossil + nuclear) growth (+1.4%), 2006-2016

FIGURE 2. Growth in Global Renewable Energy Compared to Total Final Energy Consumption, 2006-2016

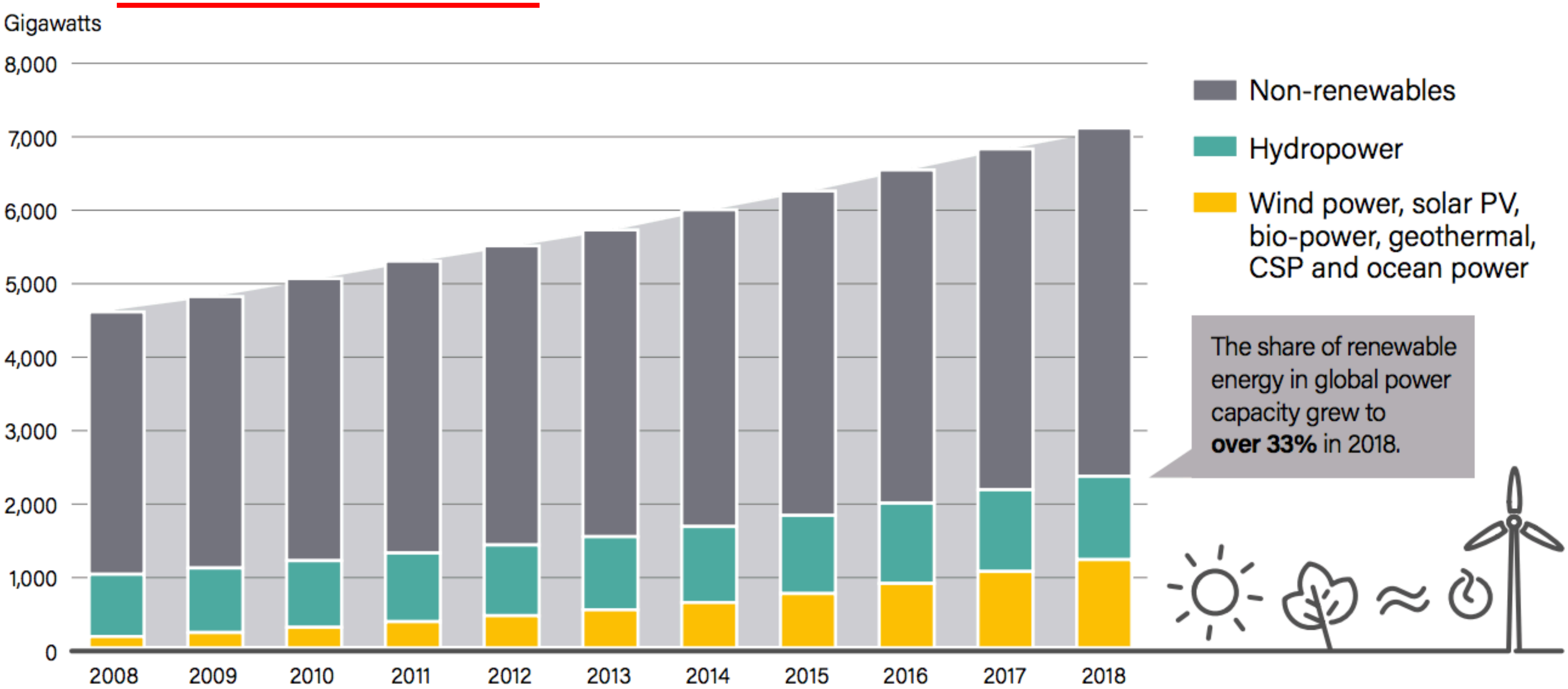


Source: Based on OECD/IEA. See endnote 57 for this chapter.

https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf

A bit more than 1/3 of global installed capacity for power production is renewable based.

FIGURE 7. Global Power Generating Capacity, by Source, 2008-2018



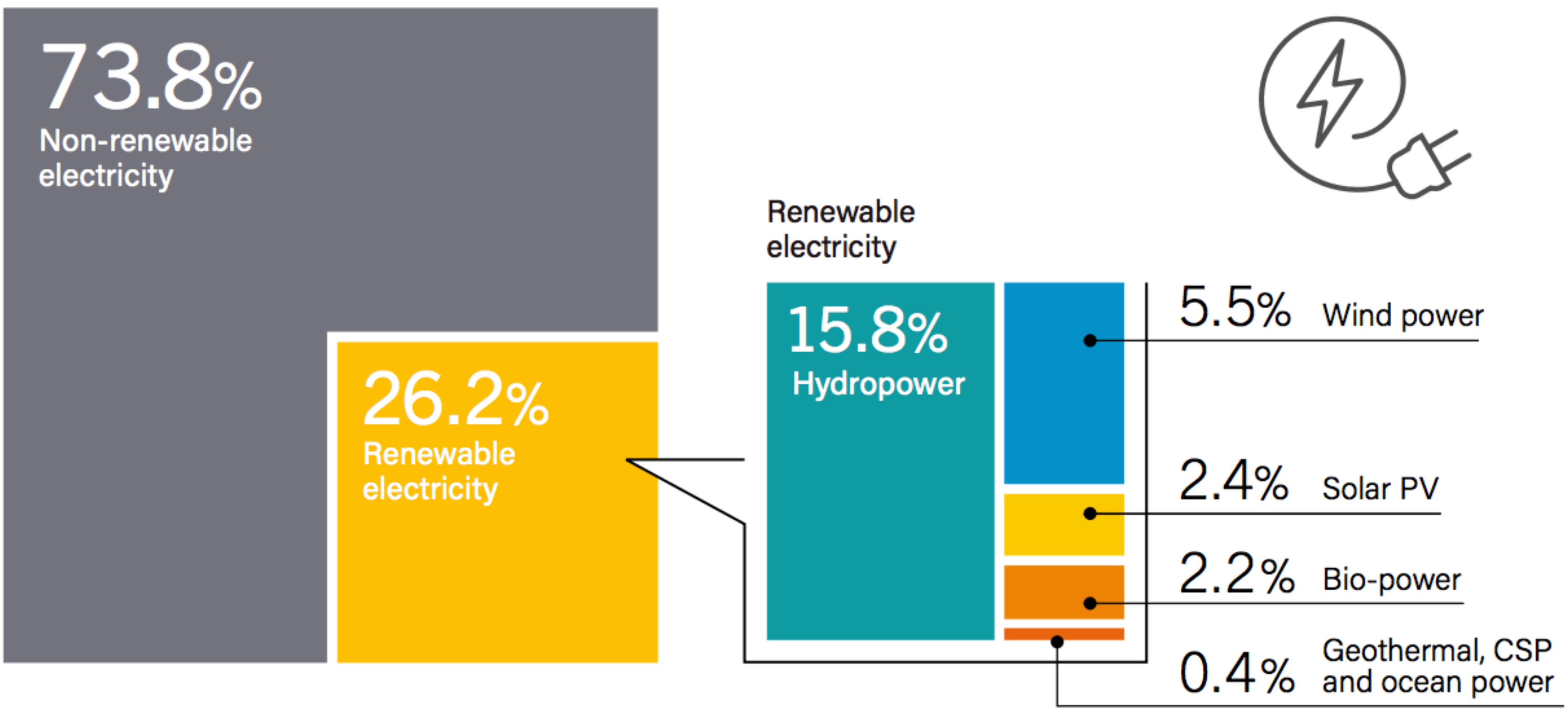
Source: See endnote 190 for this chapter.

https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf

Approximately, ¼ of global electricity production is from renewanle sources

REN21 Renewable Energy Policy Network for the 21st Century

FIGURE 8. Estimated Renewable Energy Share of Global Electricity Production, End-2018



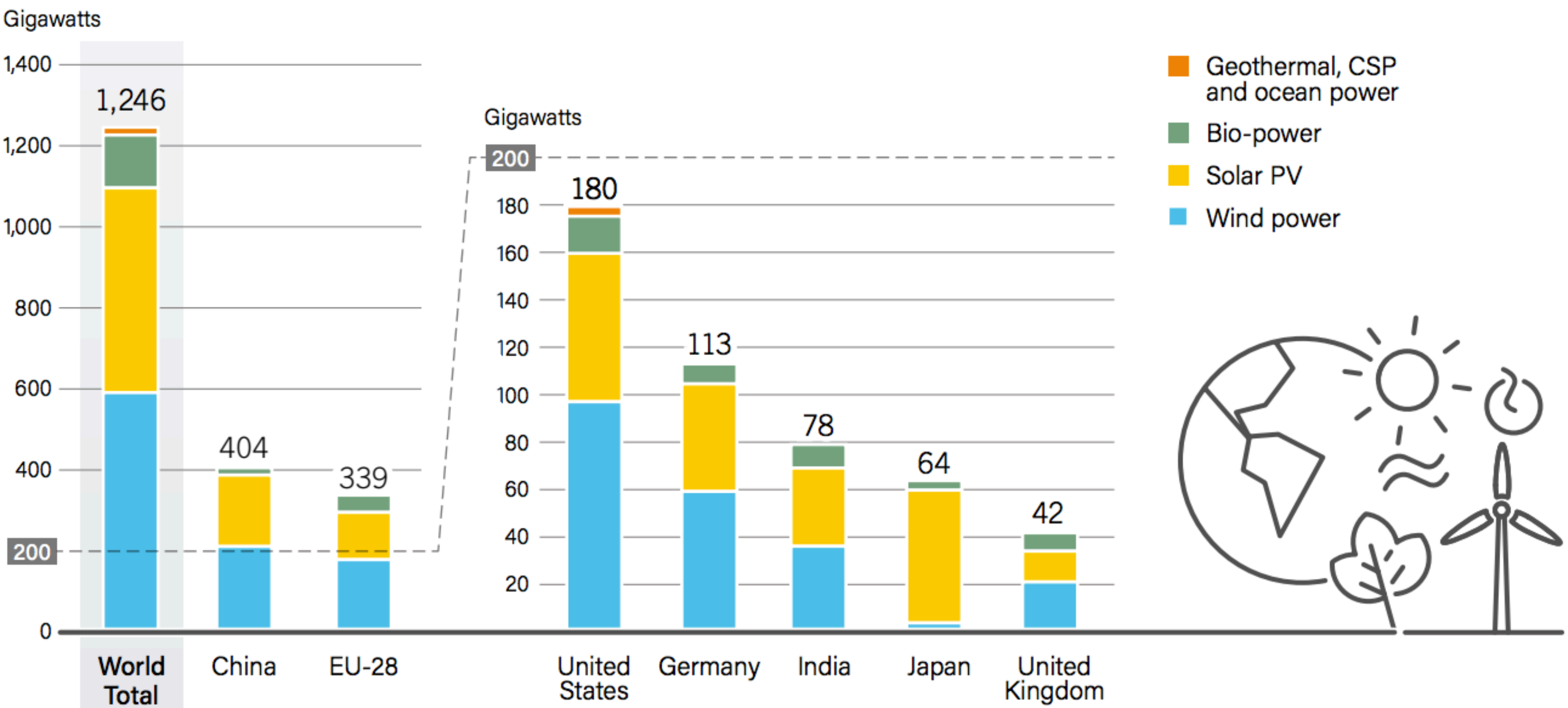
Note: Data should not be compared with previous versions of this figure due to revisions in data and methodology.

Source: See endnote 192 for this chapter.

https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf

Higher renewable installed capacity (>200GW) in China and EU28, in 2018

FIGURE 9. Renewable Power Capacities in World, EU-28 and Top 6 Countries, 2018



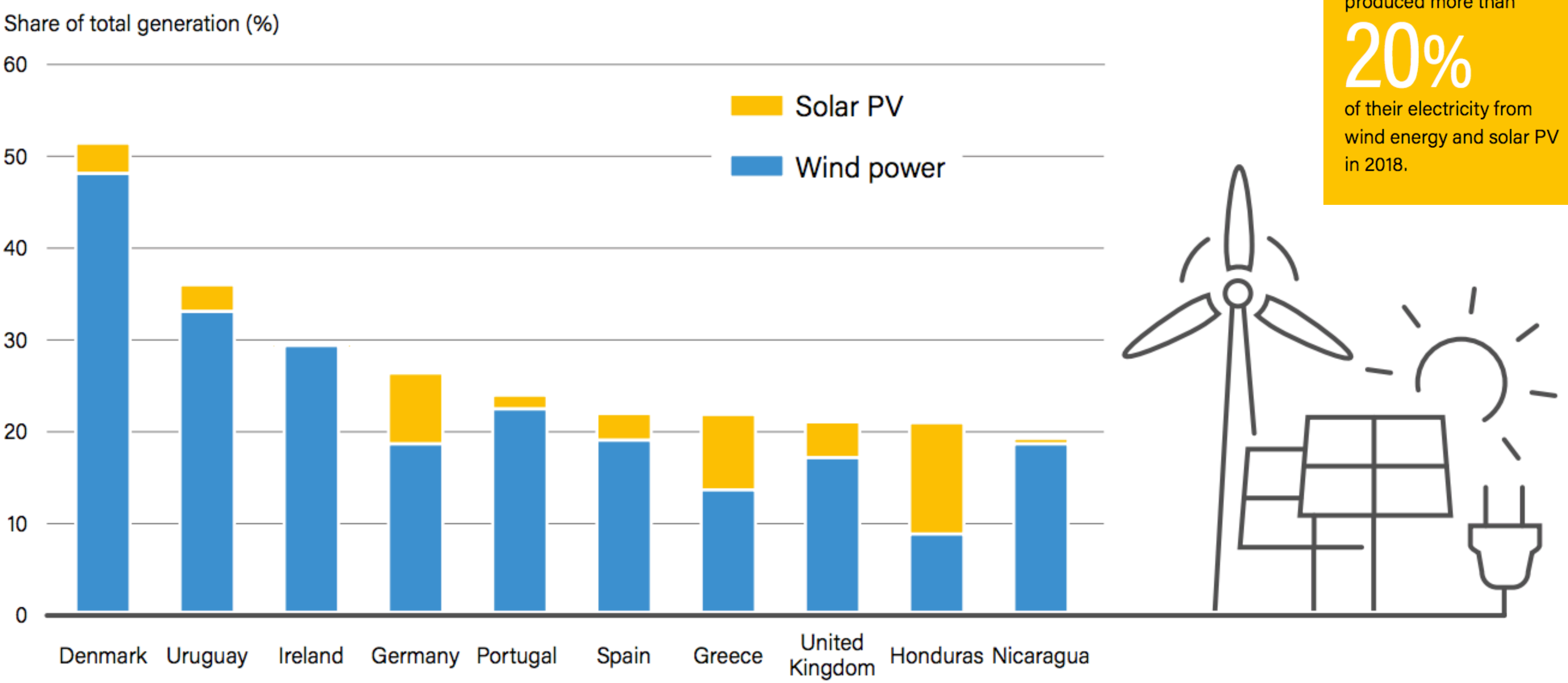
Note: Not including hydropower.

