Doutoramento em Alterações Climáticas e Políticas de Desenvolvimento Sustentável

SEMINAR ENERGY & CLIMATE CHANGE

Júlia Seixas
mjs@fct.unl.pt

NOVA SCHOOL OF SCIENCE & TECHNOLOGY

CENSE center for environmental and sustainability research

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Renewables in the energy system

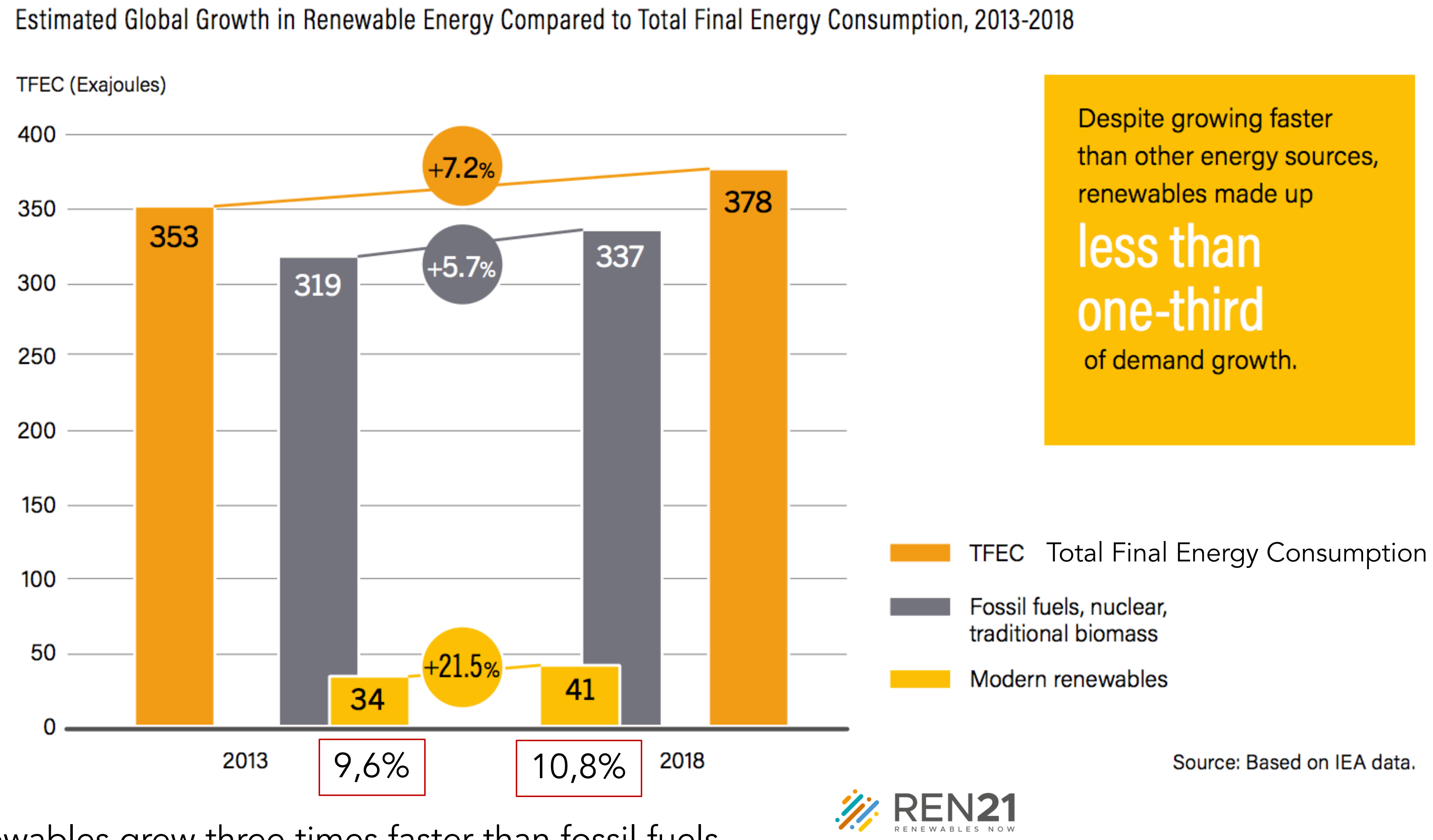
- Insights of the state of the art (SOA), mostly based on Renewables 2020 Global Status Report
- Selected concepts to reason about renewables
  - LCOE
  - Capacity Factor
  - Technology Learning curves
  - VRE: Dispatchability
  - System value

Airborne wind energy

Twingtec

Explore more on AWE systems here

SOA: Renewables growth



9,6%

10,8%

Renewables grew three times faster than fossil fuels

SOA: Renewables in energy use

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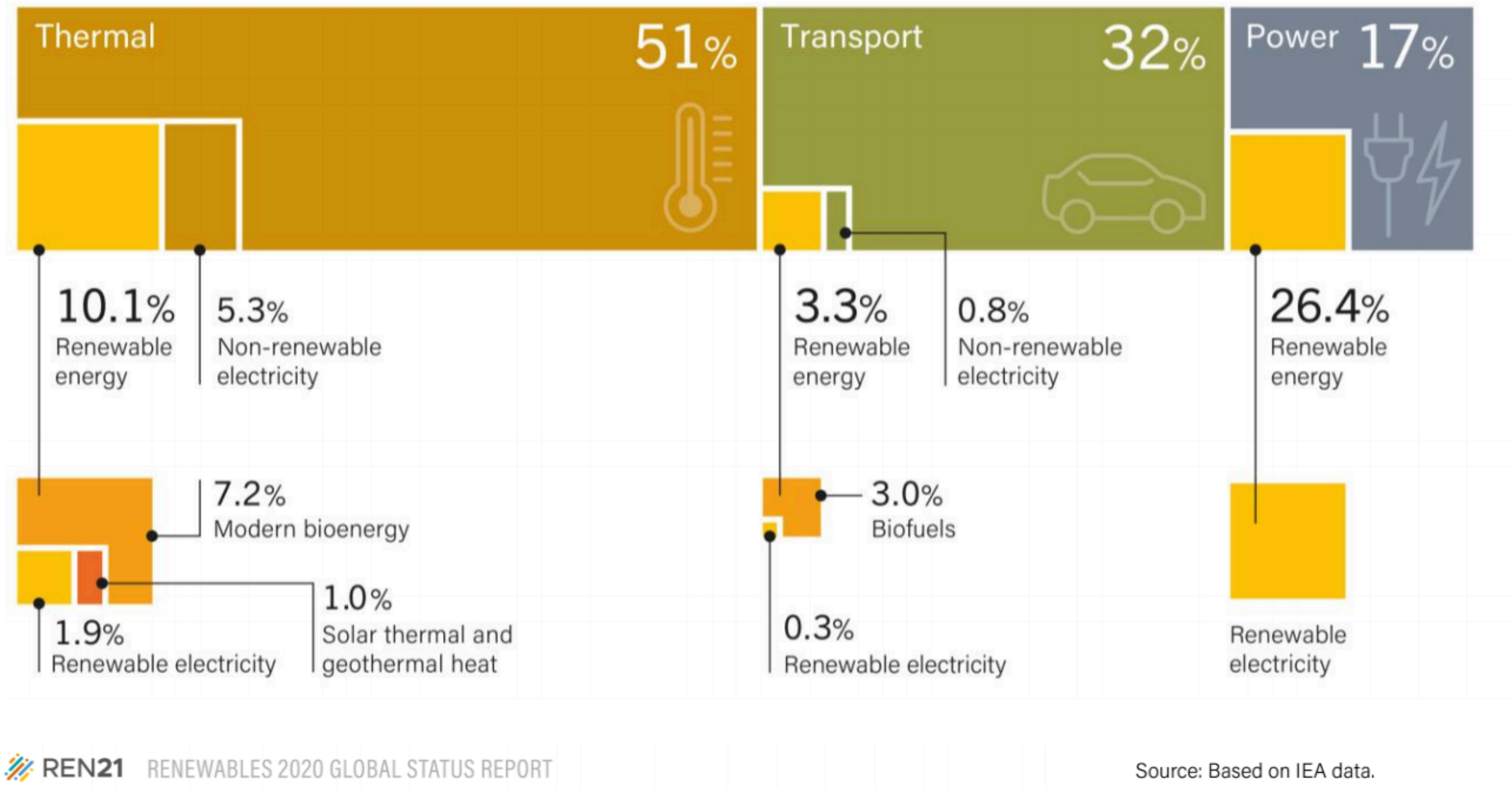
MORE THAN 80% OF OUR ENERGY FOR HEATING, COOLING, TRANSPORT

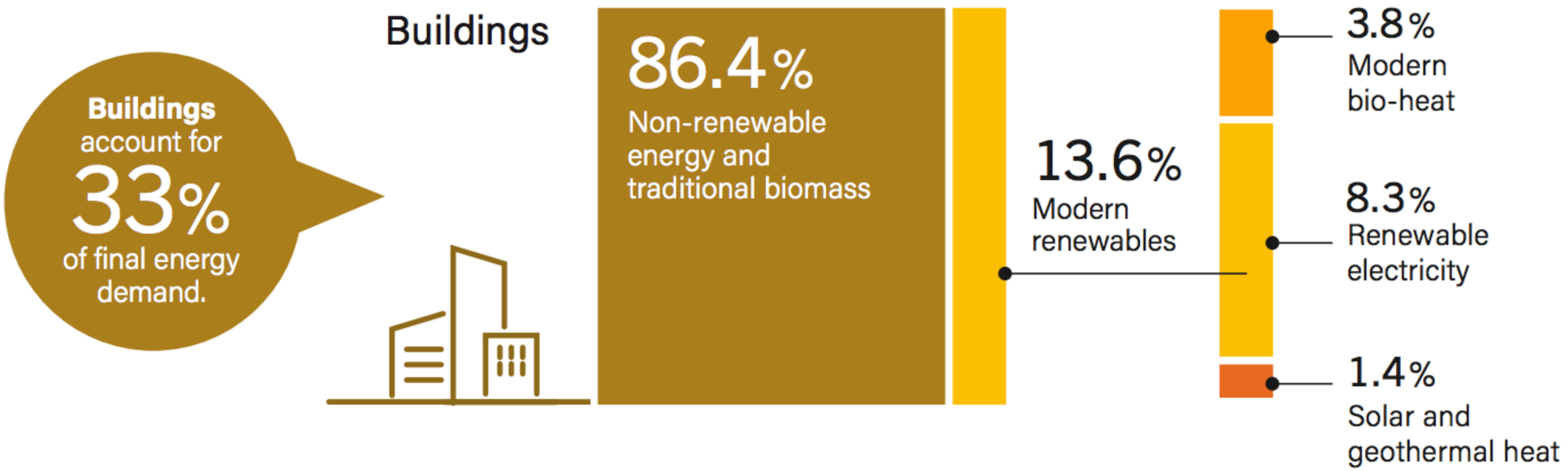


Most focus is on the power sector.

But the **greatest urgency** is in heating, cooling and transport.

SOA: Renewables in Buildings

Renewable Share of Total Final Energy Consumption in Buildings, 2017



Note: Modern bio-heat includes heat supplied by district energy networks.
Totals may not add up due to rounding.

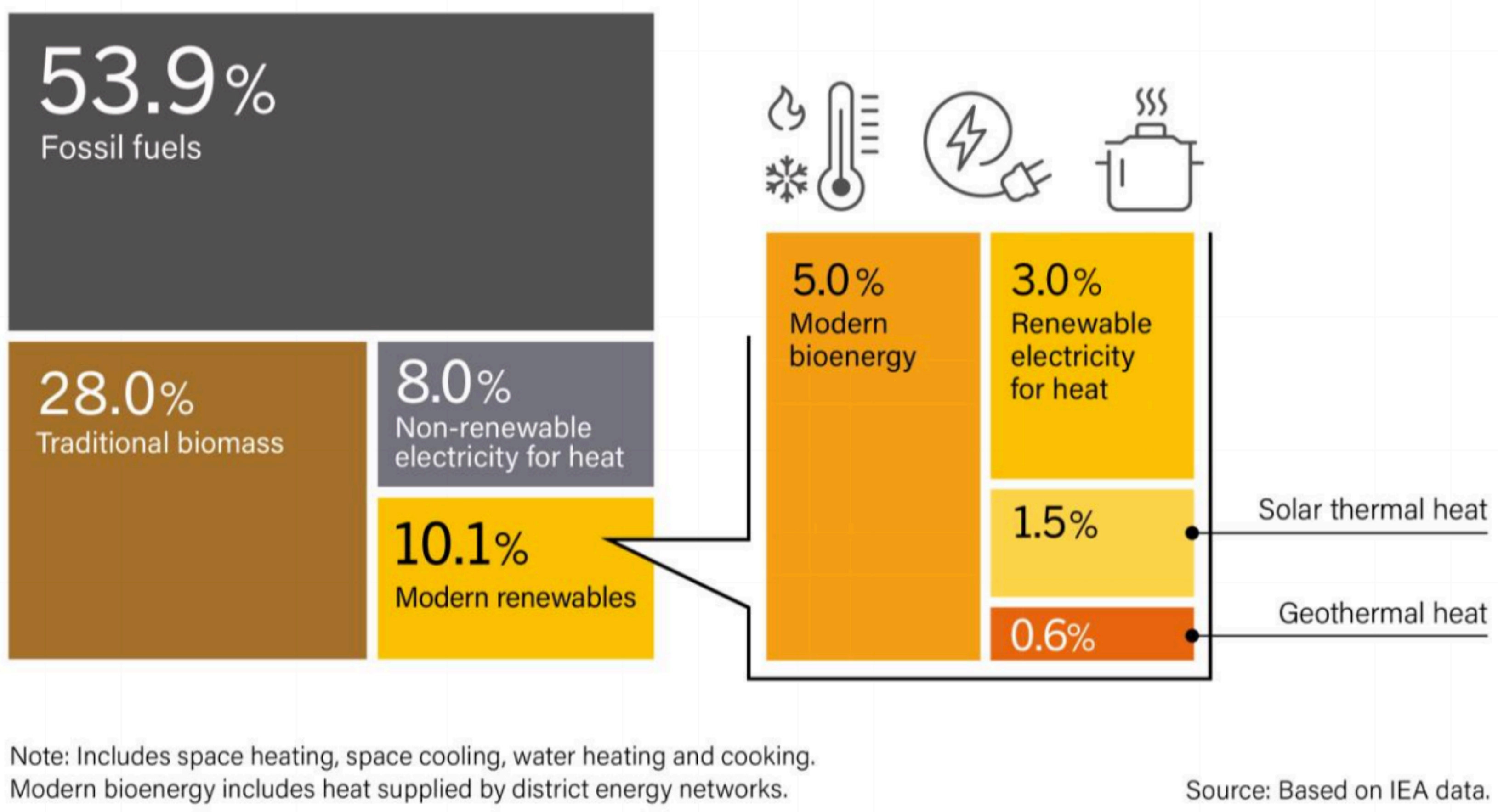
Source: Based on IEA data.

REN21 RENEWABLES NOW

RENEWABLES WERE FASTEST GROWING ENERGY SOURCE IN BUILDINGS

SOA: Renewables in Buildings

RENEWABLE HEAT IS GRADUALLY GROWING IN BUILDINGS



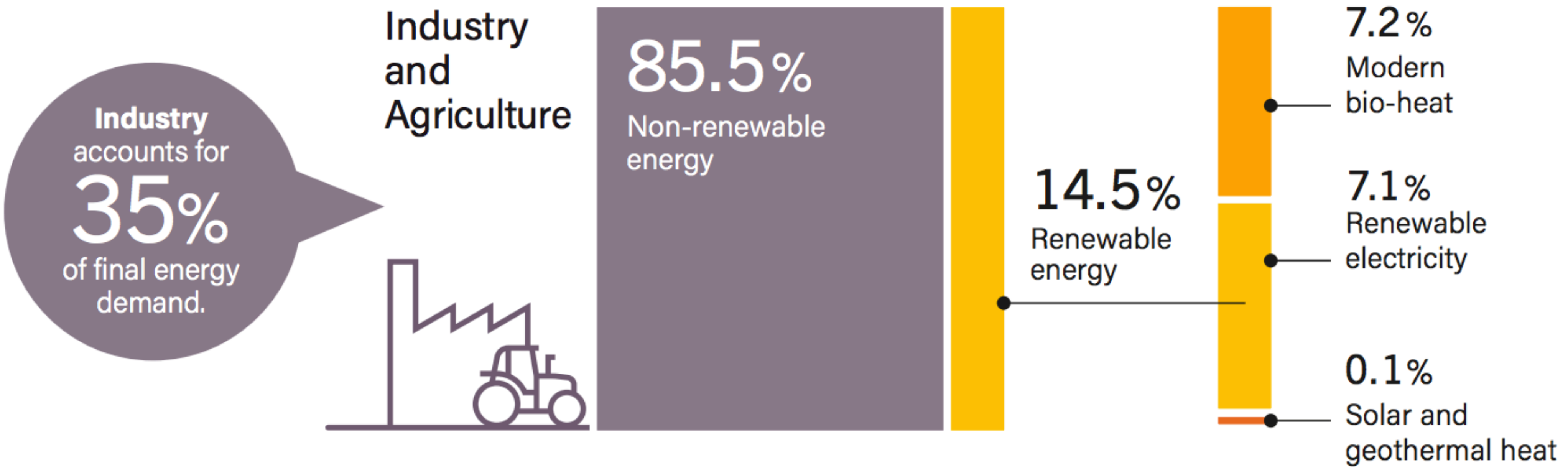
REN21 RENEWABLES NOW

Estimated Renewable Share of Heating and Cooling in Buildings, 2018

The share of renewable heating and cooling in buildings grew from **8% in 2010** to more than 10% in 2018.

SOA: Renewables in Industry & Agriculture

Renewable Share of Total Final Energy Consumption in Industry and Agriculture, 2017



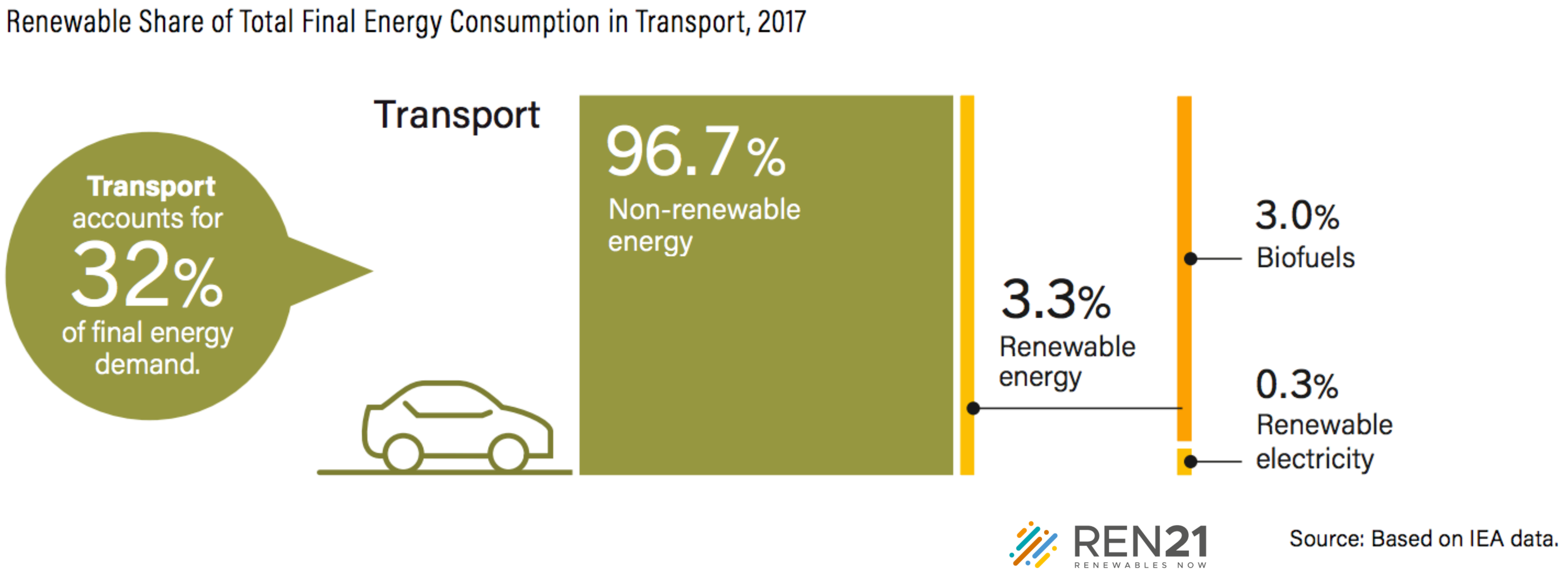
Note: Modern bio-heat includes heat supplied by district energy networks.
Totals may not add up due to rounding.

REN21 RENEWABLES NOW

Source: Based on IEA data.

RENEWABLES IN INDUSTRIAL ENERGY USE REMAINS SMALL

SOA: Renewables in Transport



KEY BARRIERS

- Sector heavily relying on fossil fuel - Fossil fuel “centered” market structures - Fossil fuel subsidies – no level playing field
- Lack of strong policy support → no new countries with biofuel blend mandates since 2017
- Exploding demand growth
- Only nine countries with advanced mandates
- Limited options in aviation and shipping

SOA: Renewables in Electricity generation

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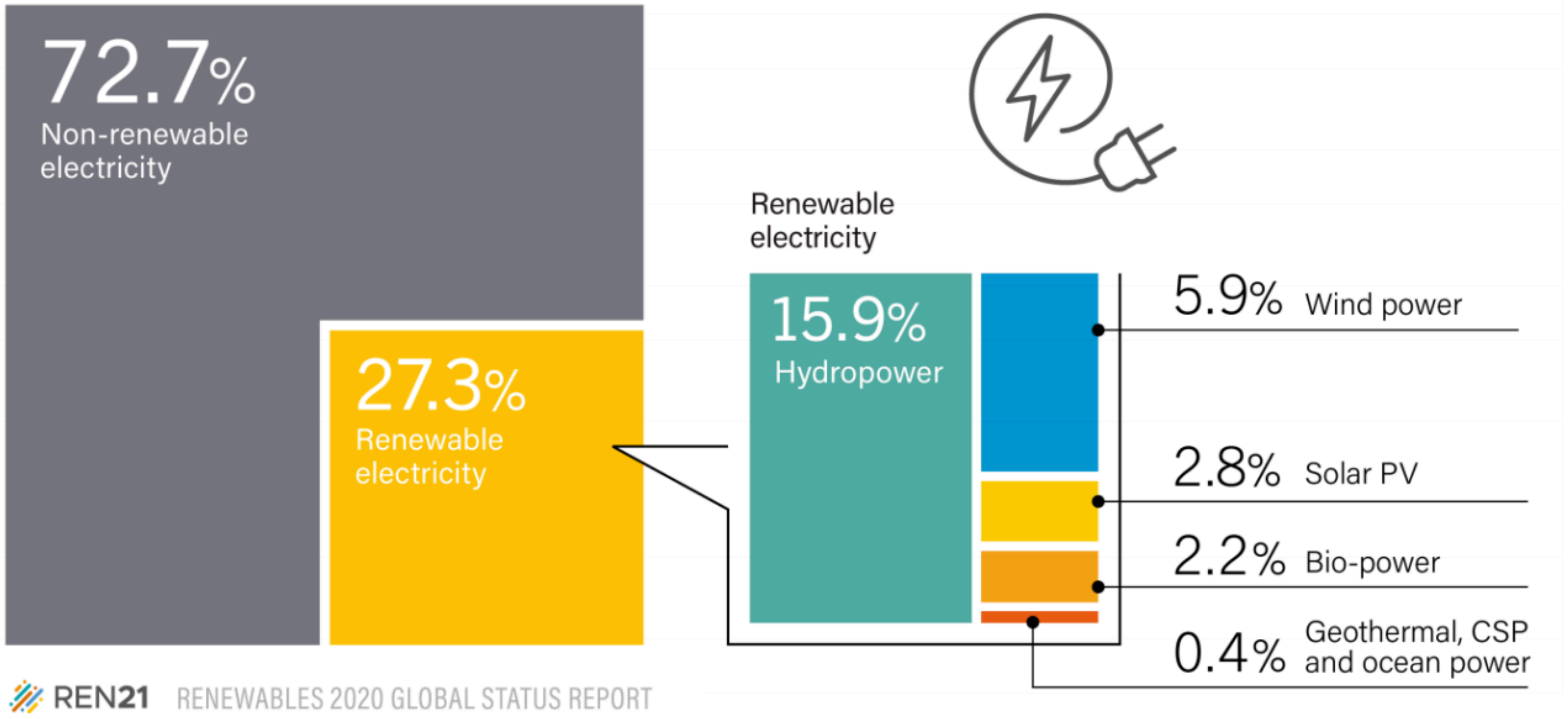
MORE THAN 27% OF GLOBAL ELECTRICITY IS NOW RENEWABLE



Estimated Renewable Energy Share of Global Electricity Production, End-2019

The share of renewables in electricity generation is **rising in many countries around the world.**

SOA: Renewables in Electricity generation

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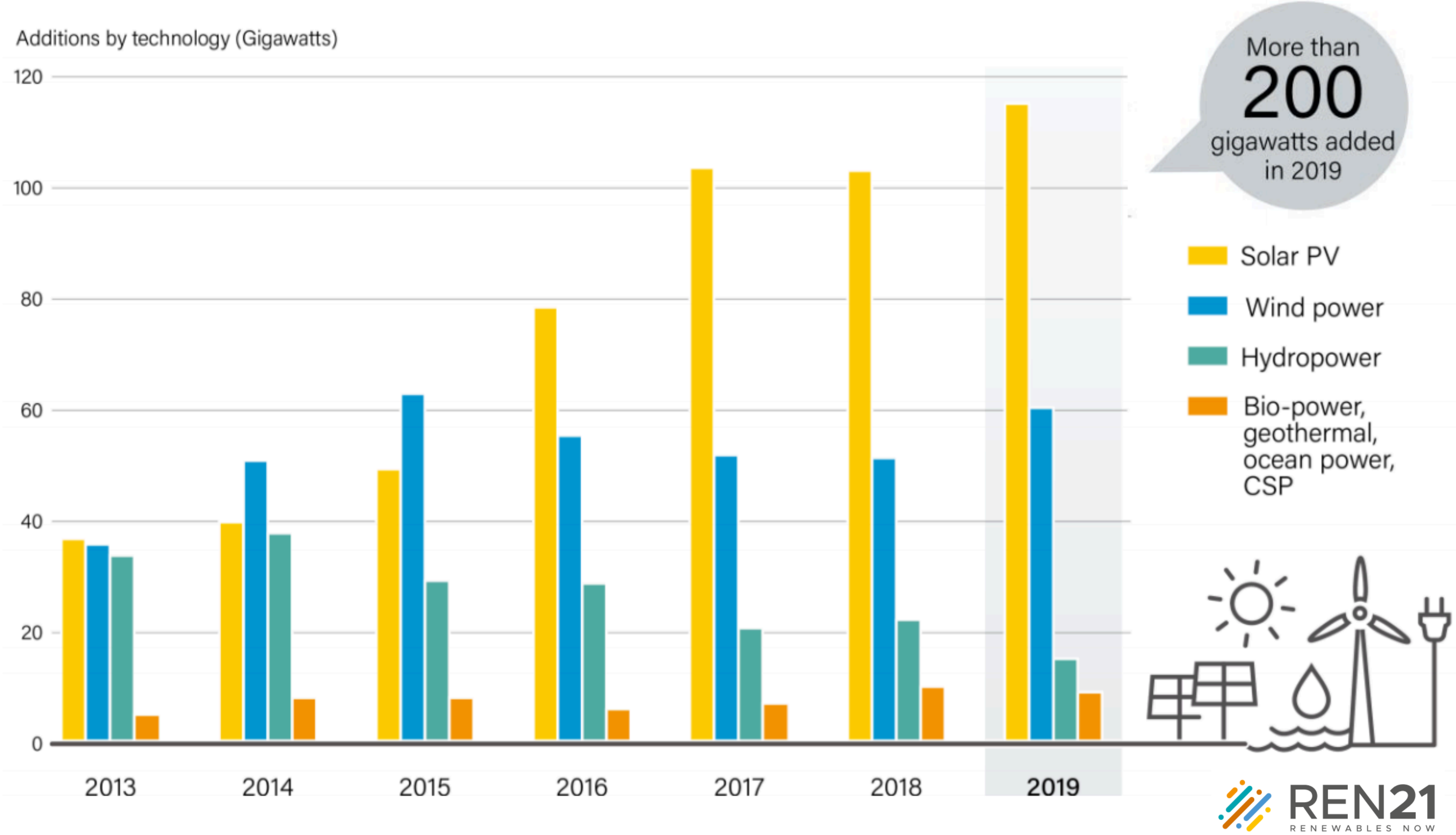
MORE THAN 200 GIGAWATTS OF RENEWABLE POWER ADDED IN 2019