Source: See endnote 195 for this chapter.

https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf

Portugal is at Top10 of countries with highest share of renewable electricity in 2018

FIGURE 10. Share of Electricity Generation from Variable Renewable Energy, Top 10 Countries, 2018



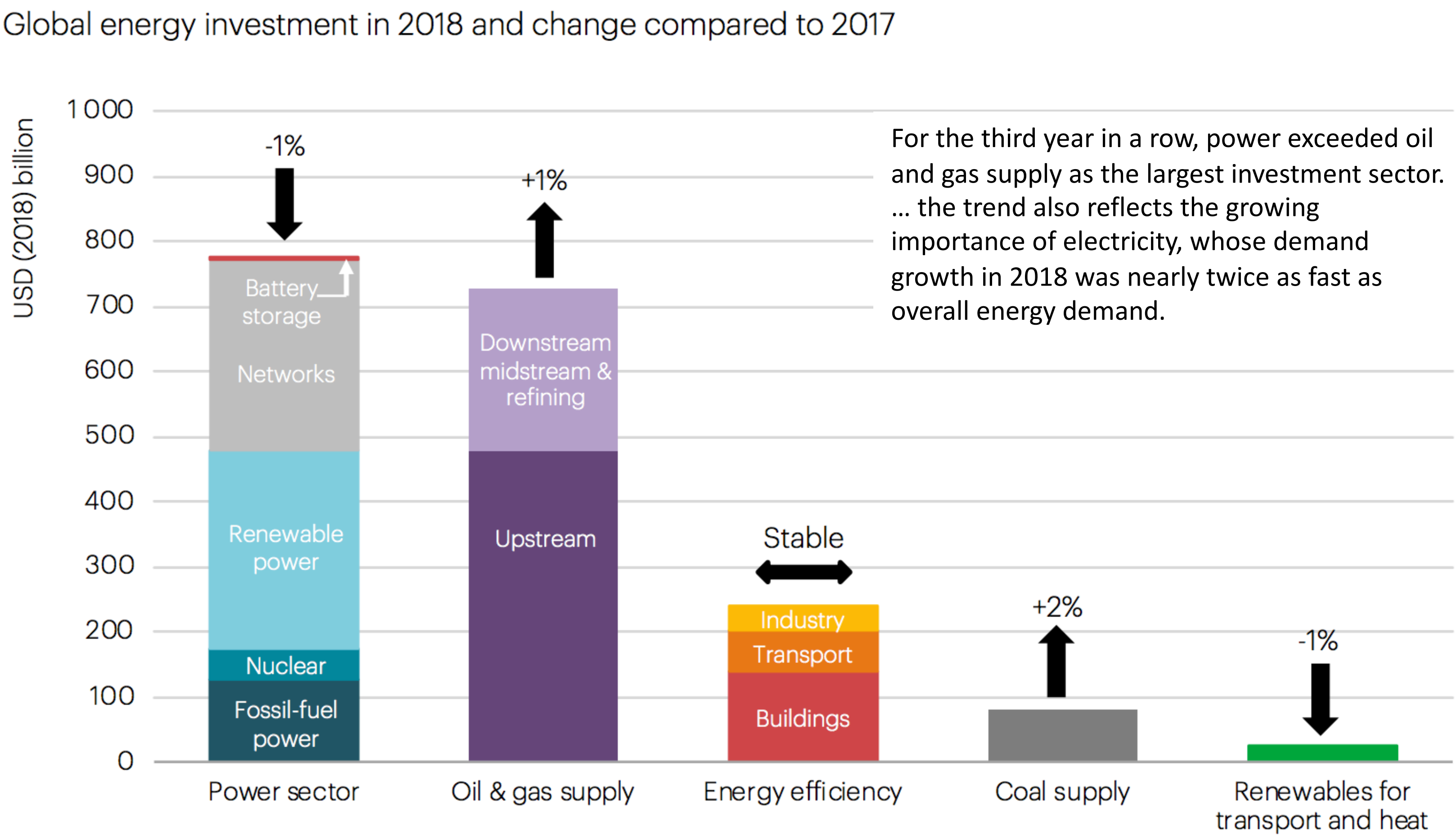
At least nine countries produced more than **20%** of their electricity from wind energy and solar PV in 2018.

Note: This figure includes the top 10 countries according to the best available data known to REN21 at the time of publication.

Source: See endnote 203 for this chapter.

https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf

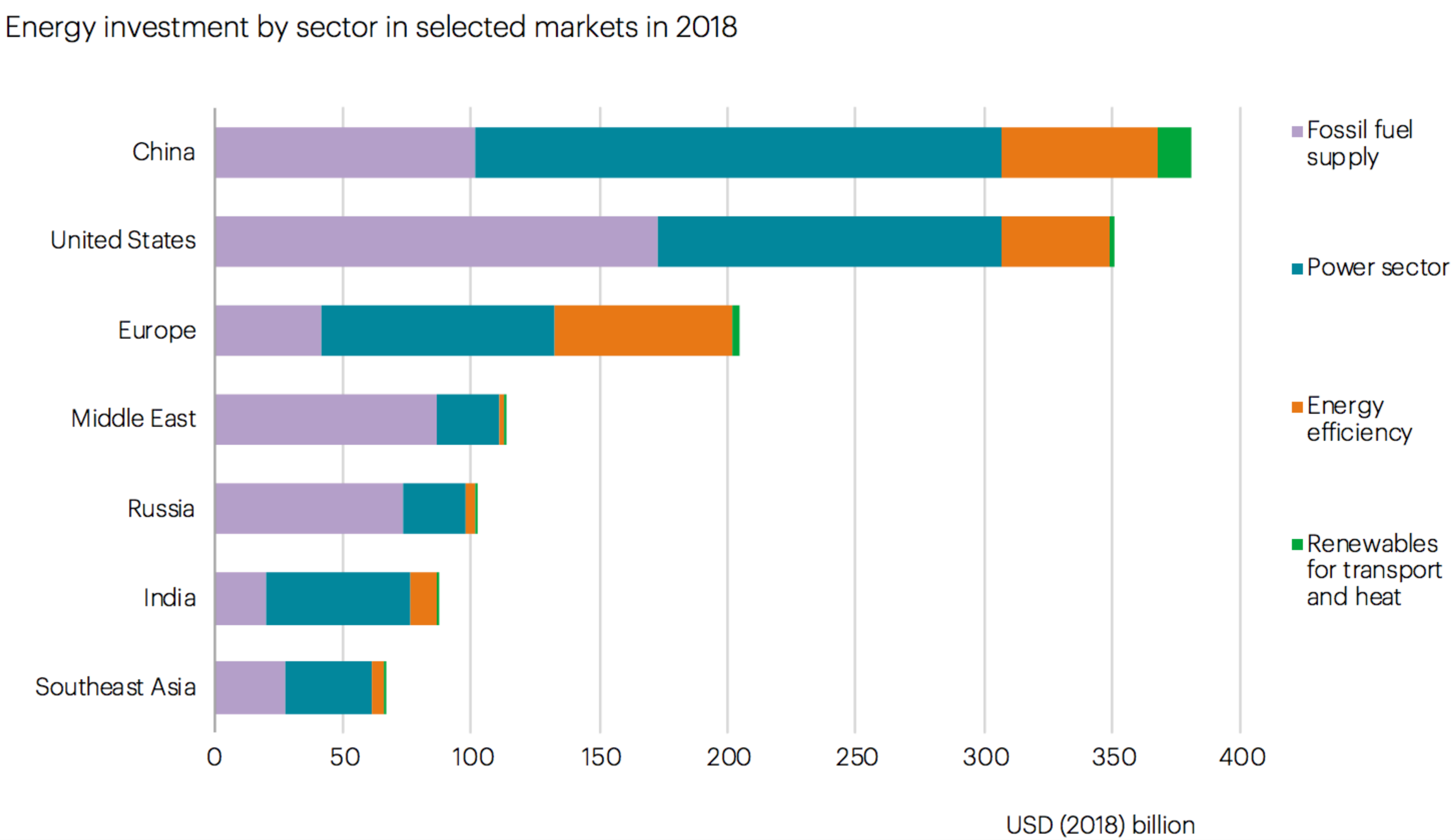
Investiment in fossil (2^{nd}+4^{rd} columns) higher than investiment in renewable power system (1^{st} column, except fossil-fuel power)



Note: Investment is measured as the ongoing capital spending in energy supply capacity and incremental spending on more efficient equipment and goods (in energy efficiency). The scope and methodology for tracking energy investments is found in the Annex of this report as well as at iea.org/media/publications/wei/WEI2019-Methodology-Annex.pdf. Renewables for transport and heat include biofuels for transport and solar thermal heating. Electricity networks include transmission and distribution.

https://webstore.iea.org/download/direct/2738?fileName=WEI2019.pdf

China remained the largest market for total energy investment in 2018



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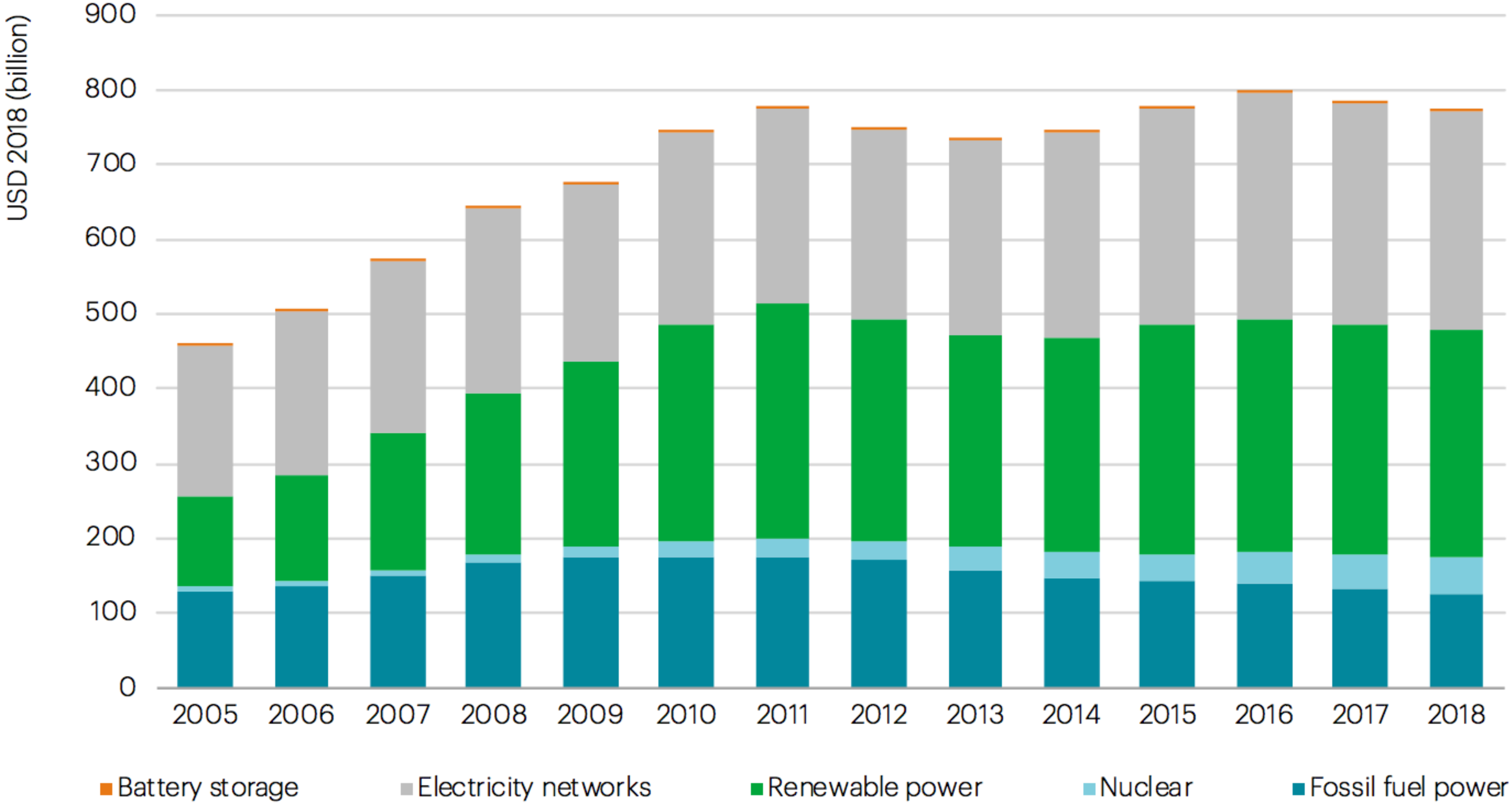
Global electricity investment declined by 1% in 2018…

Global investment in the power sector by technology

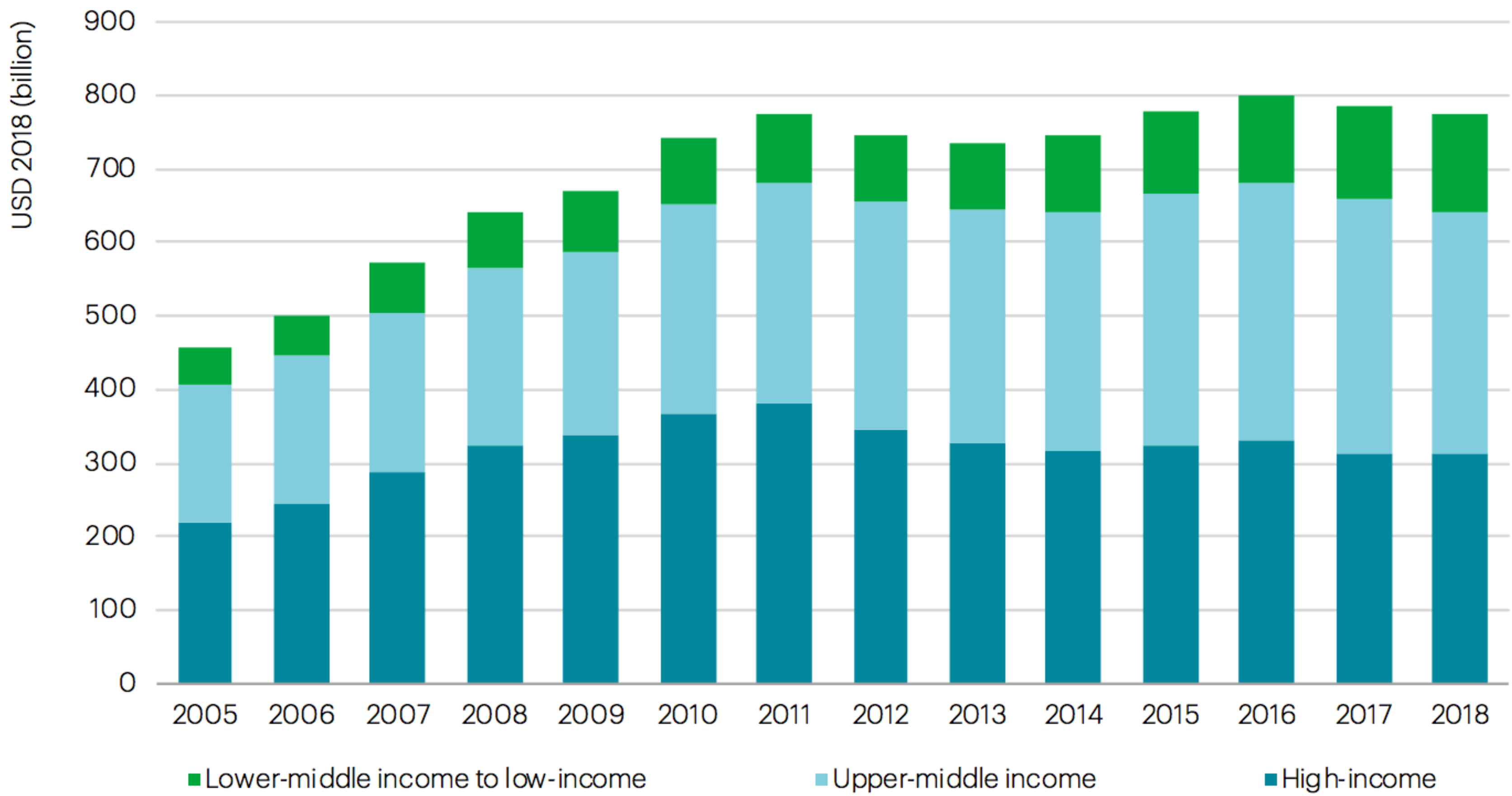


Note: Investment is measured as the ongoing capital spending in power capacity. The scope and methodology for tracking energy investments is found in the Annex of this report as well as at iea.org/media/publications/wei/WEI2019-Methodology-Annex.pdf.

https://webstore.iea.org/download/direct/2738?fileName=WEI2019.pdf

Power investment is shifting towards emerging & developing economies...

Global investment in the power sector by region, classified by current income level

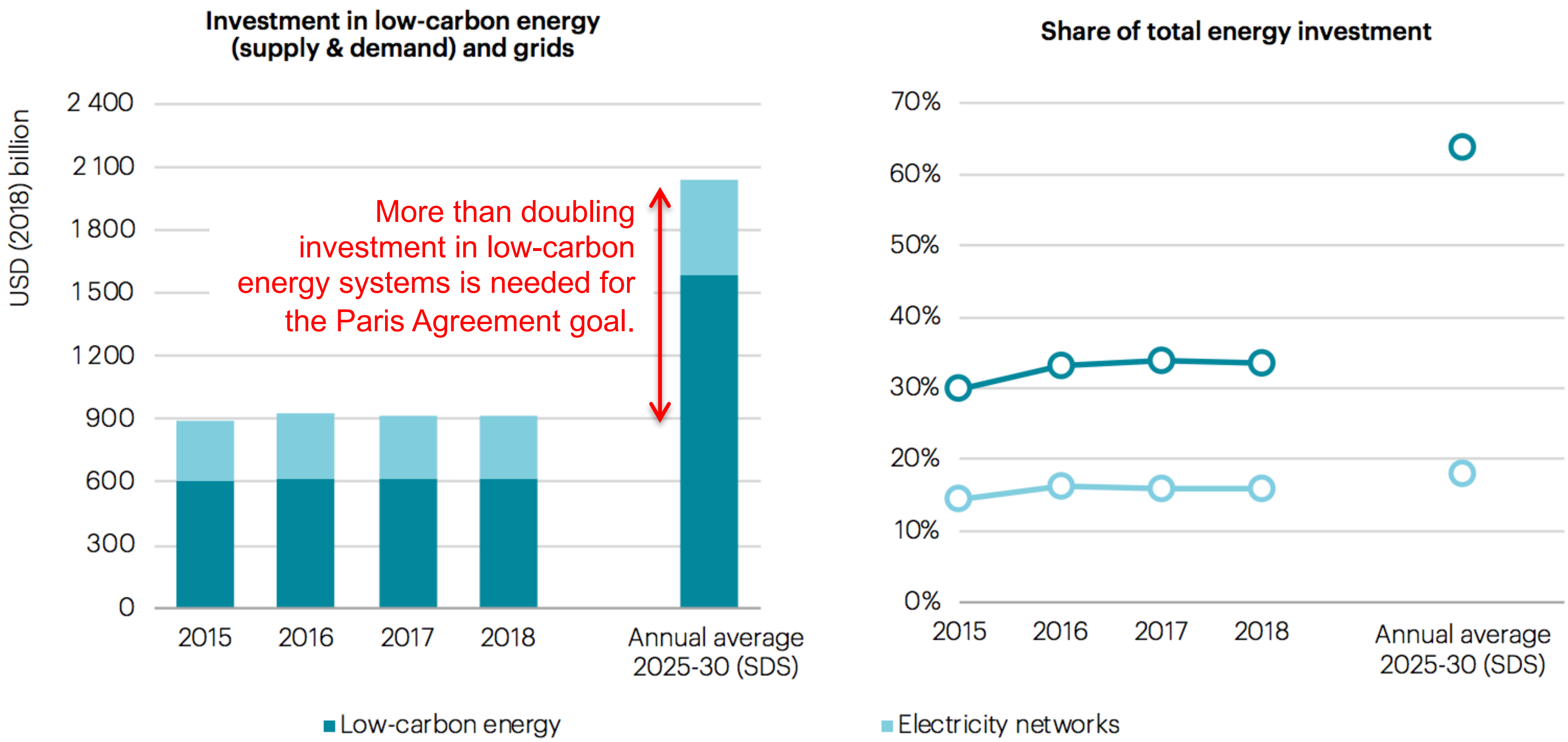


Note: Income categories are defined on the basis of gross national income/capita (current USD) thresholds by region, as of 2018, from World Bank (2019).

https://webstore.iea.org/download/direct/2738?fileName=WEI2019.pdf

Total investment across low-carbon energy – including supply and efficiency – has stalled in recent years and needs a rapid boost to keep Paris in sight

Global investment in low-carbon energy, including efficiency, and electricity networks compared with investment needs (SDS)



Note: Low-carbon energy investment includes energy efficiency, renewable power, renewables for transport and heat, nuclear, battery storage and carbon capture utilisation and storage. SDS = Sustainable Development Scenario.

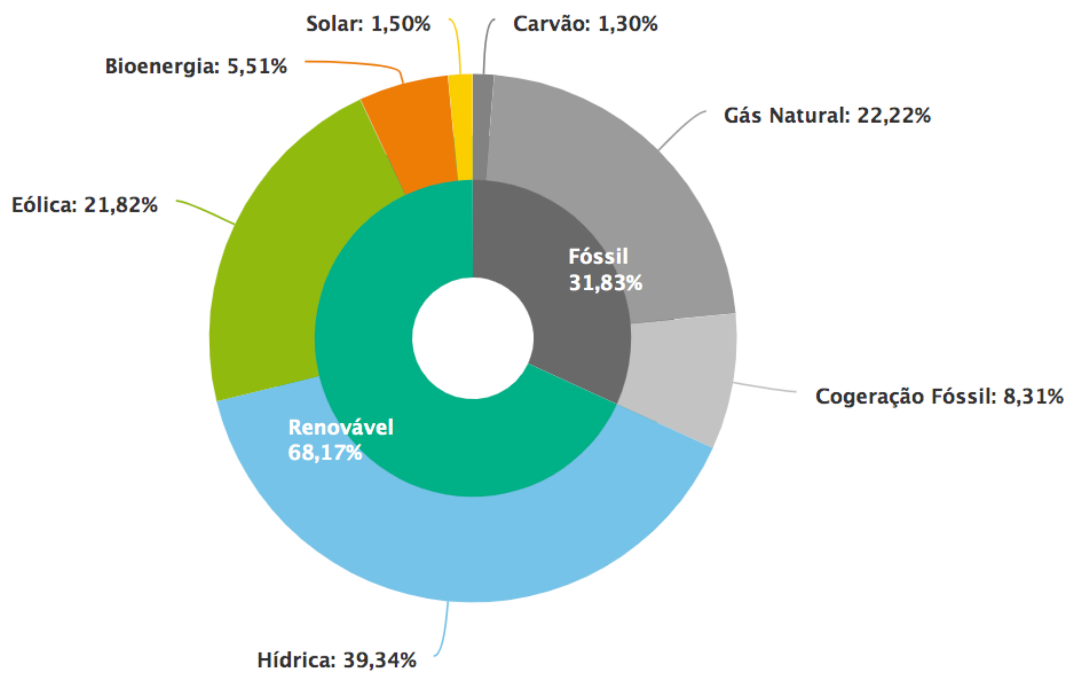
https://webstore.iea.org/download/direct/2738?fileName=WEI2019.pdf

RENEWABLES IN Portugal: one shot!

Balanço da Produção de Eletricidade de Portugal Continental (fevereiro de 2020)

Em fevereiro de 2020, as fontes de energia renovável contribuiram com 68,17% do total da geração de eletricidade.

Fonte: REN



EXPLORE MORE here:

APREN Associação de Energias Renováveis

https://www.apren.pt/pt/energias-renovaveis/producao

Key concepts to understand the role of renewables in energy systems:

- **LCOE (levelized cost of electricity)**
- **Learning curves**
- **Capacity factor**
- **Dispatchability**
- **Energy system value**

HOW TO COMPARE THE COST OF ELETRICITY PRODUCTION FROM DIFFERENT TECHNOLOGIES?

Table 5.1: Typical capital and operating costs for power plants. Note that these costs do not include subsidies, incentives, or any "social costs" (e.g., air or water emissions)

Technology	Capital Cost ($/kW)	Operating Cost ($/kWh)
Coal-fired combustion turbine	$500 — $1,000	0.02 — 0.04
Natural gas combustion turbine	$400 — $800	0.04 — 0.10
Coal gasification combined-cycle (IGCC)	$1,000 — $1,500	0.04 — 0.08
Natural gas combined-cycle	$600 — $1,200	0.04 — 0.10
Wind turbine (includes offshore wind)	$1,200 — $5,000	Less than 0.01
Nuclear	$1,200 — $5,000	0.02 — 0.05
Photovoltaic Solar	$4,500 and up	Less than 0.01
Hydroelectric	$1,200 — $5,000	Less than 0.01

Basic economics of power generation, transmission and distribution, PennState Univ
https://www.e-education.psu.edu/eme801/node/530

Why is it not possible to make direct comparison among different technologies?