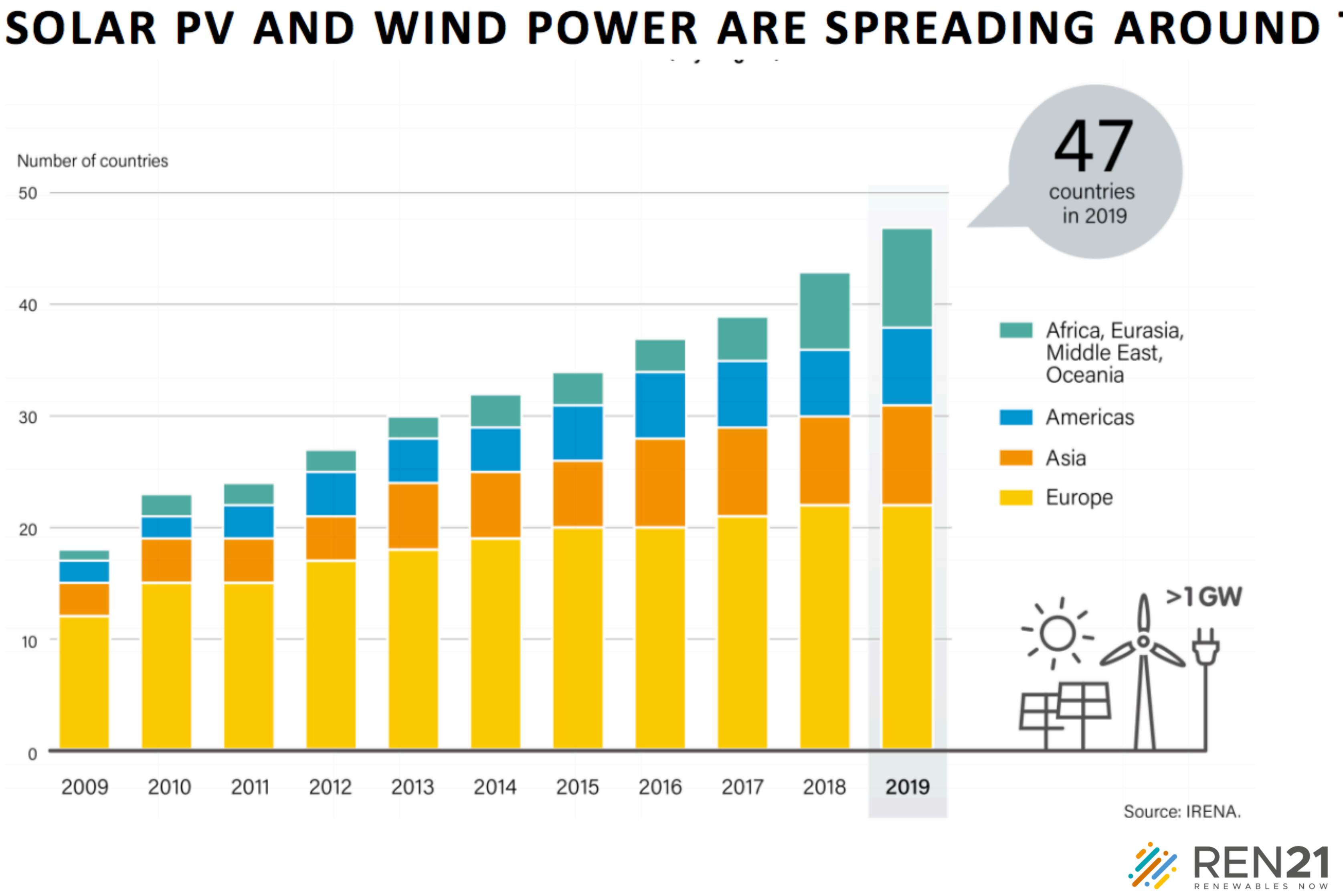


Annual Additions of Renewable Power Capacity, by Technology and Total, 2013-2019

Although most of the additions were from **solar PV (115 GW),** global markets for wind power and bio-power also grew during 2019.

Total Installed Capacity in Portugal (2019): 22,3 GW (for comparison purpose)

SOA: Renewables in Electricity generation



Number of Countries with More Than 1 GW of Solar PV and Wind Power, by Region, 2009-2019

47 countries had installed at least 1 GW of solar PV and wind power. compared to **18 countries** in 2009.

SOA: Renewables in Electricity generation

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TOTAL CAPACITY OR GENERATION AS OF END-2019

Countries in **bold** indicate change from 2018.

POWER	1	2	3	4	5
Renewable power capacity (including hydropower)	China	United States	Brazil	India	Germany
Renewable power capacity (not including hydropower)	China	United States	Germany	India	Japan
Renewable power capacity *per capita* (not including hydropower)[1]	Iceland	Denmark	**Sweden**	**Germany**	**Australia**
Bio-power capacity	China	United States	Brazil	**India**	**Germany**
Geothermal power capacity	United States	Indonesia	Philippines	Turkey	New Zealand
Hydropower capacity[2]	China	Brazil	Canada	United States	Russian Federation
Hydropower generation[2]	China	Brazil	Canada	United States	Russian Federation
Solar PV capacity	China	United States	Japan	Germany	India
Concentrating solar thermal power (CSP) capacity	Spain	United States	**Morocco**	**South Africa**	**China**
Wind power capacity	China	United States	Germany	India	Spain

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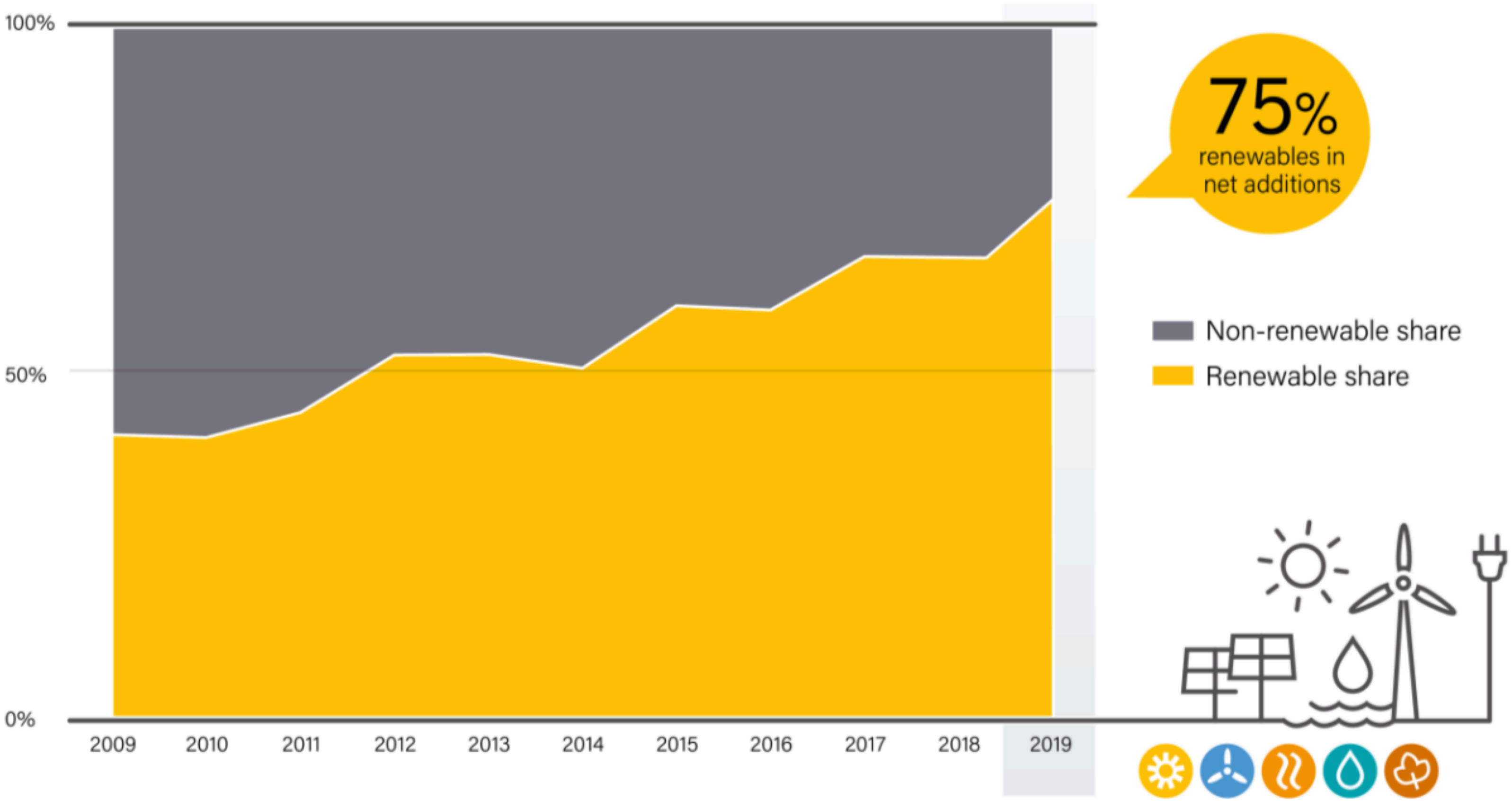
MORE RENEWABLE POWER ADDED THAN FOSSIL FUEL AND NUCLEAR



Renewable and Non-renewable Shares of Net Annual Additions in Power Generating Capacity, 2009-2019

For **the fifth year in a row**, net additions of renewable power generation capacity were higher than net installations of both fossil fuel and nuclear power capacity combined.

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Net additions mean decomissioned plants were subtracted

SOA: Renewables in Electricity generation

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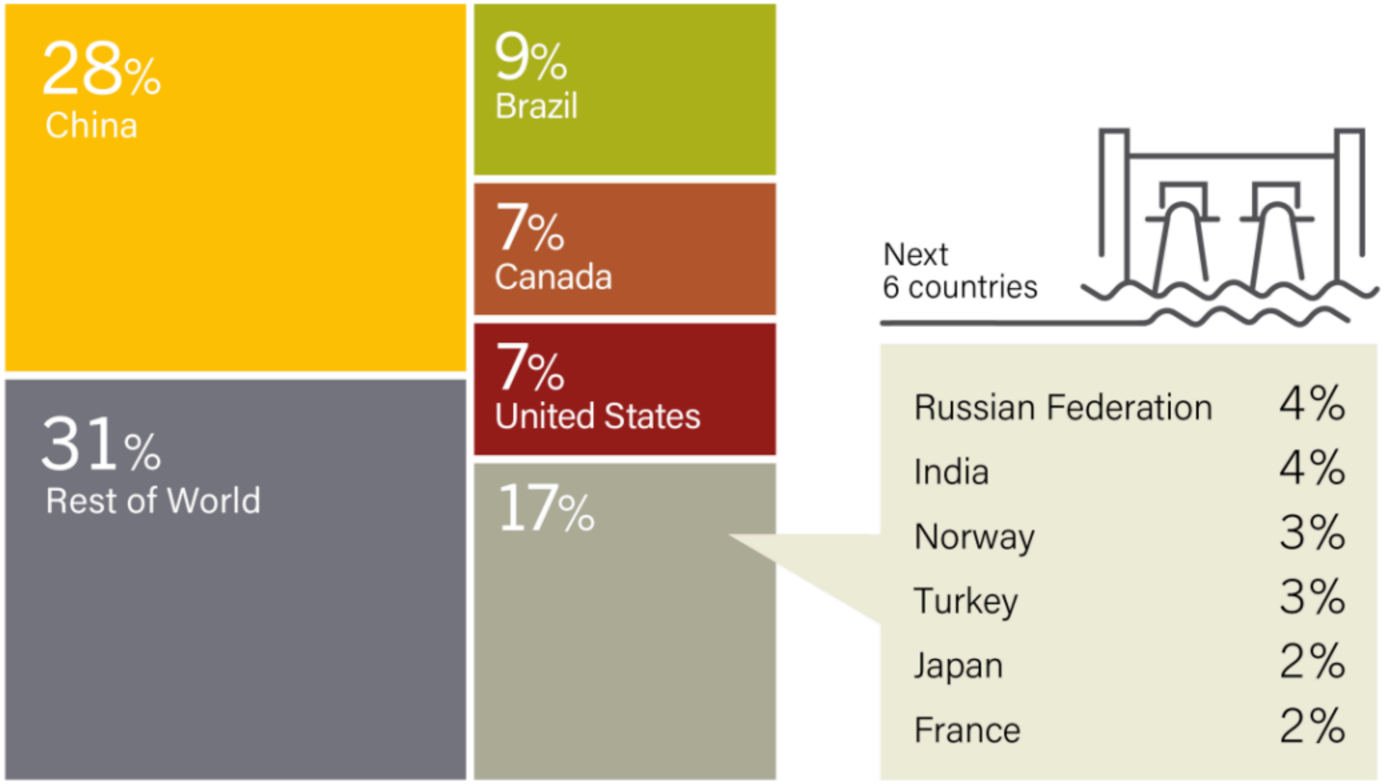
HYDROPOWER CHARACTERISED BY MARKET STABILITY



Note: Totals may not add up due to rounding.

Source: Global total from IHA.

REN21 RENEWABLES NOW

Hydropower Global Capacity, Shares of Top 10 Countries and Rest of World, 2019

Only 15.6 GW added in 2019, continuing a multi-year trend of market deceleration.