Key Concept: Levelized Cost of Energy (LCOE)

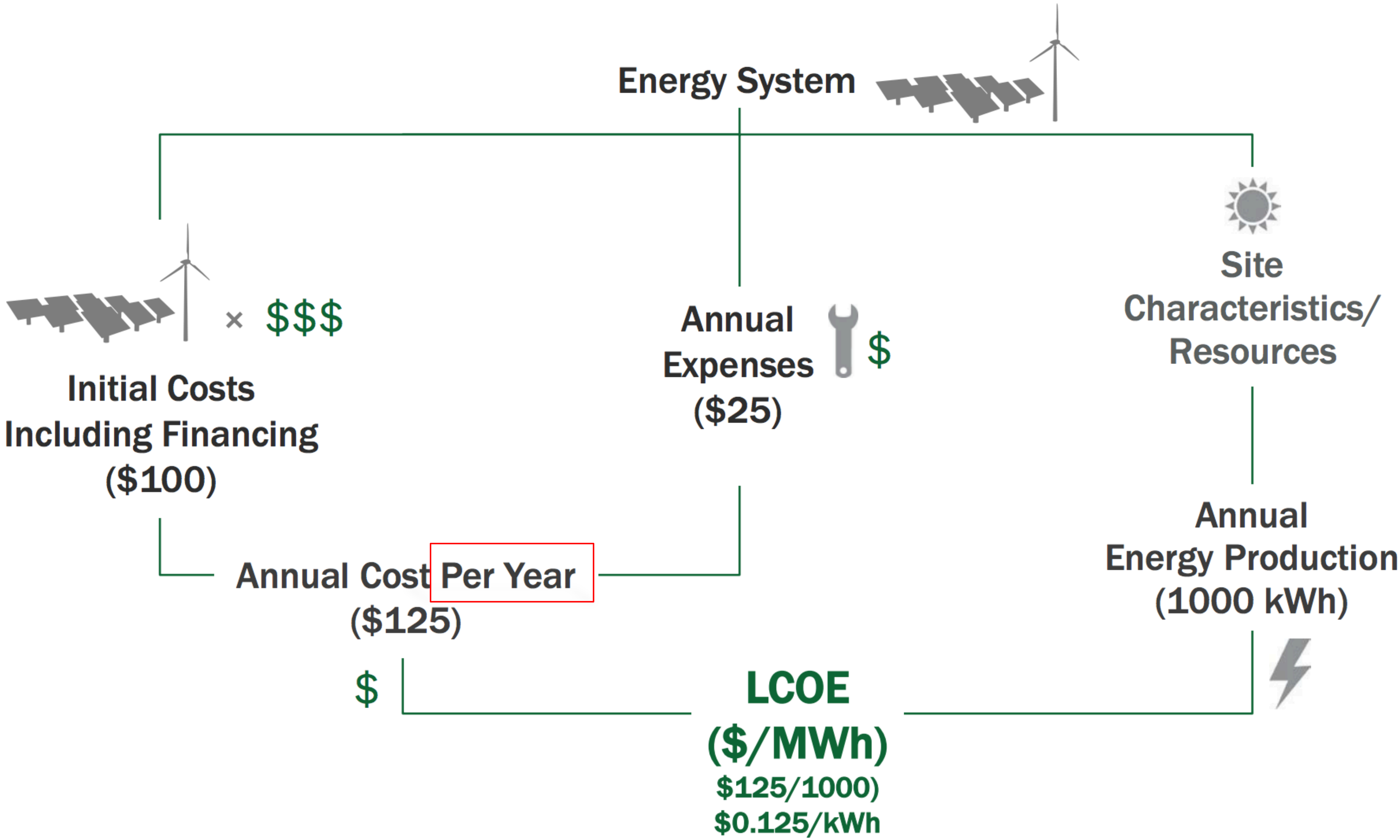
- Measures lifetime costs divided by energy production

- Calculates present value of the total cost of building and operating a power plant over an assumed lifetime.

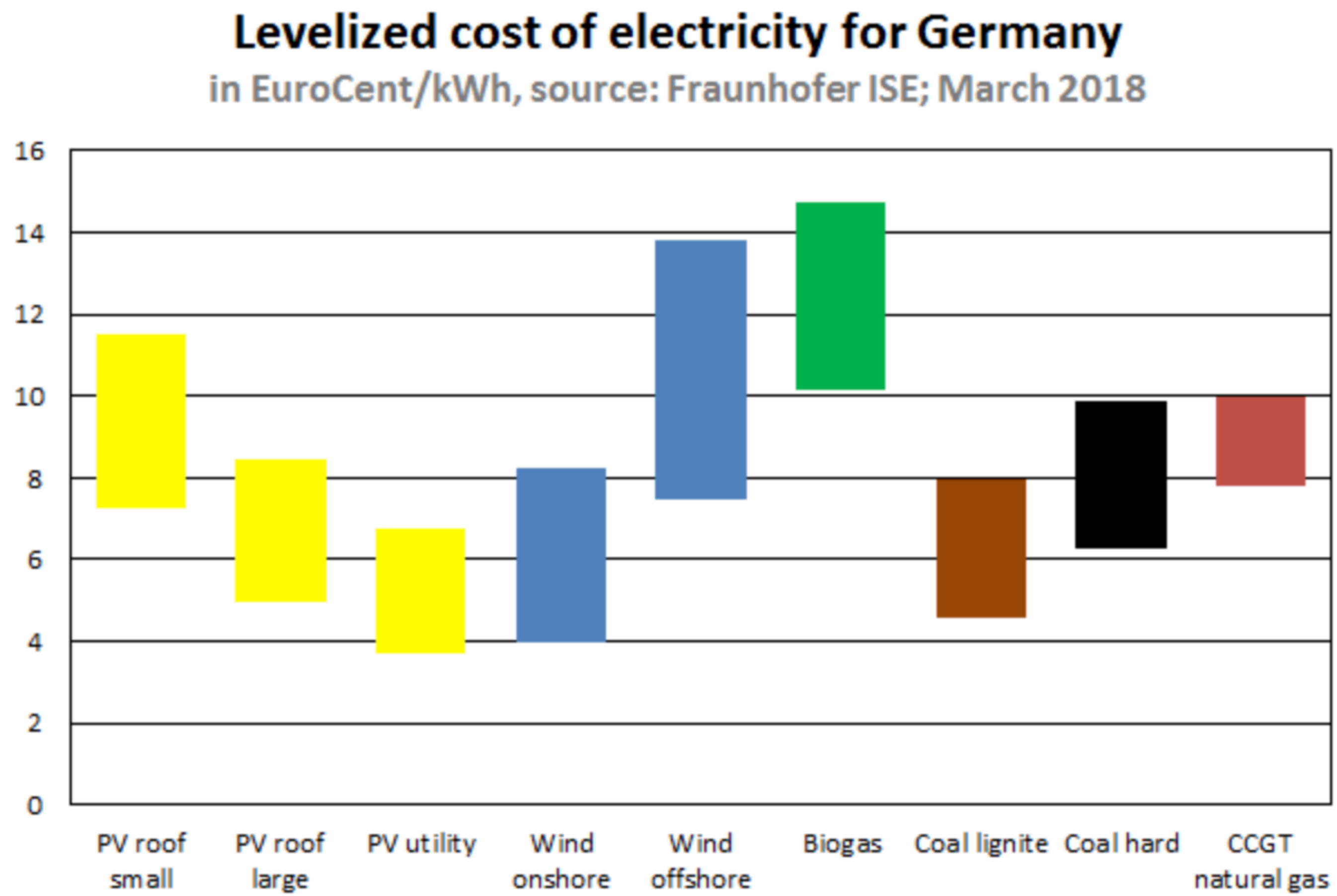
- Allows the comparison of different technologies (e.g., wind, solar, natural gas) of unequal life spans, project size, different capital cost, risk, return, and capacities

Critical to making an informed decision to proceed with development of a facility, community or commercial-scale project

Simple LCOE Concept



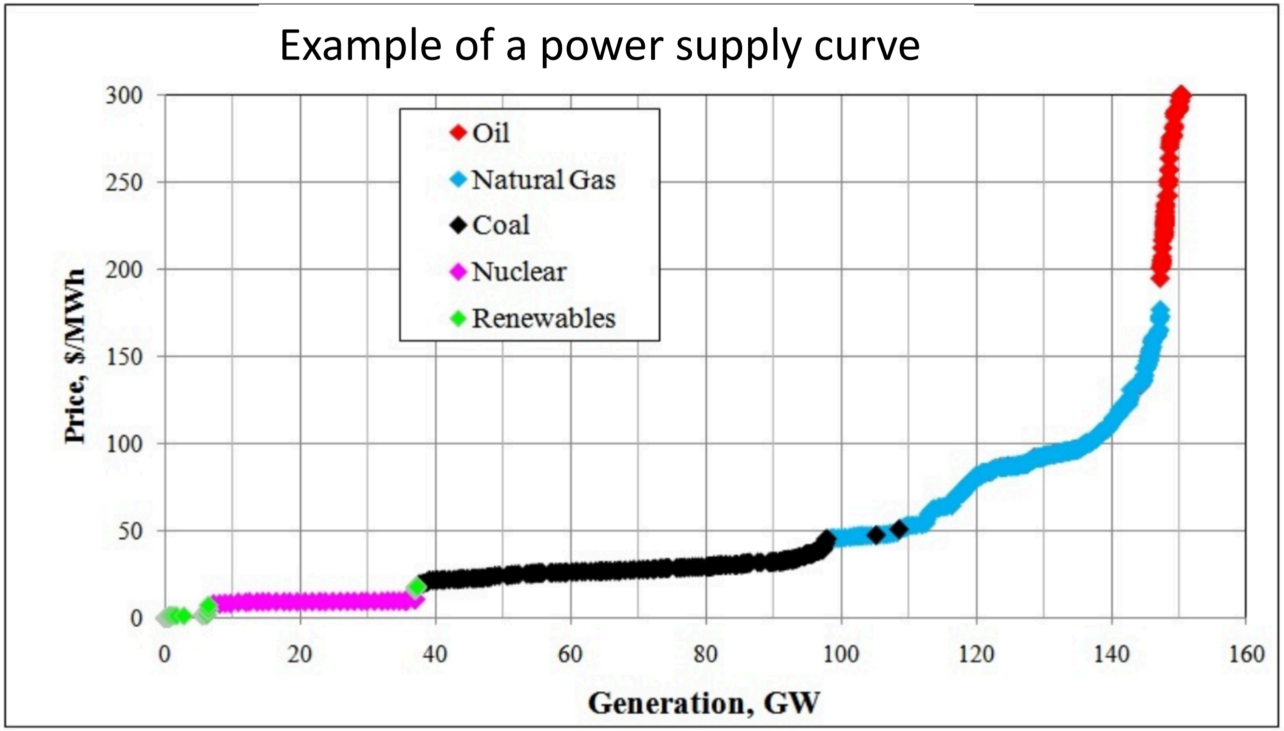
Adapted from European Wind Energy Association, "Economics of Wind Energy,"
http://www.ewea.org/fileadmin/ewea_documents/documents/00_POLICY_document/Economics_of_Wind_Energy__March_2009_.pdf



Comparison of the levelized cost of electricity for some newly built renewable and fossil-fuel based power stations in EuroCent per kWh (Germany, 2018)

HOW TO DECIDE TO PUT A POWER PLANT OPERATING WITHIN A POWER SYSTEM?

A supply curve consists of a series of discrete steps, each step having two components: the cost of an energy resource and the capacity or energy available at that cost. The first component (the cost of energy from PV) may be expressed as the "levelized cost of electricity" (LCOE)



https://www.e-education.psu.edu/ebf200/node/151

New renewable power technologies: Rapidly maturing

IRENA
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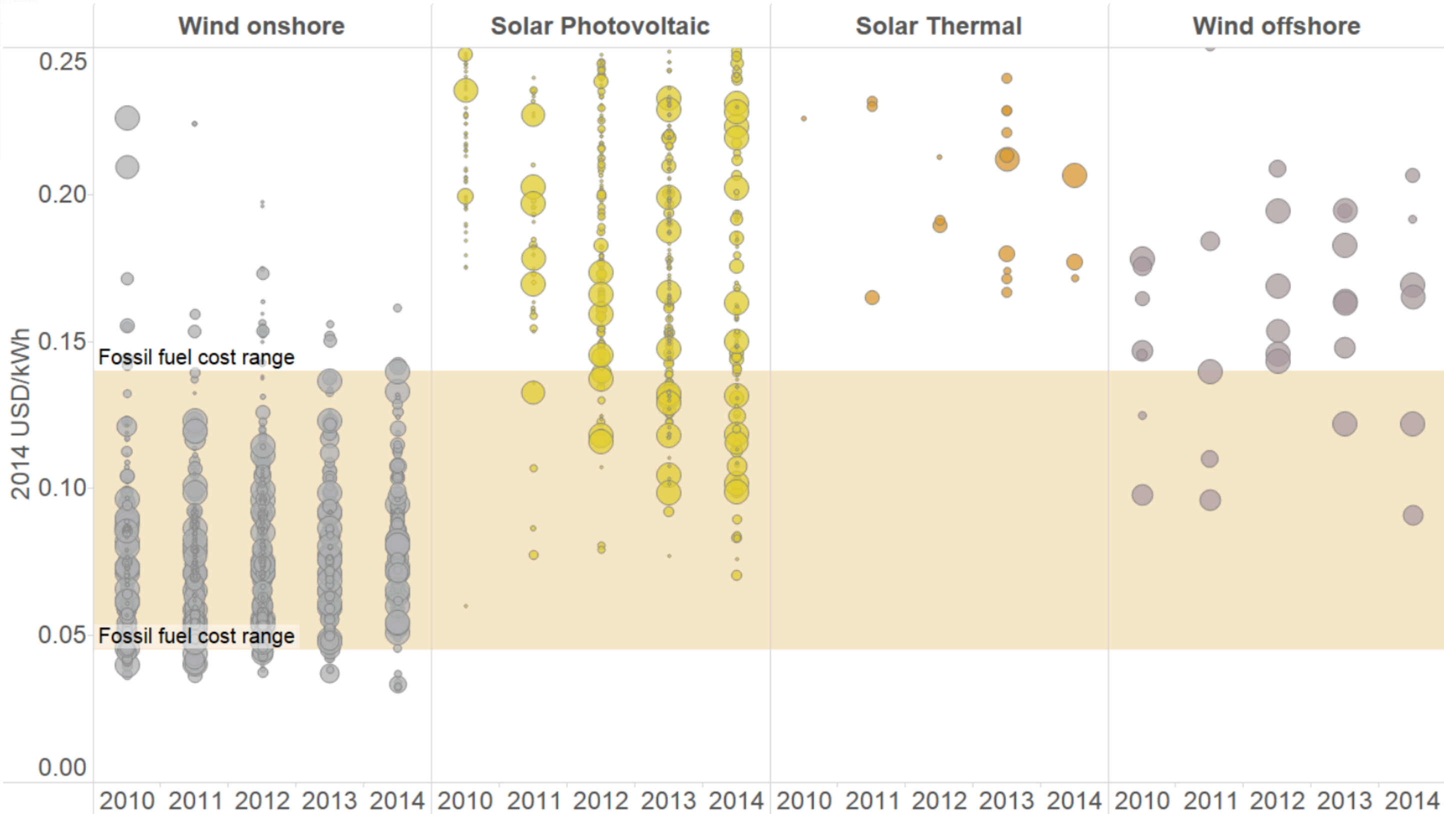
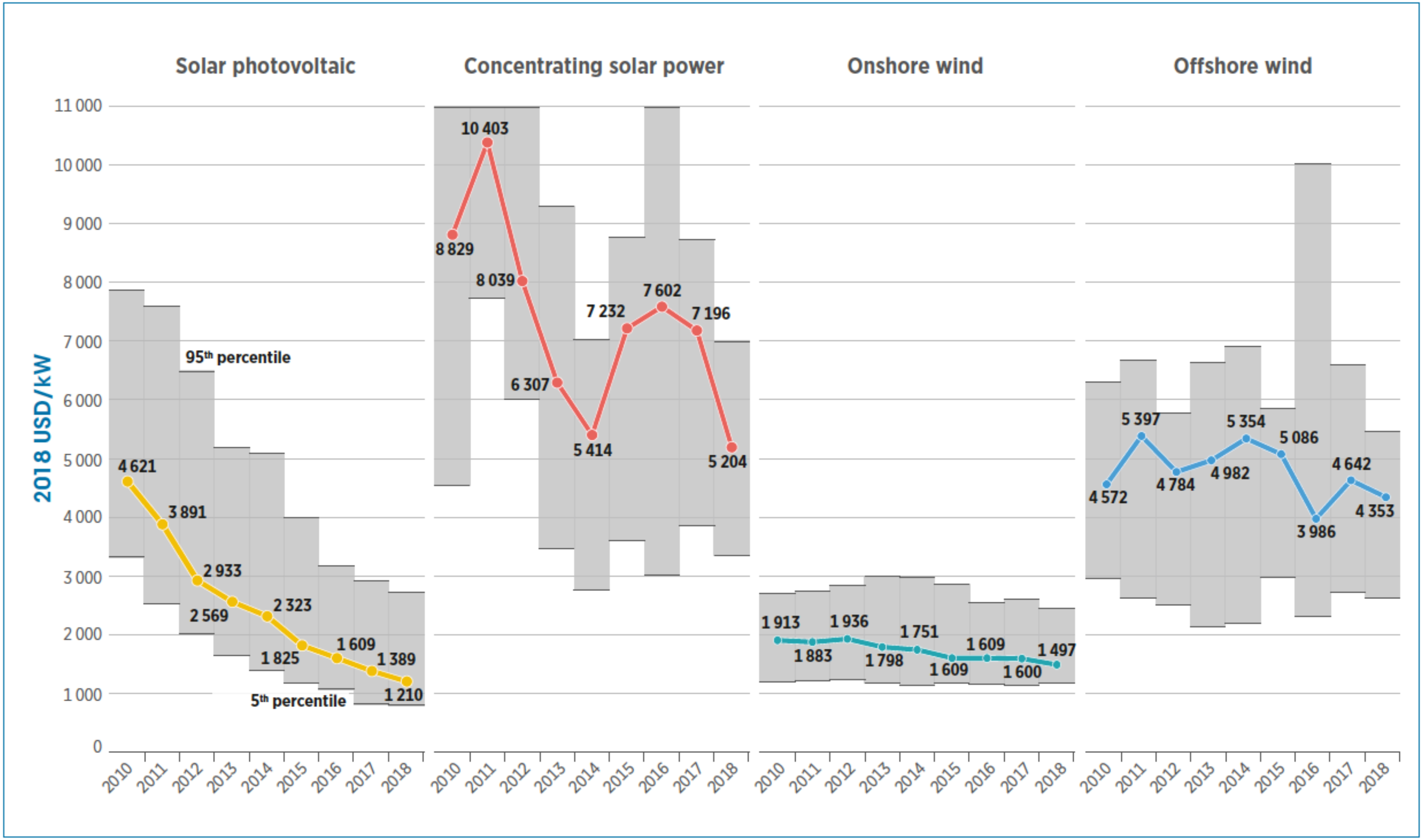


Note: each circle represents a utility-scale project, centre of circle is LCOE value and diameter of circle the project size

https://www.irena.org/publications/2016/Jun/The-Power-to-Change-Solar-and-Wind-Cost-Reduction-Potential-to-2025 2016

LCOE changes along the time, because tecnologies become mature (CAPEX reduces)

Figure S.2 Global weighted average total installed costs and project percentile ranges for CSP, solar PV, onshore and offshore wind, 2010–2018



https://www.irena.org/publications/2019/May/Renewable-power-generation-costs-in-2018

2016	2030	2050

2016	2030	2050

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Technology		CF Range		CAPEX Range		OPEX			LCOE Range	
		Min. (%)	Max. (%)	Min. ($/kW)	Max. ($/kW)	Fuel Costs ($/MWh)	Fixed O&M ($/kW-yr)	Variable O&M ($/MWh)	Min. ($/MWh)	Max. ($/MWh)
Dispatchable										
Coal	PC	53%	85%	$ 3,896	$ 3,896	$ 19	$ 33	$ 5	$ 74	$ 105
	IGCC	53%	85%	$ 4,180	$ 4,180	$ 19	$ 54	$ 8	$ 84	$ 118
	CCS-30%	53%	85%	$ 5,392	$ 5,392	$ 21	$ 69	$ 7	$ 102	$ 145
	CCS-90%	53%	85%	$ 5,962	$ 5,962	$ 25	$ 80	$ 10	$ 117	$ 166
Natural Gas	CT	8%	30%	$ 898	$ 898	$ 28	$ 12	$ 7	$ 59	$ 122
	CC	56%	87%	$ 1,050	$ 1,050	$ 19	$ 10	$ 3	$ 30	$ 36
	CC-CCS	56%	87%	$ 2,192	$ 2,192	$ 22	$ 33	$ 7	$ 49	$ 61
Nuclear		92%	92%	$ 6,070	$ 6,070	$ 7	$ 99	$ 2	$ 63	$ 63
Biopower		56%	56%	$ 3,942	$ 4,070	$ 39	$ 53	$ 5	$ 107	$ 109
Geothermal		80%	90%	$ 5,100	$13,601	$ 0	$ 145	$ 317	$ 76	$ 219
CSP with 10-hr TES		44%	60%	$ 7,842	$ 7,842	$ 0	$ 67	$ 4	$ 95	$ 128
Non-Dispatchable										
Wind	Land-based	11%	48%	$ 1,523	$ 1,744	$ 0	$ 51	$ 0	$ 22	$ 166
	Offshore	31%	51%	$ 3,776	$ 8,152	$ 0	$ 131	$ 0	$ 95	$ 241
Photovoltaic	Utility	15%	27%	$ 1,774	$ 1,774	$ 0	$ 14	$ 0	$ 35	$ 63
	Commercial	12%	20%	$ 2,591	$ 2,591	$ 0	$ 18	$ 0	$ 69	$ 113
	Residential	13%	21%	$ 3,782	$ 3,782	$ 0	$ 23	$ 0	$ 92	$ 153
Hydropower		60%	66%	$ 3,956	$ 7,383	$ 0	$ 41	$ 0	$ 35	$ 69

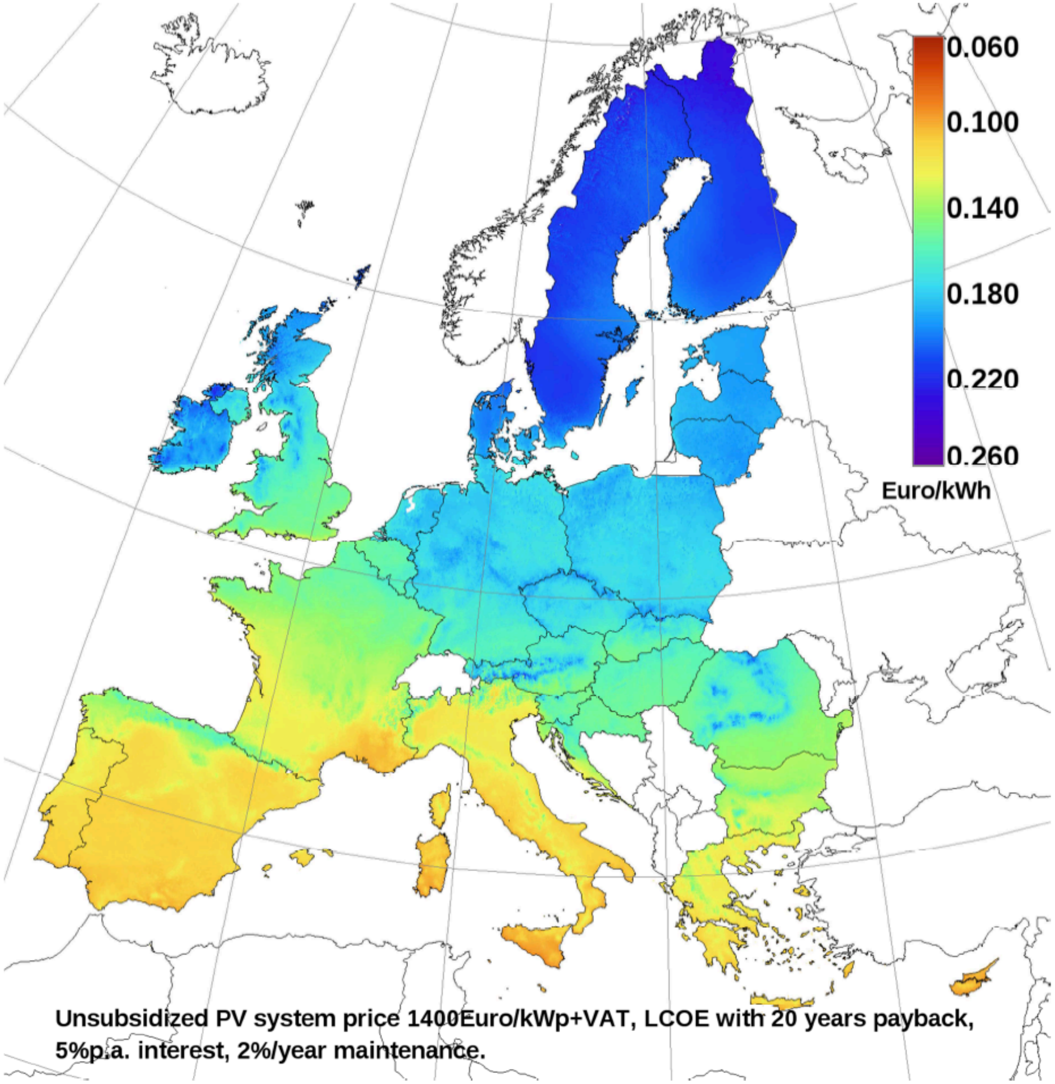
https://atb.nrel.gov/electricity/2018/summary.html

2016 2030 2050 2016 2030 2050

Technology		CF Range Min. (%)	CF Range Max. (%)	CAPEX Range Min. ($/kW)	CAPEX Range Max. ($/kW)	OPEX Fuel Costs ($/MWh)	OPEX Fixed O&M ($/kW-yr)	OPEX Variable O&M ($/MWh)	LCOE Range Min. ($/MWh)	LCOE Range Max. ($/MWh)
Dispatchable										
Coal	PC	53%	85%	$ 3748	$ 3748	$ 20	$ 33	$ 5	$ 85	$ 120
	IGCC	53%	85%	$ 3,898	$ 3,898	$ 17	$ 54	$ 8	$ 90	$ 128
	CCS-30%	53%	85%	$ 5,099	$ 5,099	$ 21	$ 69	$ 7	$ 113	$ 164
	CCS-90%	53%	85%	$ 5,638	$ 5,638	$ 21	$ 80	$ 10	$ 125	$ 181
Natural Gas	CT	8%	30%	$ 849	$ 849	$ 41	$ 12	$ 7	$ 76	$ 147
	CC	56%	87%	$ 997	$ 997	$ 28	$ 10	$ 3	$ 42	$ 48
	CC-CCS	56%	87%	$ 1,983	$ 1,983	$ 34	$ 33	$ 7	$ 64	$ 77
Nuclear		92%	92%	$ 5,803	$ 5,803	$ 7	$ 99	$ 2	$ 72	$ 72
Biopower		56%	56%	$ 3,706	$ 3,928	$ 39	$ 51	$ 5	$ 115	$ 117
Geothermal		80%	90%	$ 4,922	$13,125	$ 0	$ 145	$ 317	$ 83	$ 240
CSP with 10-hr TES		44%	60%	$ 5,784	$ 5,784	$ 0	$ 50	$ 4	$ 88	$ 119
Non-Dispatchable										
Wind	Land-based	16%	51%	$ 1,299	$ 2,046	$ 0	$ 47	$ 0	$ 32	$ 147
	Offshore	33%	52%	$ 2,514	$ 5,909	$ 0	$ 127	$ 0	$ 74	$ 193
Photovoltaic	Utility	15%	27%	$ 819	$ 819	$ 0	$ 7	$ 0	$ 22	$ 40
	Commercial	12%	20%	$ 1,108	$ 1,108	$ 0	$ 8	$ 0	$ 40	$ 66
	Residential	13%	21%	$ 1,493	$ 1,493	$ 0	$ 9	$ 0	$ 50	$ 83
Hydropower		60%	66%	$ 3,956	$ 7,105	$ 0	$ 41	$ 0	$ 45	$ 83

https://atb.nrel.gov/electricity/2018/summary.html

LCOE changes with countries, because physical conditions,e.g. sun hours in the case of PV (amount of electricity varies)



https://www.researchgate.net/publication/269100308_Cost_Maps_for_Unsubsidised_Photovoltaic_Electricity

Fig. 1 Distribution of the levelised cost of PV electricity in Europe.