SOA: Renewables in Electricity generation

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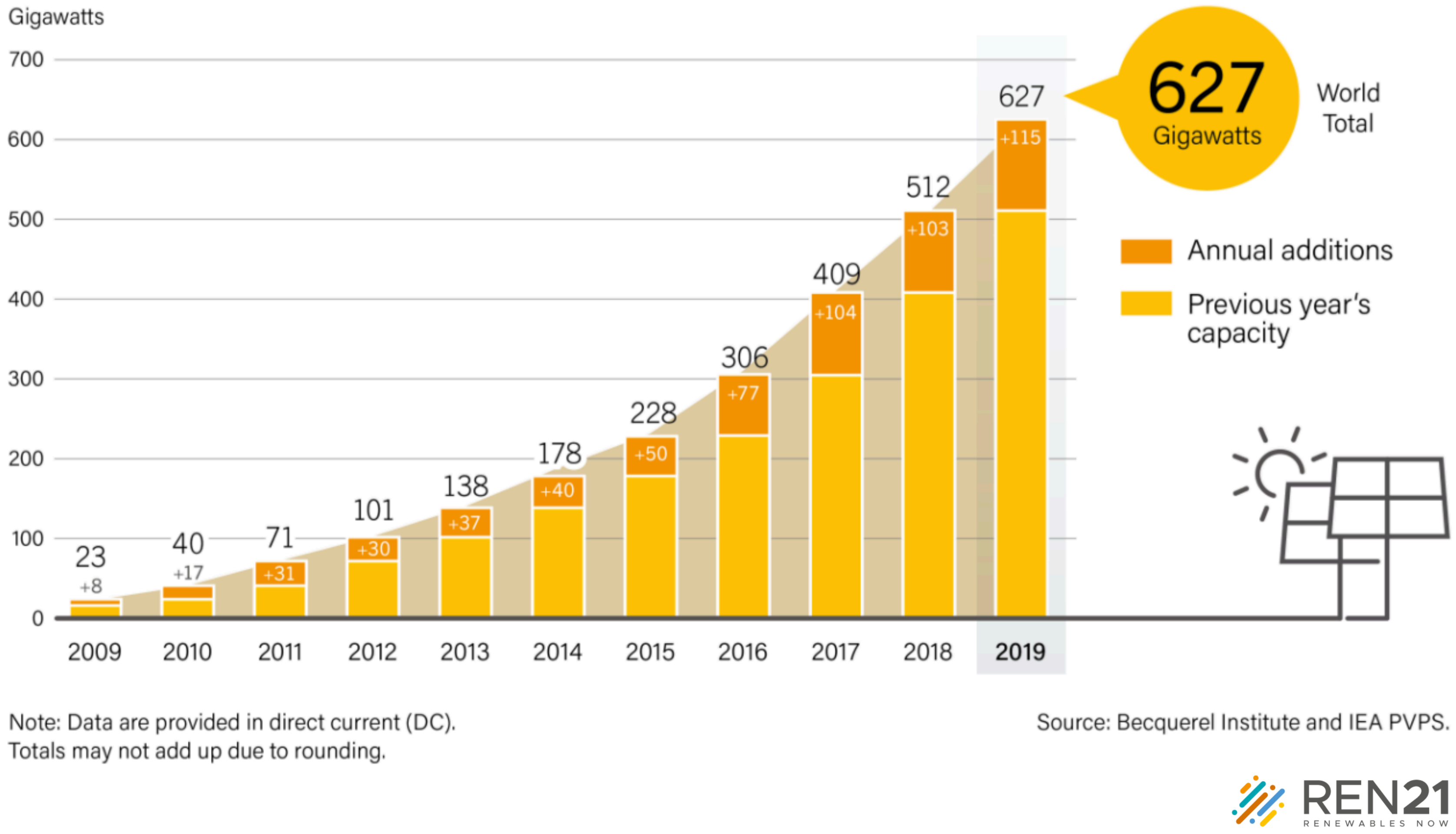
SOLAR PV CAPACITY ADDITIONS PASSED 115 GW MARK IN 2019



Solar PV Global Capacity and Annual Additions, 2009-2019

By the end of 2019, **22 countries** had enough capacity in operation to meet **at least 3% of their** electricity demand with solar PV.

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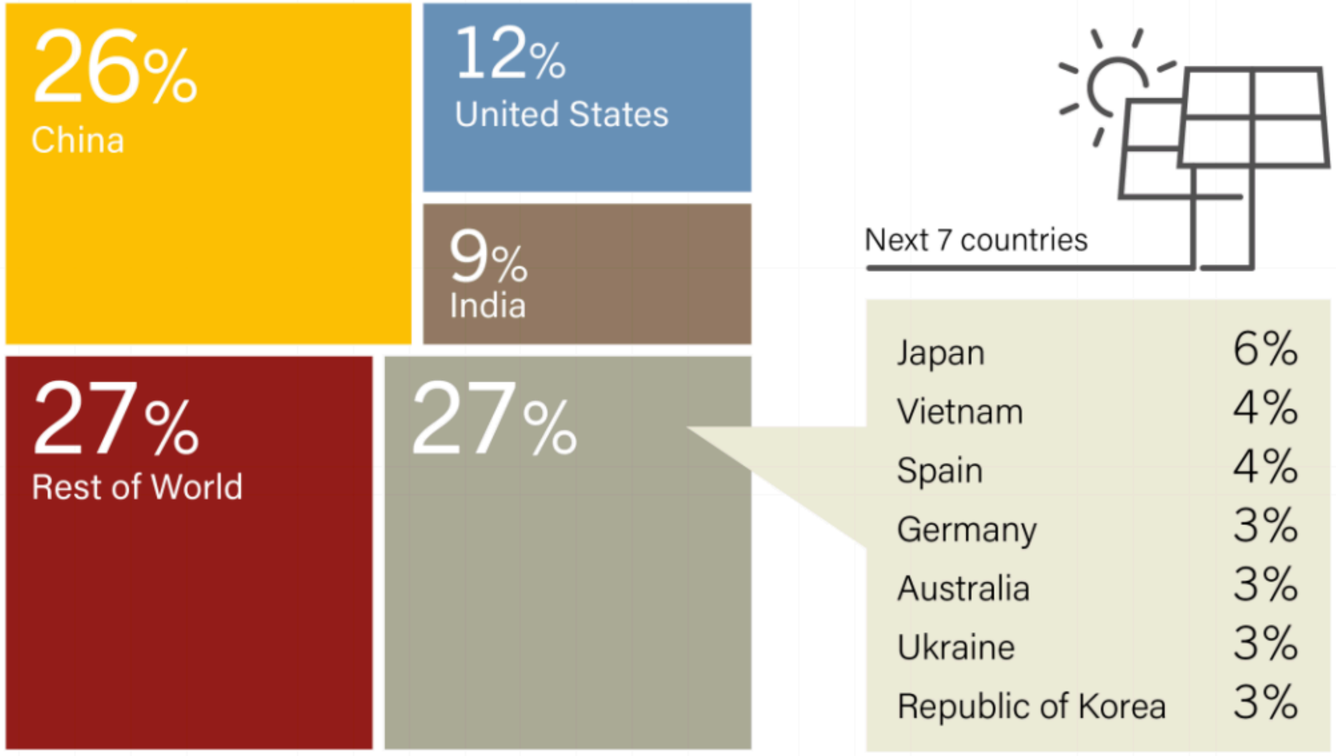
ASIA: MAIN REGIONAL SOLAR PV MARKET FOR 7TH CONSECUTIVE YEAR



REN21 RENEWABLES 2020 GLOBAL STATUS REPORT

Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2019

Asia accounted for half of global additions, despite declines in the region's top three markets (China, India and Japan).

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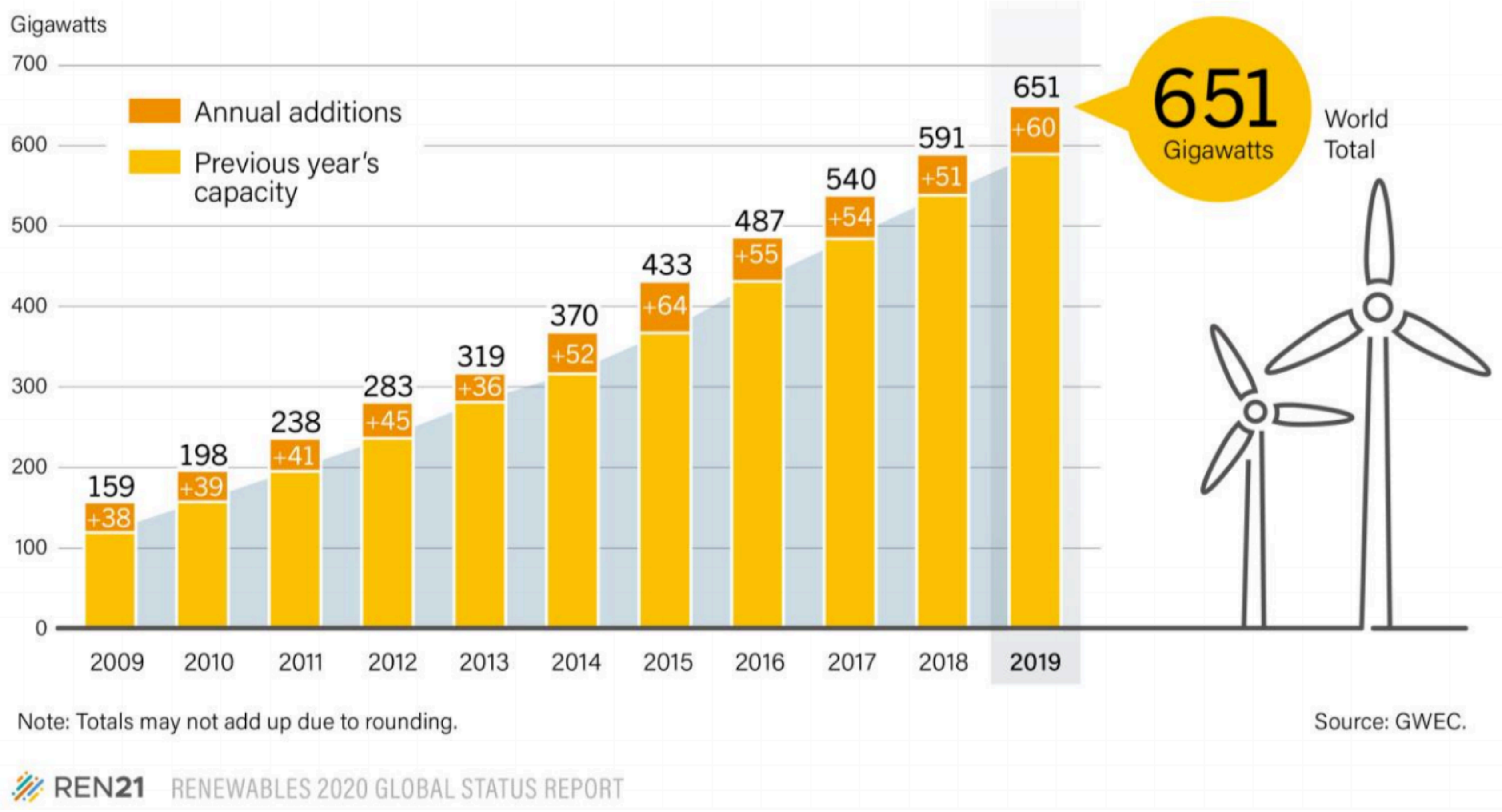
WIND POWER CAPACITY CONTINUES INCREASE STEADILY YEAR-ON-YEAR



Wind Power Global Capacity and Annual Additions, 2009-2019

The global wind power market saw its **second largest** annual increase in 2019.

China again saw an increase in new installations (**up 22%**) during 2019, adding around 26.8 GW.

MORE THAN HALF OF NEW WIND POWER CAPACITY IN ASIA

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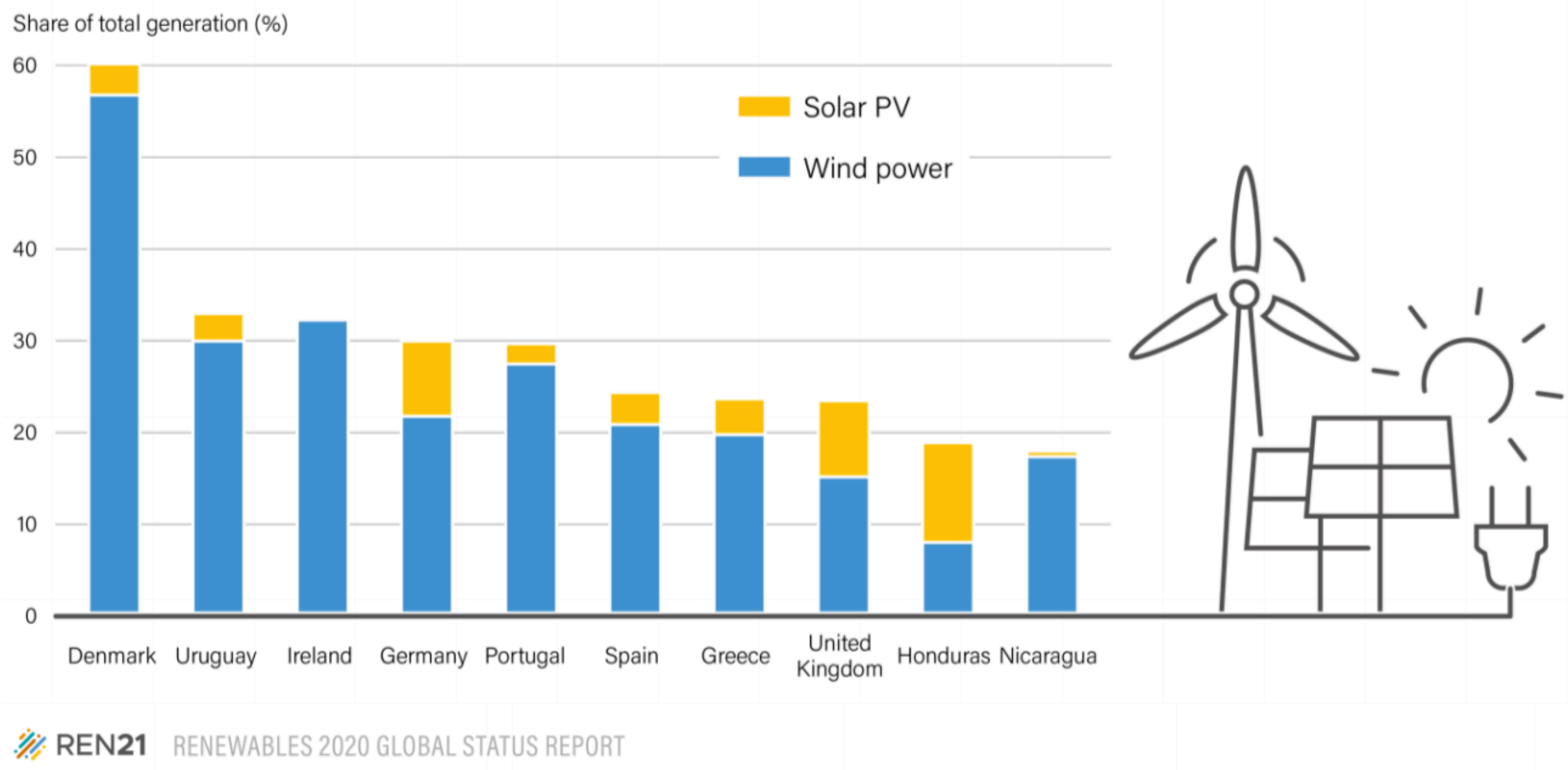
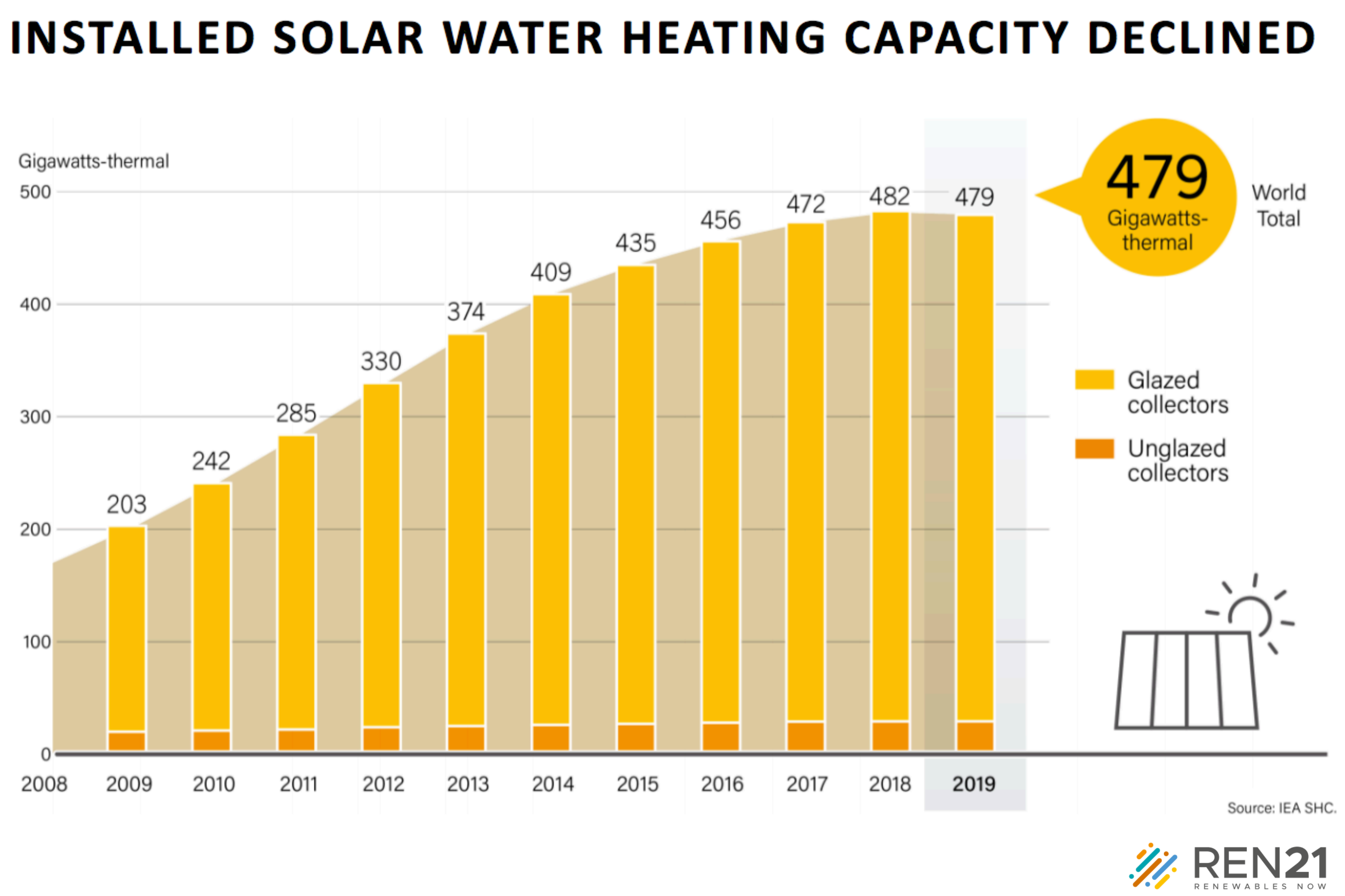
VARIABLE RENEWABLES REACHING HIGH SHARES IN MANY COUNTRIES



Share of Electricity Generation from Variable Renewable Electricity, Top Countries, 2019

At least four countries met **more than 30%** of their electricity generation from VRE in 2019 including **Denmark, Germany, Ireland** and **Uruguay.**

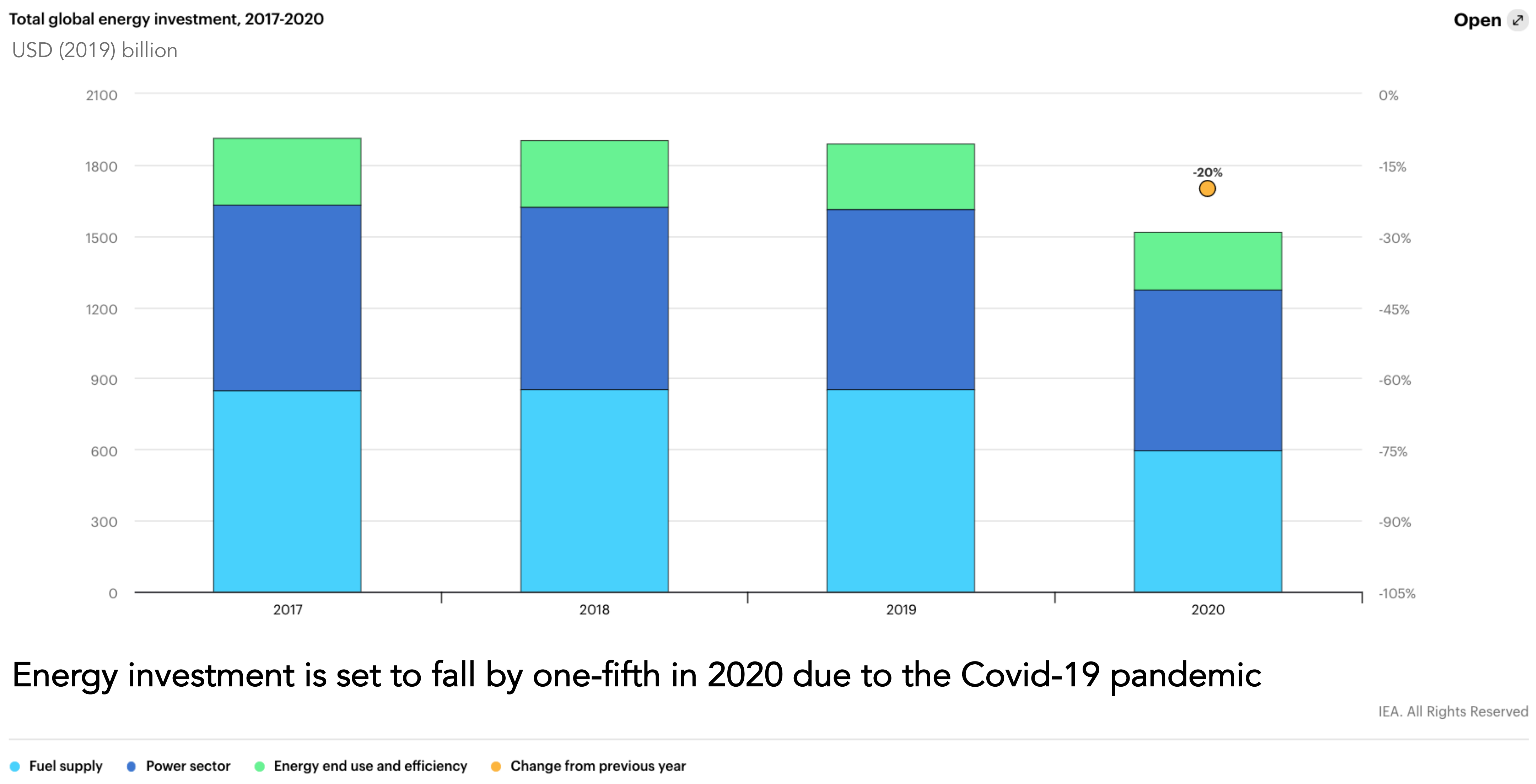
SOA: Renewables in water heating



Solar Water Heating Collectors Global Capacity, 2009-2019

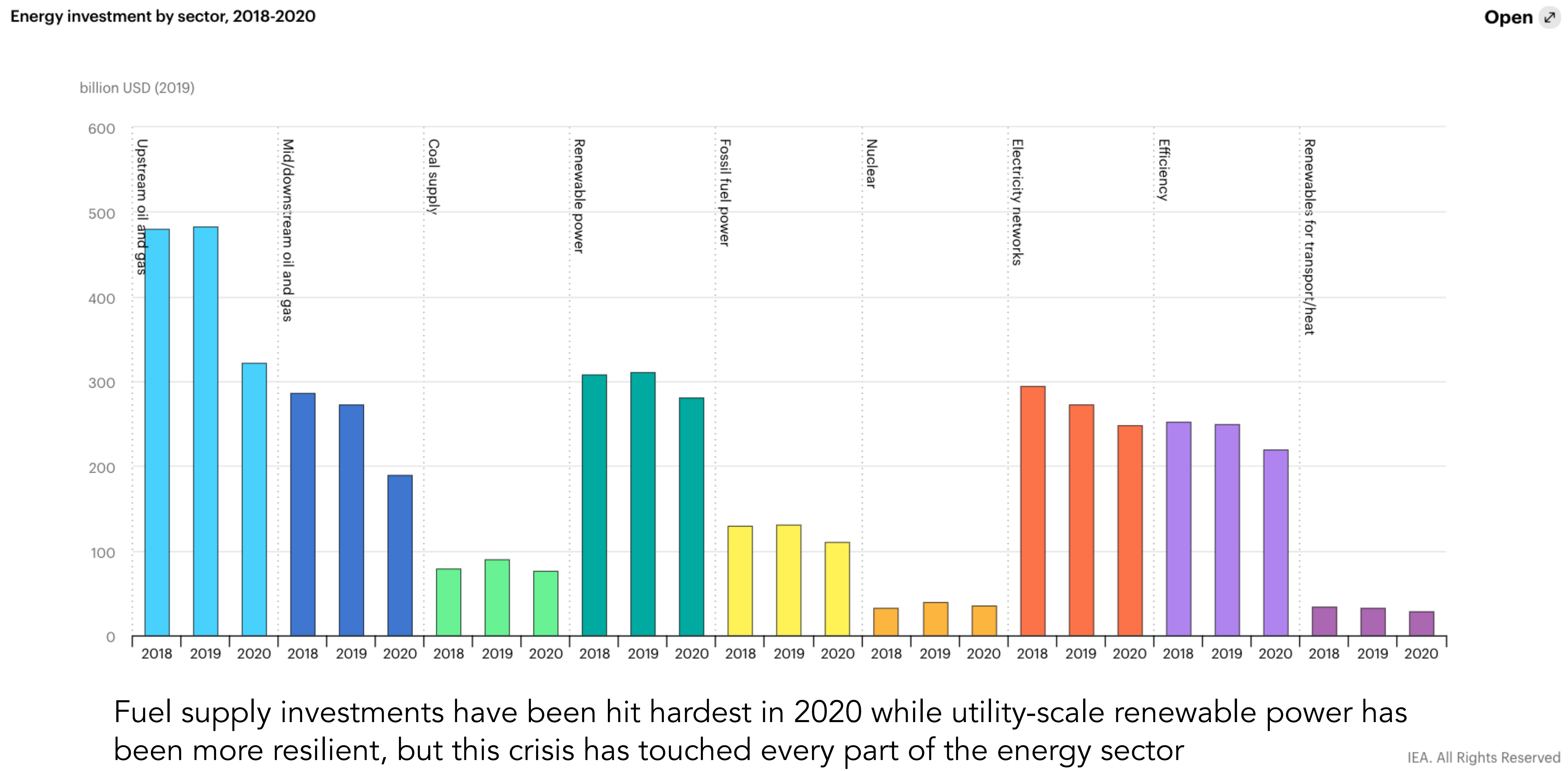
For the first time ever, global operating solar thermal capacity **declined**, down 1% from 2018.

SOA: Renewables investment



Read more here.