HOW TO REFER TO THE LOCAL CONDITIONS OF A RENEWABLE POWER TECHNOLOGY?

Capacity factor is the ratio of the actual electrical energy produced in a given period of time, to the hypothetical maximum possible electrical energy output over that period.

What factors limit the electricity generation along the day or along the year?

- availability of the technology (e.g. maintenance)
- availability of the resources (sun: daily profile; hydro: seasonal profile), depending on the local

$$\text{Annual Capacity Factor} = \frac{\text{Actual generation}}{\text{Maximum generation}}$$

$$= \frac{10{,}000\ kWh}{2\ kW * 8760\ hr} = 57\%$$

Number of total hours in a year

The capacity factor (CF) is directly related with natural endogenous conditions and impacts the amount of electricity generated: higher CF more electricity produced

Capacity factors varies with technology and along the year (also with the regions of the planet)

Table 6.7.B. Capacity Factors for Utility Scale Generators Not Primarily Using Fossil Fuels, January 2013-February 2018

Period	Nuclear	Conventional Hydropower	Wind	Solar Photovoltaic	Solar Thermal	Landfill Gas and Muncipal Solid Waste	Other Biomass Including Wood	Geothermal
Annual Factors								
2013	89.9%	38.9%	32.4%	NA	NA	68.9%	56.7%	73.6%
2014	91.7%	37.3%	34.0%	25.9%	19.8%	68.9%	58.9%	74.0%
2015	92.3%	35.8%	32.2%	25.8%	22.1%	68.7%	55.3%	74.3%
2016	92.3%	38.2%	34.5%	25.1%	22.2%	69.7%	55.6%	73.9%
2017	92.2%	45.2%	36.7%	27.0%	21.8%	70.9%	50.7%	76.4%
Year 2016								
January	98.5%	43.6%	33.9%	15.2%	6.8%	68.3%	58.5%	73.4%
February	95.3%	43.8%	39.6%	22.9%	19.5%	67.6%	61.2%	73.2%
March	89.9%	45.9%	40.2%	24.9%	19.6%	67.2%	55.8%	72.5%
April	88.1%	44.6%	39.3%	27.2%	20.9%	69.3%	45.8%	68.8%
May	90.5%	42.8%	34.2%	30.2%	28.9%	72.9%	47.0%	73.9%
June	94.2%	40.6%	30.5%	30.3%	33.5%	72.0%	54.7%	71.2%
July	94.5%	36.1%	31.9%	31.7%	36.9%	70.9%	59.3%	72.2%
August	96.1%	33.0%	24.5%	31.7%	29.2%	70.3%	63.5%	73.0%
Sept	90.9%	28.6%	30.4%	28.5%	30.2%	67.9%	58.5%	75.5%
October	81.7%	29.3%	36.4%	24.0%	19.1%	63.8%	48.9%	74.6%
November	90.9%	32.8%	35.3%	20.4%	14.4%	72.6%	54.9%	77.7%
December	96.7%	37.9%	38.8%	16.2%	7.0%	73.4%	59.6%	80.1%

The efficiency is directly related with technological development and impacts the amount of electricity generated: higher efficiency generates more electricity for the same capacity.

PV cells efficiency evolution

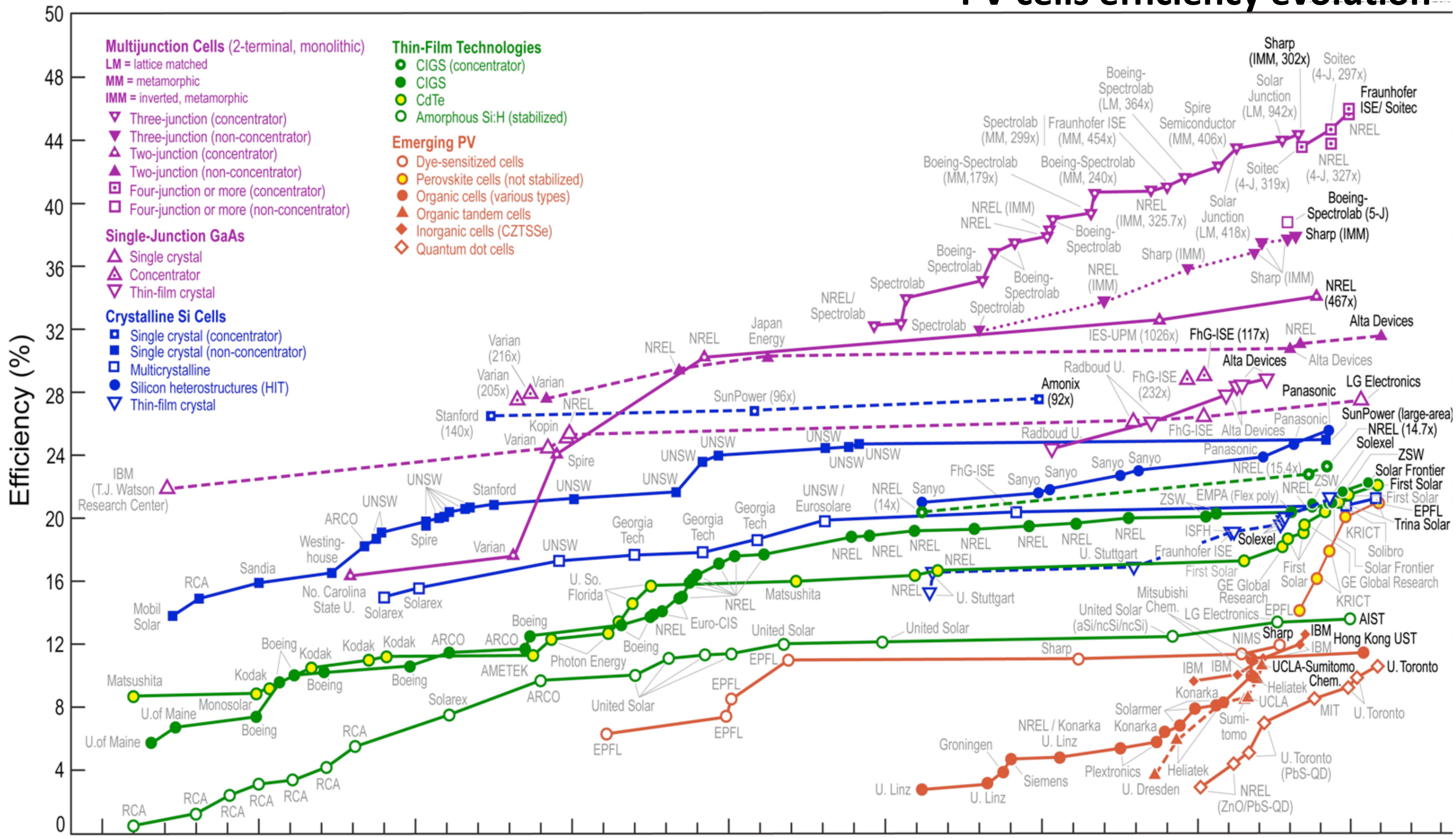
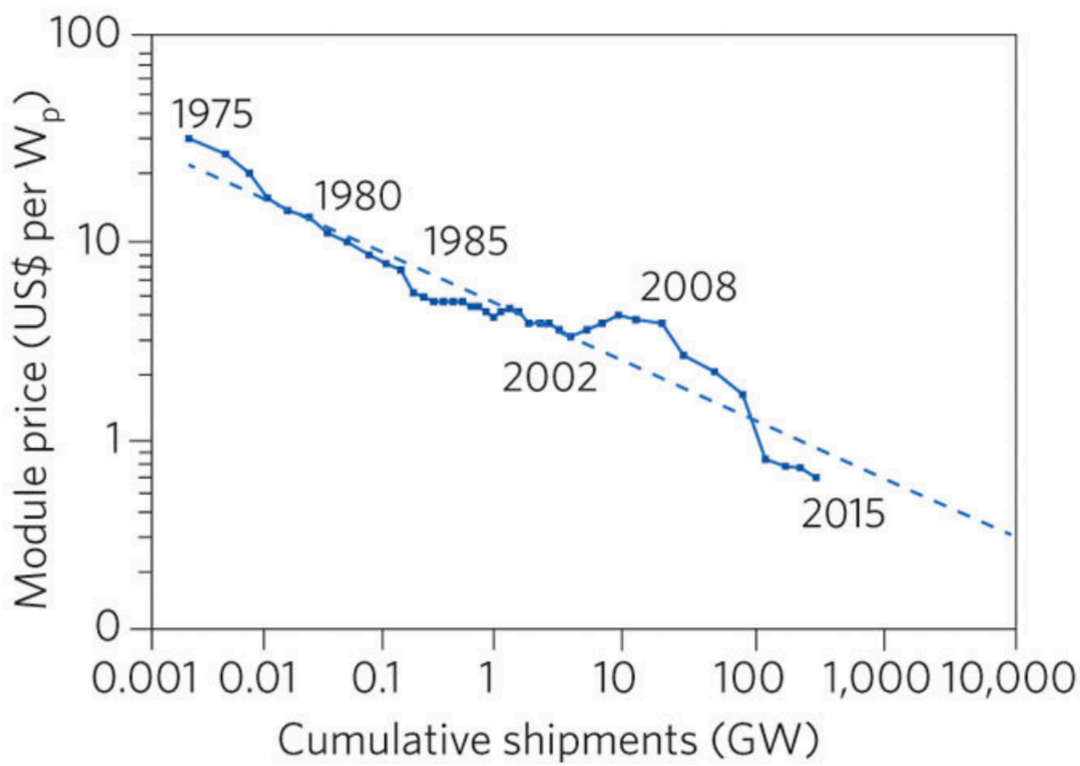


Figure 1 - Best research-Cell Efficiencies (Source: NREL 2016)

HOW TO ASSESS COST EVOLUTION?

Figure 2 : Historical learning curve for PV modules.

From: Solar power needs a more ambitious cost target

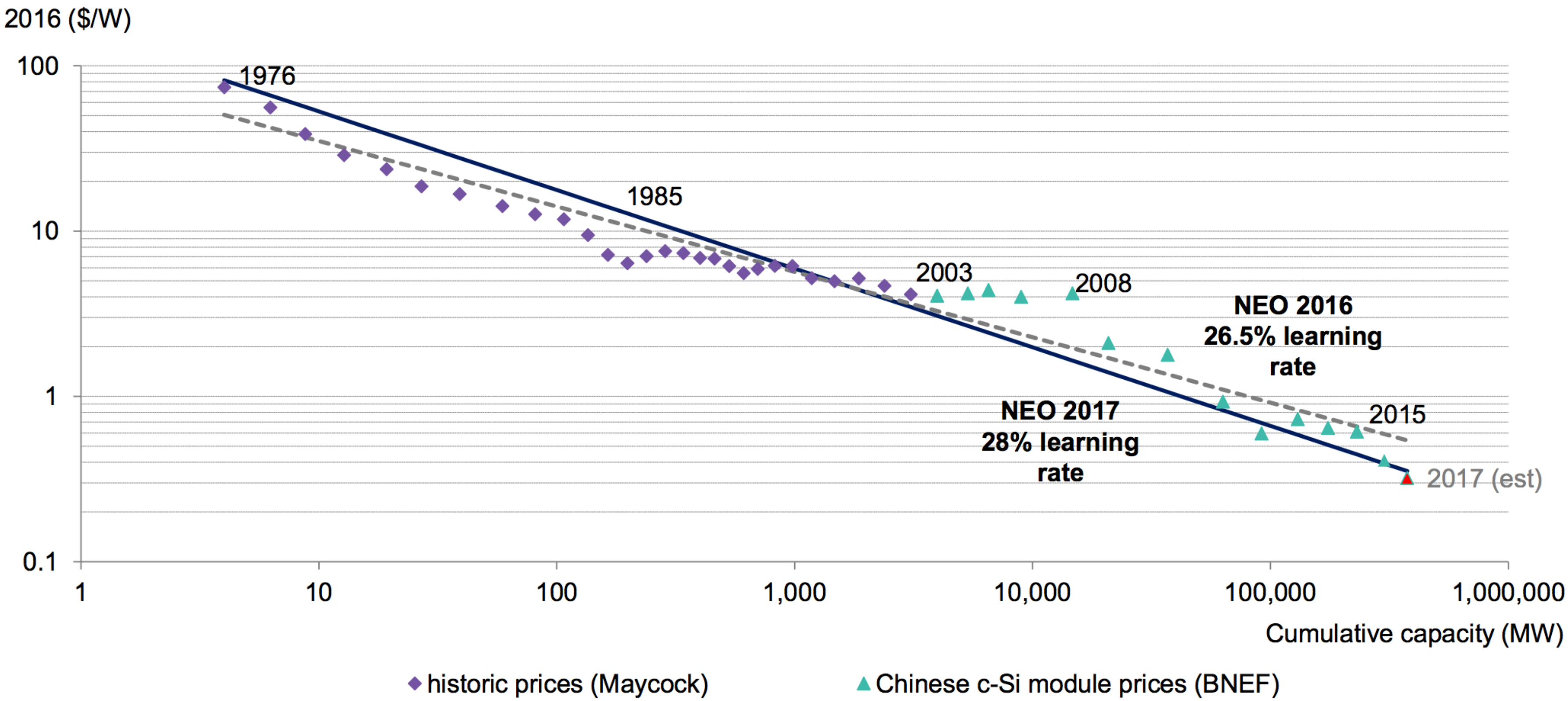


The dashed line shows the average decline in module price as a function of cumulative production, which from 1975 to 2015 has been approximately 18% for every doubling of cumulative production. Note that price is an imperfect proxy for cost in the short term. For example, above-average declines in price between 2008 and 2012 comprise a cost-reduction component as well as a profit margin compression component. Over long periods, however, price trends should reflect underlying cost trends. W_p, peak power output in watts. Data taken from GTM Research PV Cost Database, 2016.