SOA: Renewables investment

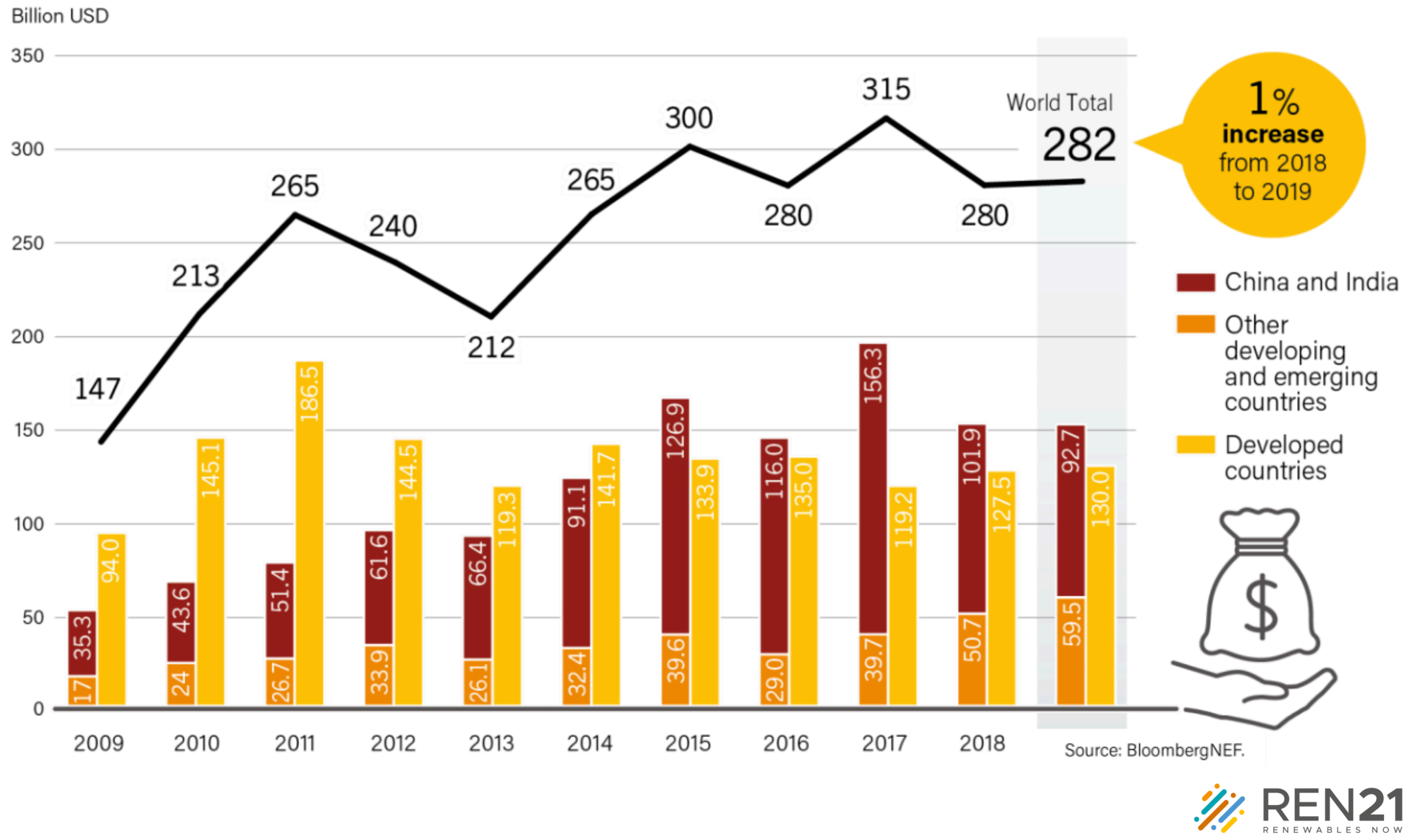


Fuel supply investments have been hit hardest in 2020 while utility-scale renewable power has been more resilient, but this crisis has touched every part of the energy sector

Read more here.

SOA: Renewables investment

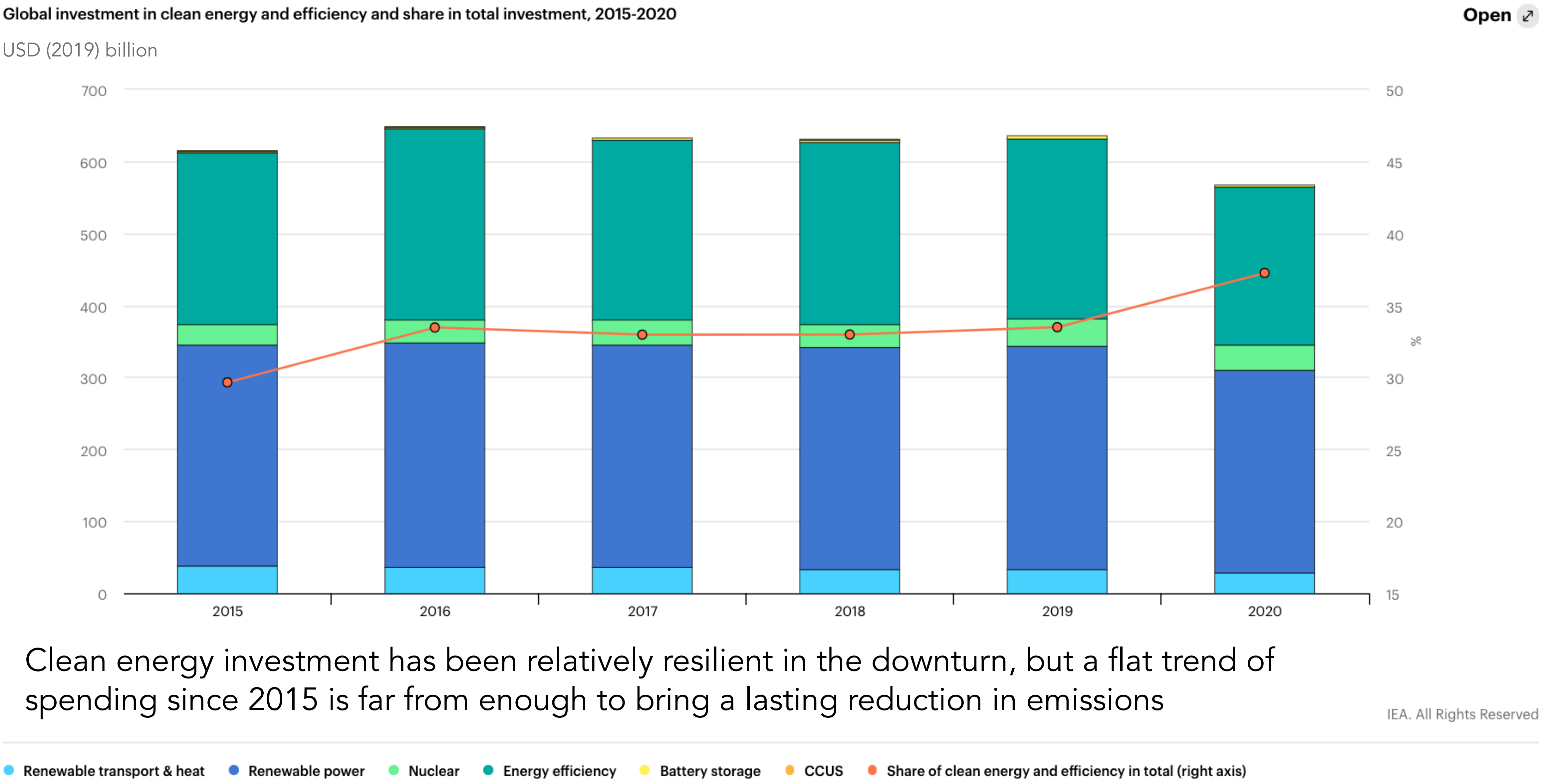
INVESTMENT IN RENEWABLES HAS BARELY GROWN



Global New Investment in Renewable Power and Fuel Capacity in Developed, Emerging and Developing Countries, 2009-2019

Developing and emerging economies surpassed developed countries in renewable energy capacity investment for the fifth year running, reaching USD 152 billion.

SOA: Renewables investment



Clean energy investment has been relatively resilient in the downturn, but a flat trend of spending since 2015 is far from enough to bring a lasting reduction in emissions

Read more here.

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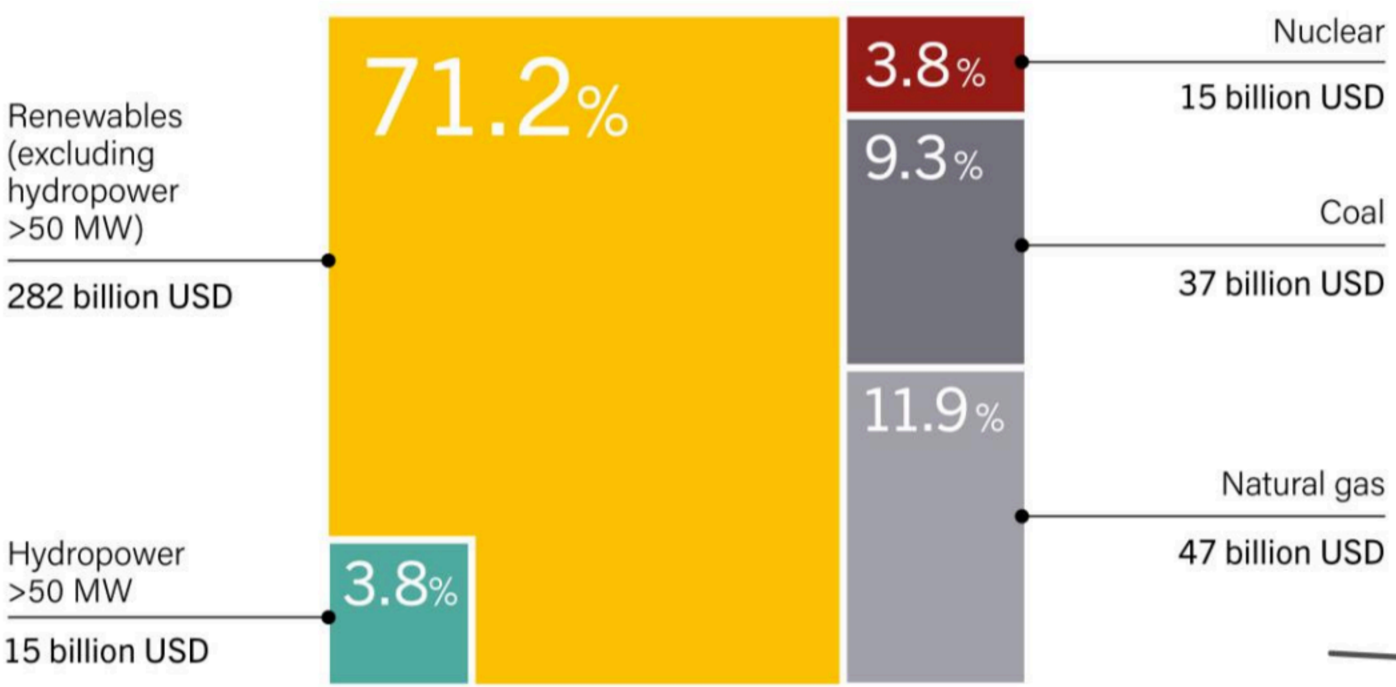
3X MORE INVESTMENT IN RENEWABLES THAN IN COAL, GAS AND NUCLEAR



Note: Renewable investment data in figure exclude biofuels and some types of non-capacity investment.

Source: BloombergNEF.

Global Investment in New Power Capacity by Type (Renewables, Coal, Gas and Nuclear Power), 2019

In 2019, **renewable power technologies continued to attract far more investment dollars** than did coal, natural gas or nuclear power generating plants.

Concepts to understand renewables

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Key concepts to understand the role of renewable sin the energy systems

- LCOE: levelized cost of electricity
- Technology learning curve
- Capacity factor
- Dispatchability
- Energy system value

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

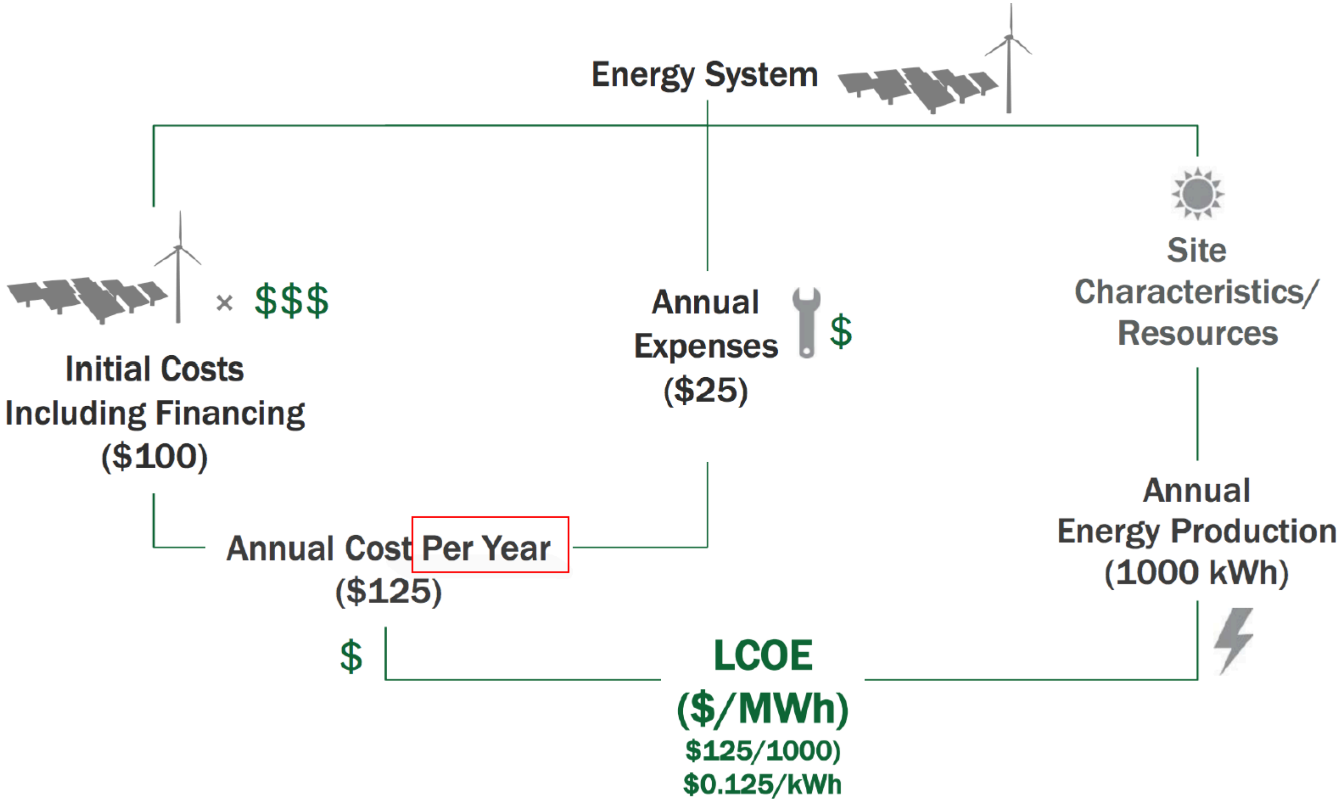
Table 5.1: Typical capital and operating costs for power plants. Note that these costs do not include subsidies, incentives, or any "social costs" (e.g., air or water emissions)

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

Read more here

LCOE



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

Measure 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. coal, gas, solar) of unequal life spans, project size, different capital costs, risk, return and capacities

$$\text{LCOE} = \frac{\text{NPV of Total Costs Over Lifetime}}{\text{NPV of Electrical Energy Produced Over Lifetime}}$$

$$\text{LCOE} = \frac{\sum \frac{(I_t + M_t + F_t)}{(1+r)^t}}{\sum \frac{E_t}{(1+r)^t}}$$

Learn more here, with examples.

The total costs associated with the project will include:
- The initial cost of investment expenditures (I)
- Maintenance and operations expenditures (M)
- Fuel expenditures (if applicable) (F)

The total output of the power-generating asset will include:
- The sum of all electricity generated (E)

Two important factors to be considered are:
- The discount rate of the project (r)
- The life of the system (n)

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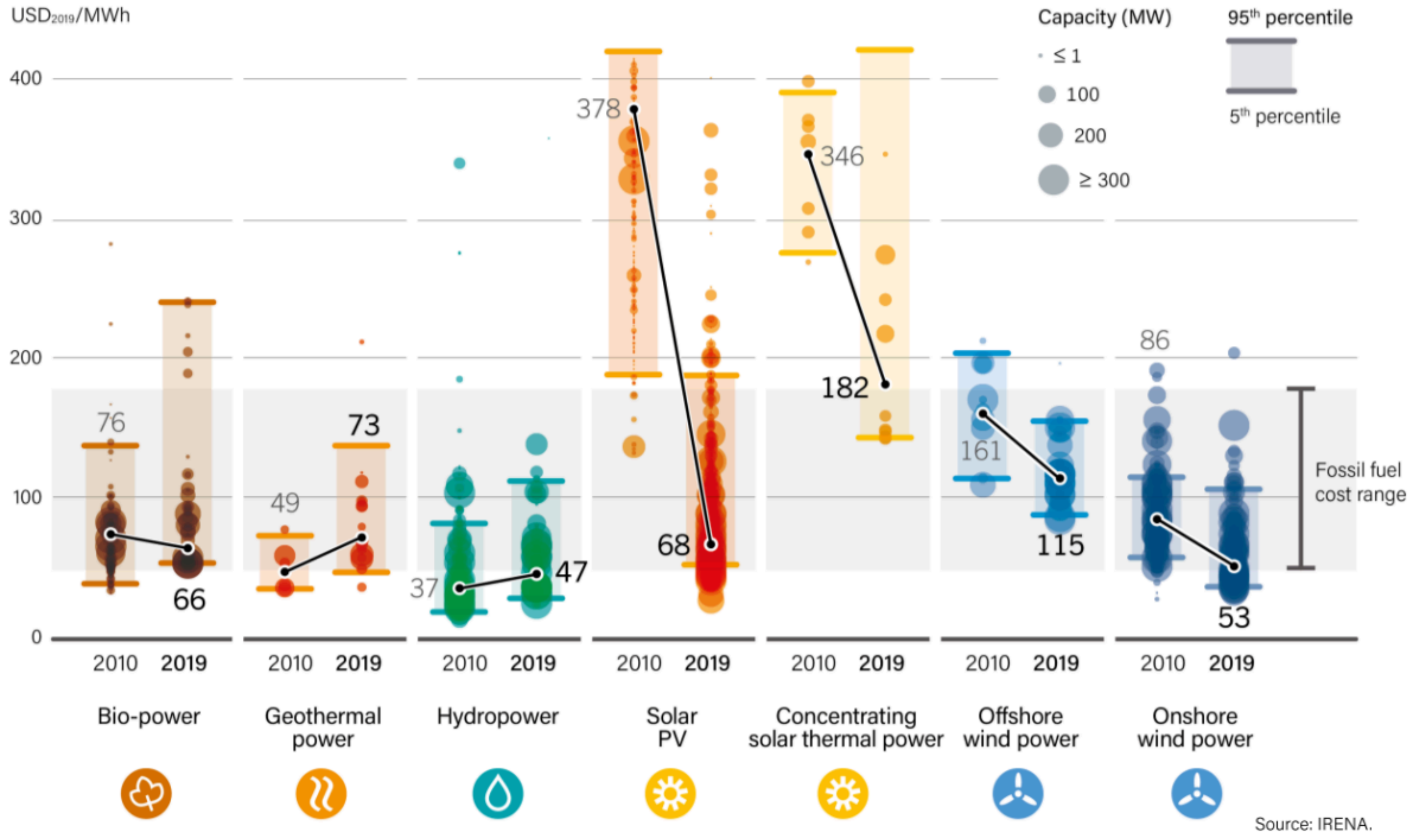
RENEWABLE POWER COSTS KEEP FALLING



Global Levelised Cost of Electricity from Newly Commissioned, Utility-scale Renewable Power Generation Technologies, 2010-2019

Costs for solar PV and CSP as well as onshore and offshore wind have **fallen sharply over the past decade.**

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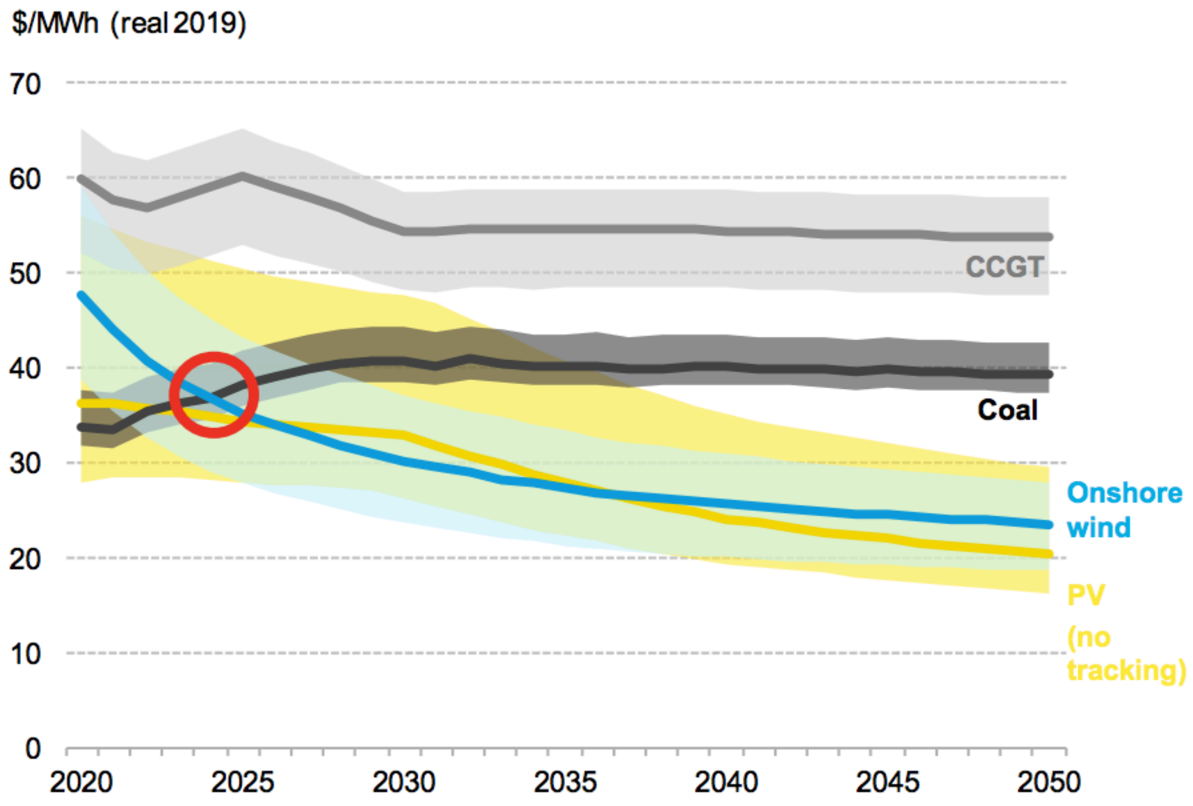
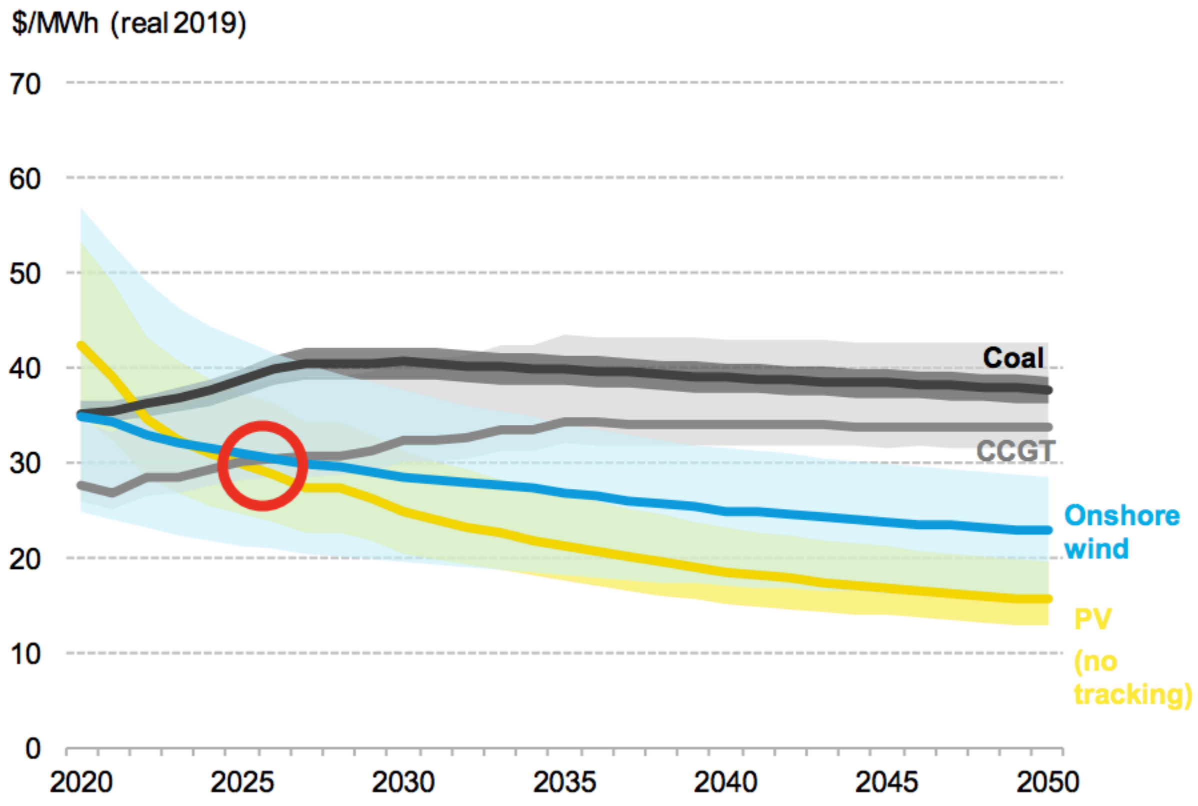
In the next 5 years, wind & PV are on track to be cheaper than running existing coal and gas

China: new wind & PV vs. existing coal & gas



Source: BloombergNEF

United States: new wind and PV vs. existing coal & gas



Source: BloombergNEF

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2016 2030 2050 2016 2030 2050

NREL NATIONAL RENEWABLE ENERGY LABORATORY

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%	$ 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

Explore more [here]

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2016 | 2030 | 2050 | 2016 | 2030 | 2050

NREL NATIONAL RENEWABLE ENERGY LABORATORY

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

Explore more here

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

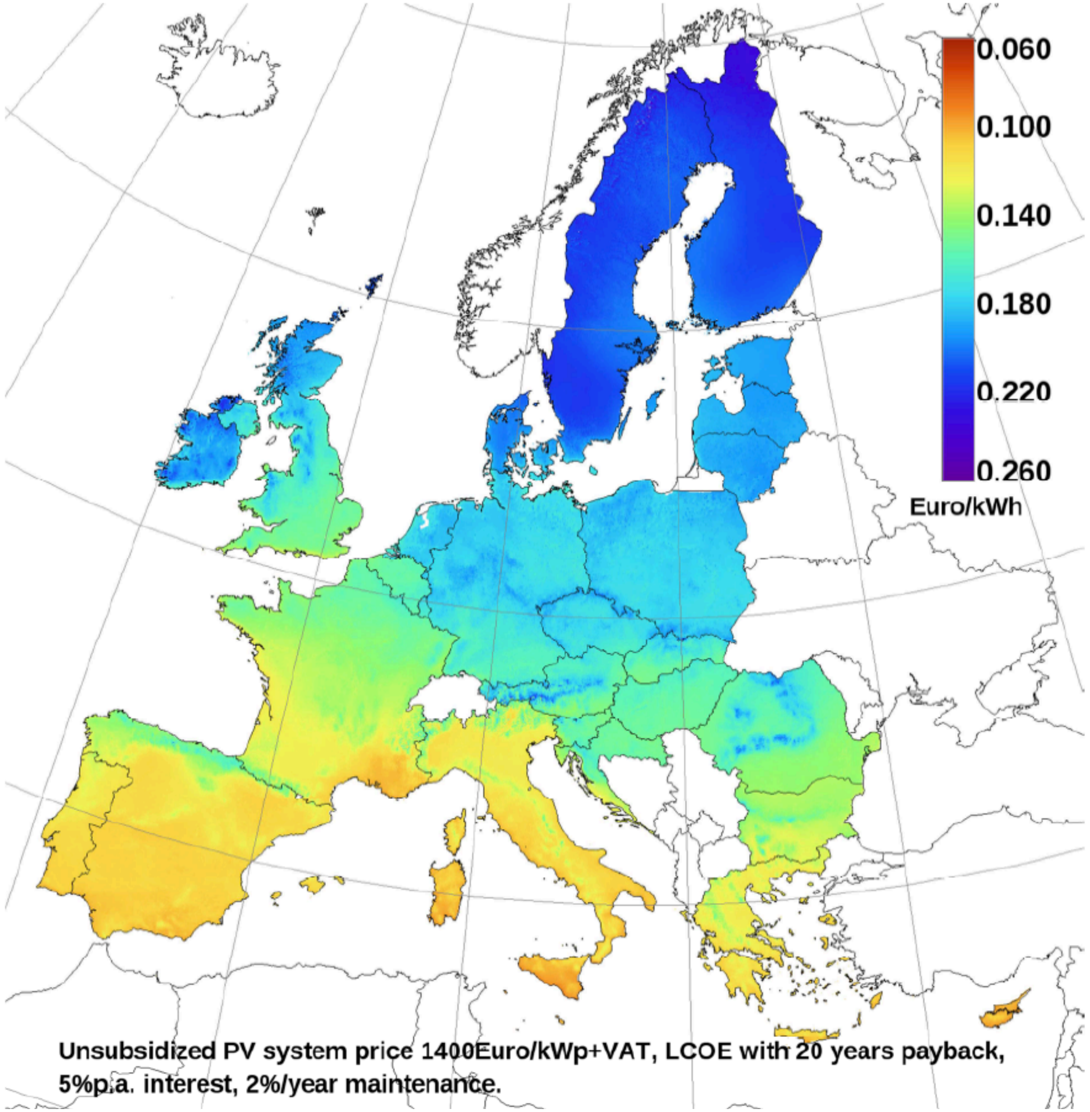

Fig. 1 Distribution of the levelised cost of PV electricity in Europe (Read here)