V. Sivaram & S. Kann (2016), Nature Energy

Learning curves are usually linear trends from logarithimic scales

Solar technology is getting cheaper, faster



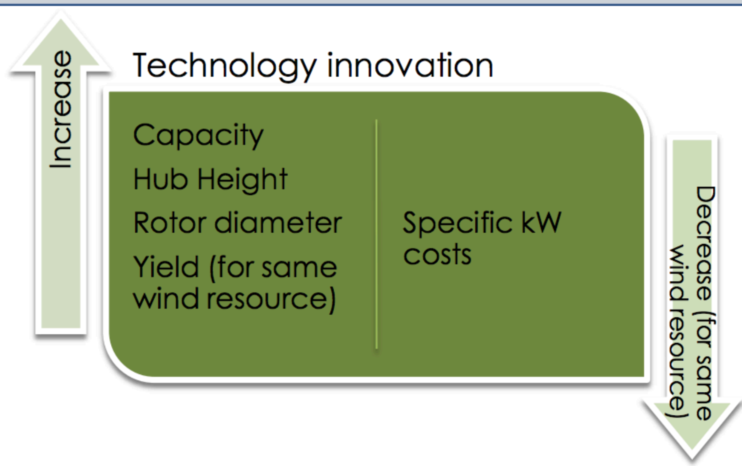
Source: Maycock, Bloomberg New Energy Finance

Onshore wind

The cost of onshore wind farms will continue to fall

Historically every doubling of global capacity has meant:

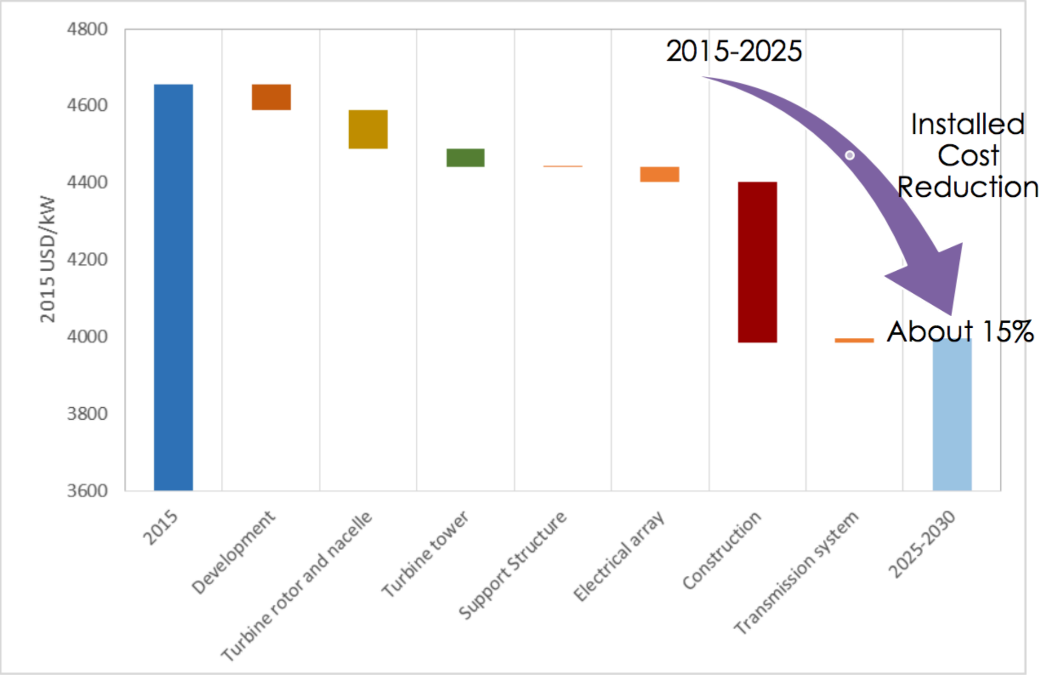
- 6% declined in investment costs
- 9% decline in LCOE



1983-2014	Global weighted average investment cots declined by two thirds: ▪ USD 4766/kW to USD 1623/kW
Drivers	Increased economies of scale ▪ Broader market (100+ countries) ▪ Greater competition in VC ▪ Technology innovation
US 1998-2014	▪ Avg. turbine capacity:+ 170% ▪ Avg. Hub height: +48% ▪ Avg. rotor diam.: +108%

Offshore wind: Installed costs

There are incremental opportunities to reduce capital costs by 2025 across the entire wind farm, from interconnection to project development



Projected installed cost reductions for offshore wind, 2015 to 2025

Inst. costs	Reduction driven by: ▪ construction and installation (about 60% of total cost reduction potential)
Other	▪ Incremental cost reductions for turbine rotors and nacelles

CSP: a set of technologies

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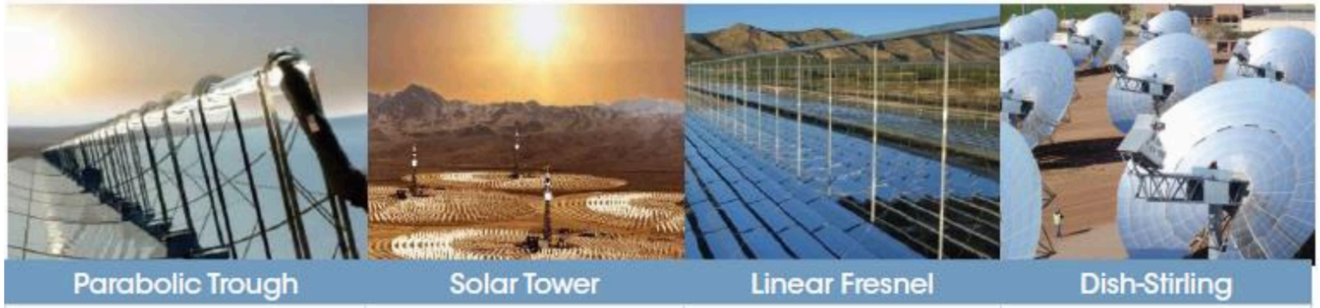
International Renewable Energy Agency

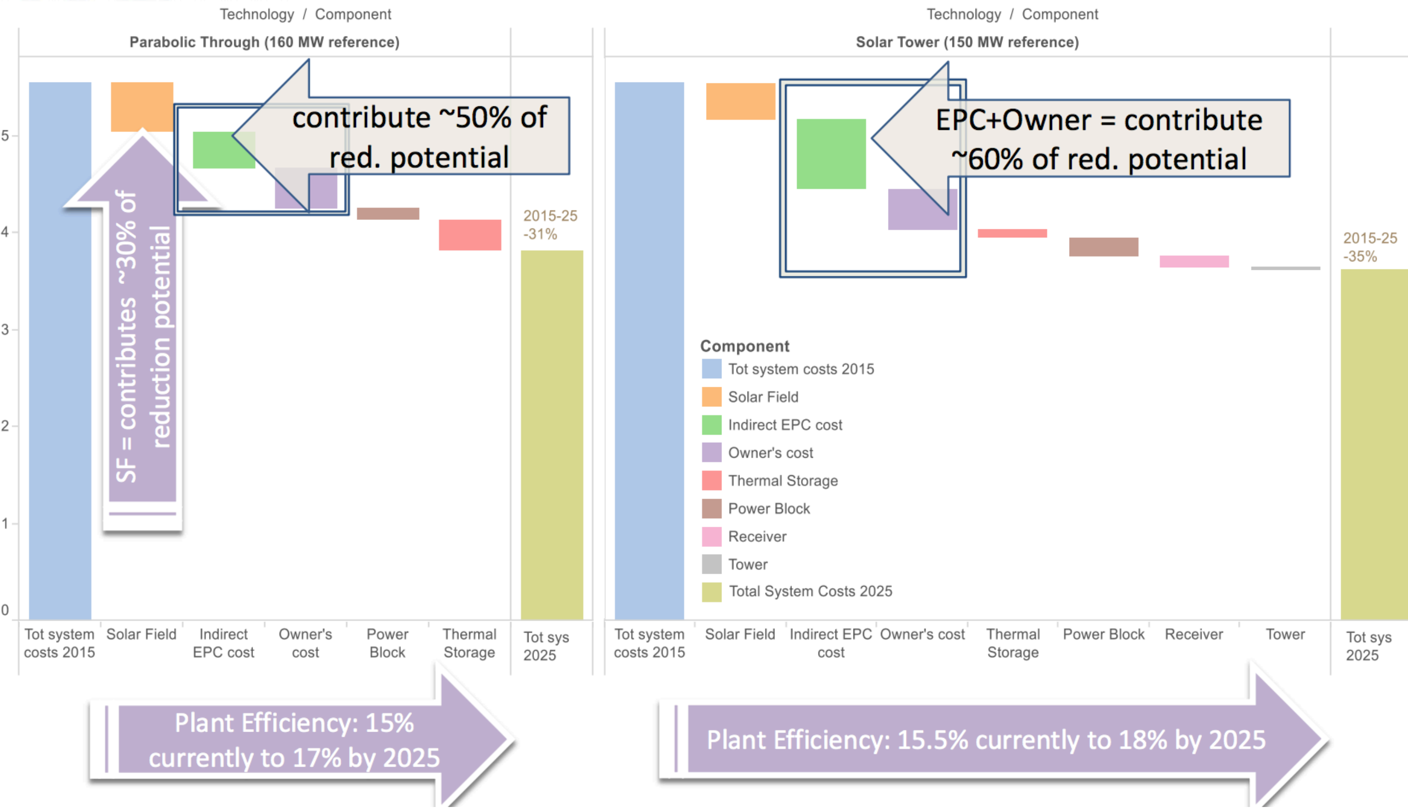


- Deployment is in its infancy (~5 GW)
- Cost reduction potential is good. IRENA analysis is focusing on parabolic trough (PT) and solar tower (ST)
- Solar towers have greater cost reduction potential with higher operating temperatures and lower cost thermal energy storage
- Cheap thermal energy storage allows dispatchable power -> potentially more valuable generation (particularly in high RE scenarios)

Concentrating solar power

Deployment in its infancy!

CAPEX could decline by one-third by 2025



PT -31% CAPEX (15-25)

- USD 5550/kW to USD 3800/kW 2025

ST -35% CAPEX (15-25)

- USD 5450/kW to USD 3600/kW

Indirect EPC costs + Owner's costs also major contributors to reduction potential

EPC stands for Engineering, Procurement, and Construction

HOW TO MANAGE THE VARIABILITY OF RENEWABLES [VRE: VARIABLE RENEWABLE ENERGY]?

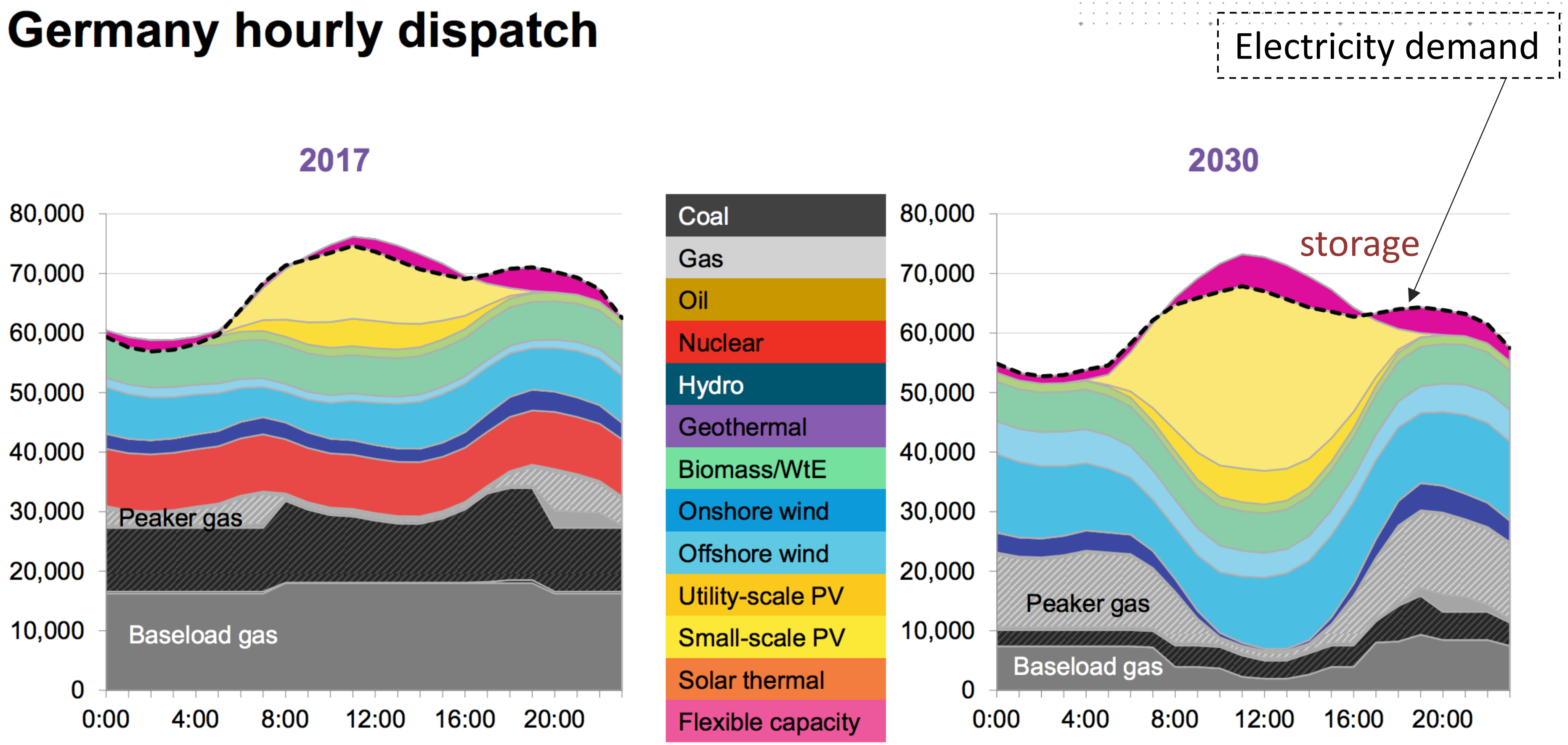
A dispatchable source of electricity refers to an electrical power system, such as a power plant, that can be turned on or off; in other words **they can adjust their power output supplied to the electrical grid on demand**. Most conventional power sources such as coal or nuclear power plants are dispatchable in order to meet the always changing electricity demands of the population. In contrast, many renewable energy sources are intermittent and non-dispatchable, such as wind power or solar power which can only generate electricity while their energy flow is input on them.

https://energyeducation.ca/encyclopedia/Dispatchable_source_of_electricity

HOW TO MANAGE THE VARIABILITY OF RENEWABLES?

"despachibility"

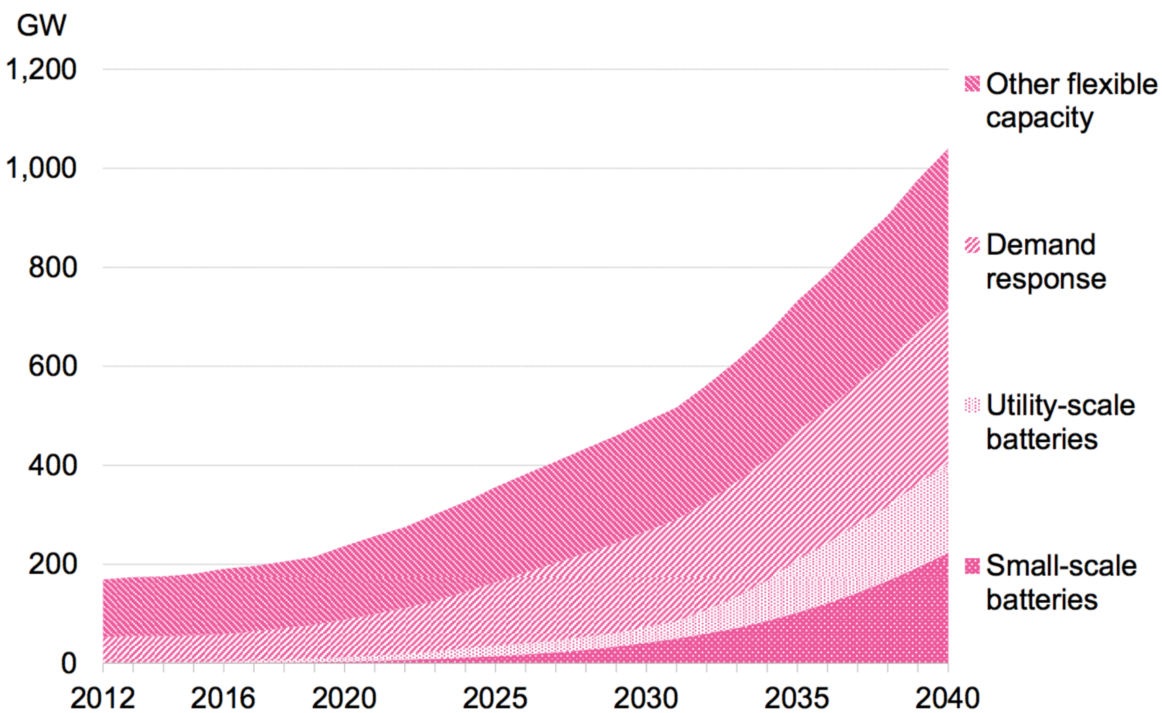
Germany hourly dispatch



Source: Bloomberg New Energy Forecast

Source: Bloomberg New Energy Finance

Demand response and batteries help meet peak demand and help balance the grid

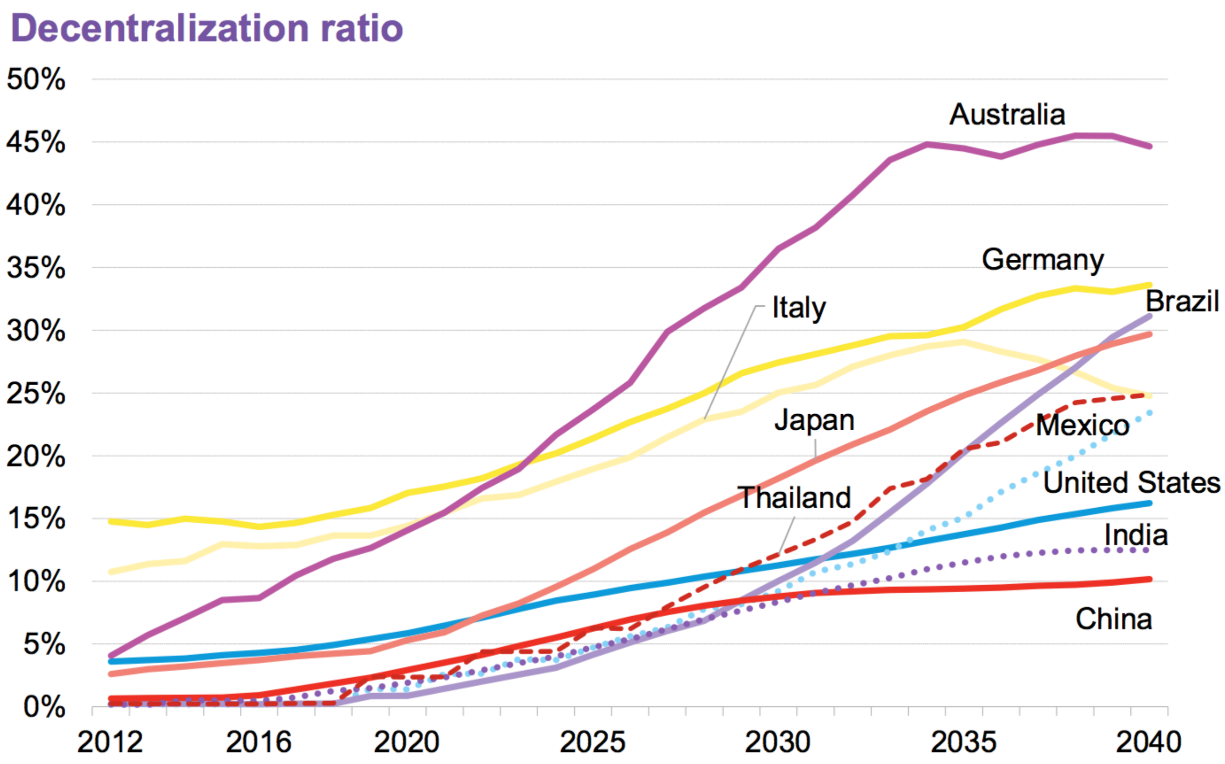


Top 5 markets in 2040	
China	343GW
U.S.	200GW
India	127GW
Japan	62GW
Germany	30GW

Source: Bloomberg New Energy Finance

MANAGEMENT OF VRE IS INCREASING

Australia, Germany, Japan, Brazil – most decentralized



Source: Bloomberg New Energy Finance Note: decentralization ratio is the ratio of non-grid-scale capacity to total installed capacity.

Mainland Portugal: electricity consumption was ensured only by renewable sources between 4 pm on Friday, 9 March, and 1 pm on Monday, 12 March. SEE EXPLANATION HERE

IS LCOE ENOUGH TO CAPTURE THE VALUE OF RENEWABLES?

FROM COST TO VALUE:

The development and deployment of renewable energy (RE) can make a contribution to energy, environmental and economic policy in three interacting areas.

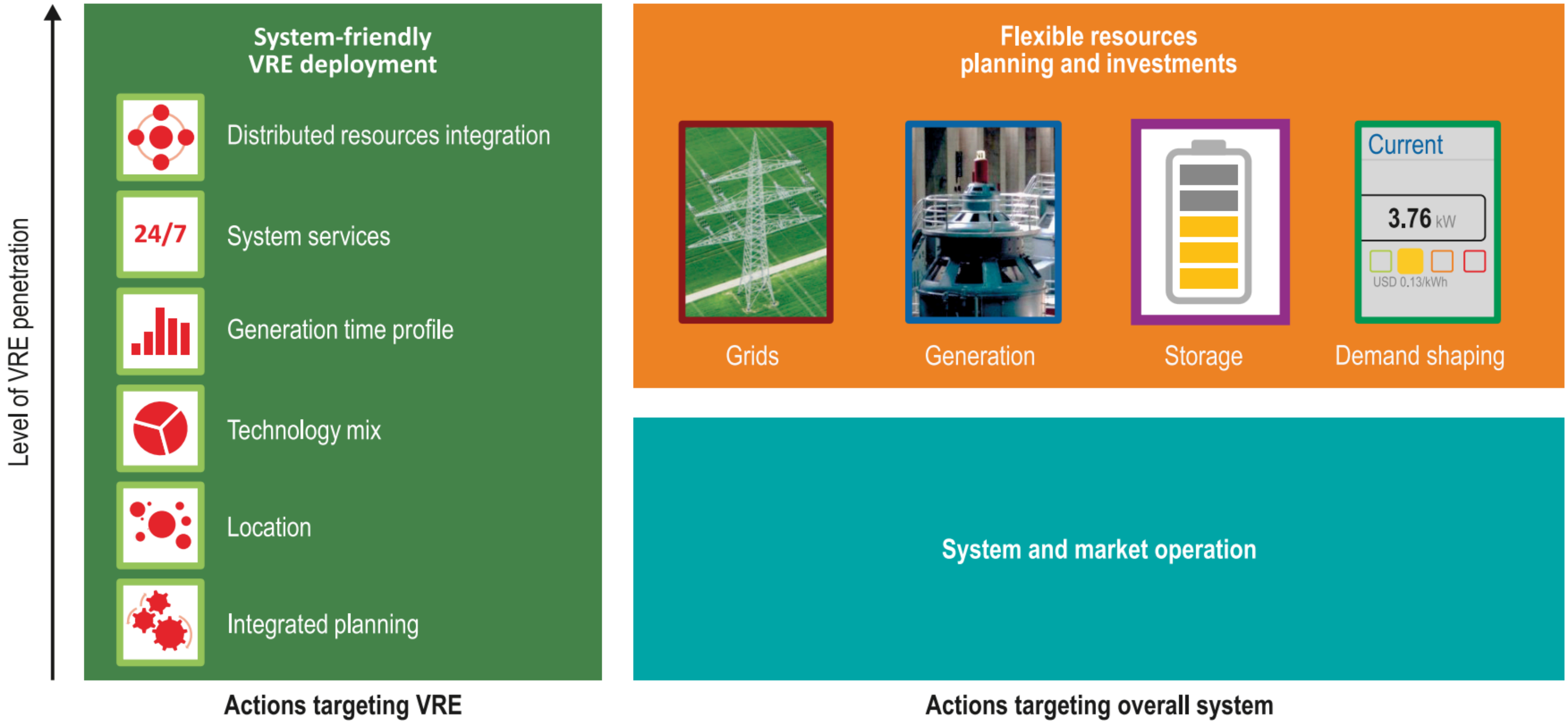
1) energy security (including smart grids);
2) reduction of carbon dioxide (CO2) emissions and other environmental impacts (air pollution reduction);
3) economic development (jobs creation)
4) new businesses based on local empowerment schemes (*prosumers*)

LCOE is not enough! –> energy systems analysis

Ler mais em:
https://www.iea.org/publications/freepublications/publication/Next_Generation_Windand_Solar_PowerFrom_Cost_to_ValueFull_Report.pdf

https://webstore.iea.org/download/direct/309

Figure ES.2 • Three pillars of system transformation



Key point: VRE can facilitate system integration in combination with improved operations and investment in flexible resources.