(Huld et al, 2014)

Capacity Factor

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 Factor

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%

Capacity Factor / Efficiency

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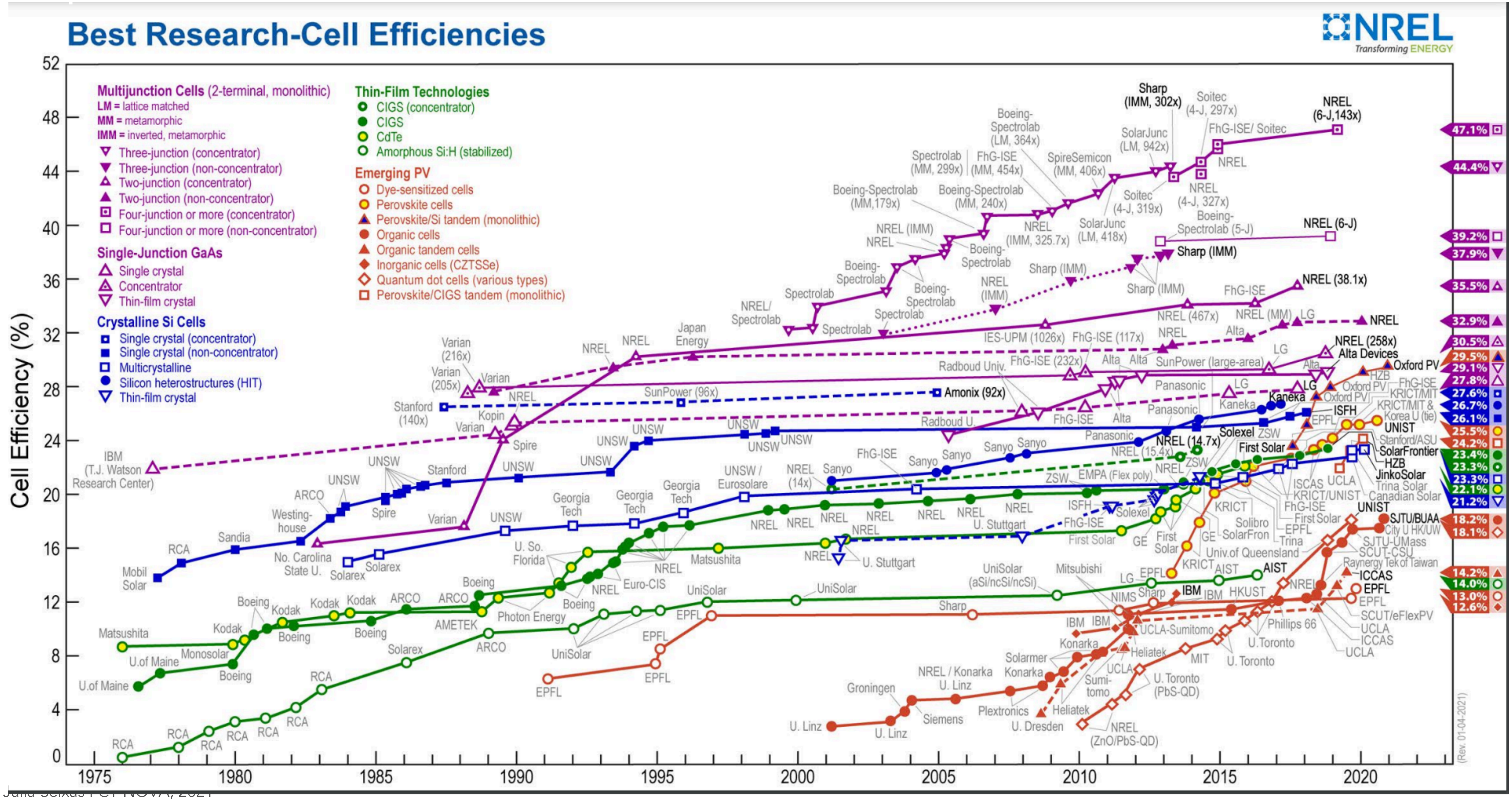

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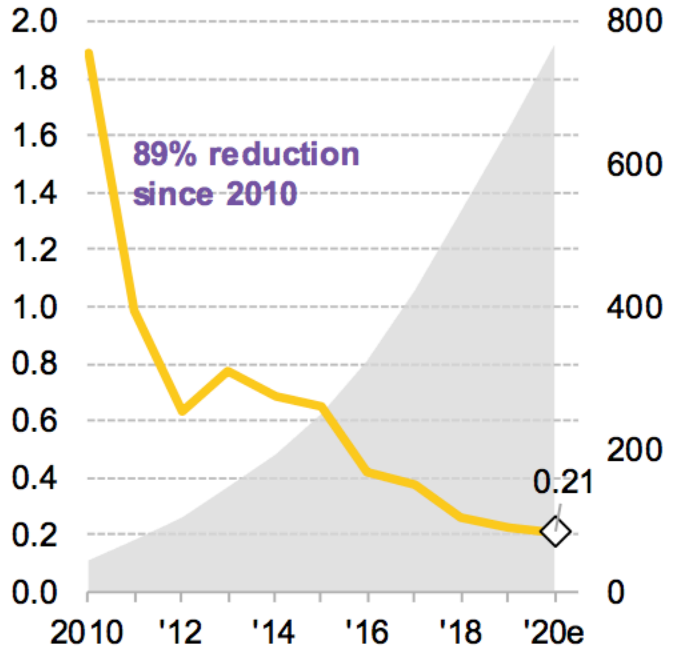
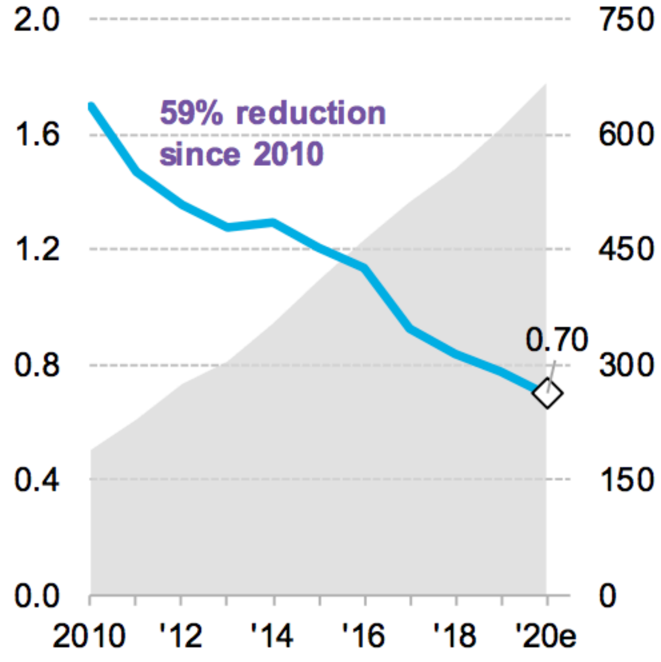
Innovation and scale have driven down the costs of renewable technology…

PV module price and cumulative installed capacity



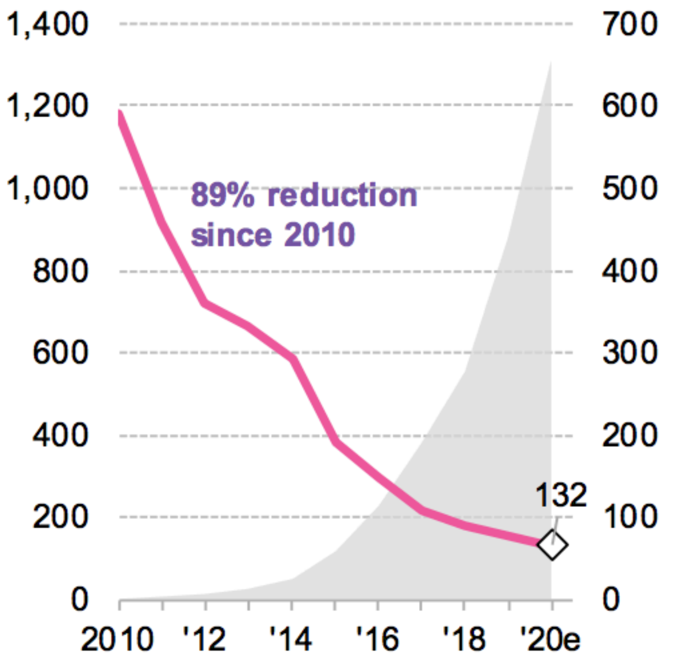
Source: BloombergNEF

Onshore wind turbine price and cumulative installed capacity



Source: BloombergNEF

Li-ion battery pack price and demand



Source: BloombergNEF

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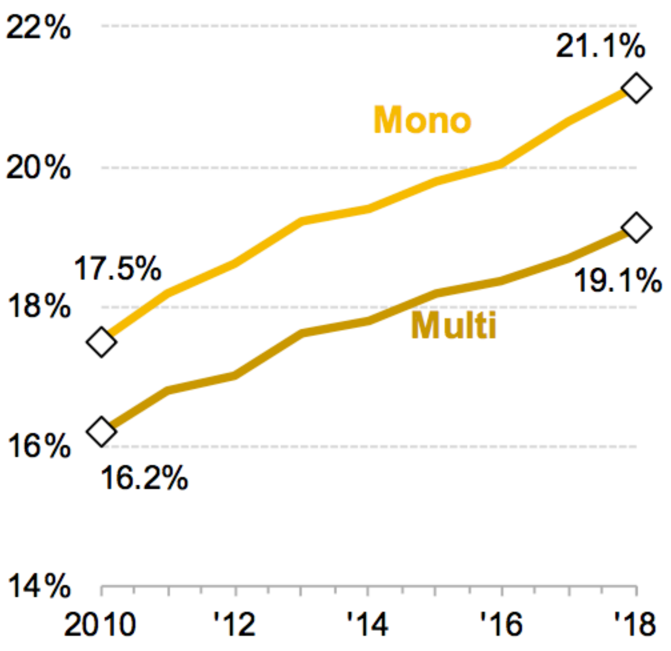
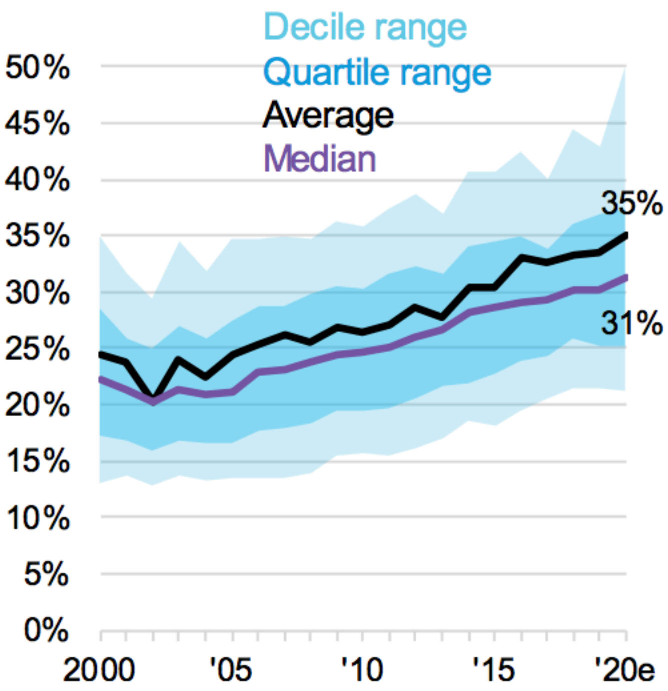
…and at the same time the technology keeps getting better

PV module efficiency



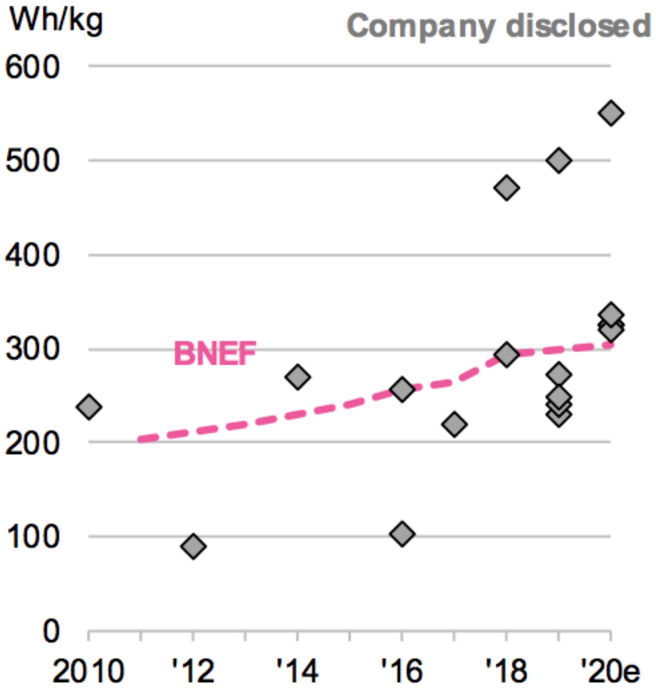
Source: BloombergNEF

Onshore wind capacity factors



Source: BloombergNEF

Battery cell energy density



Source: BloombergNEF, public announcements, company interviews

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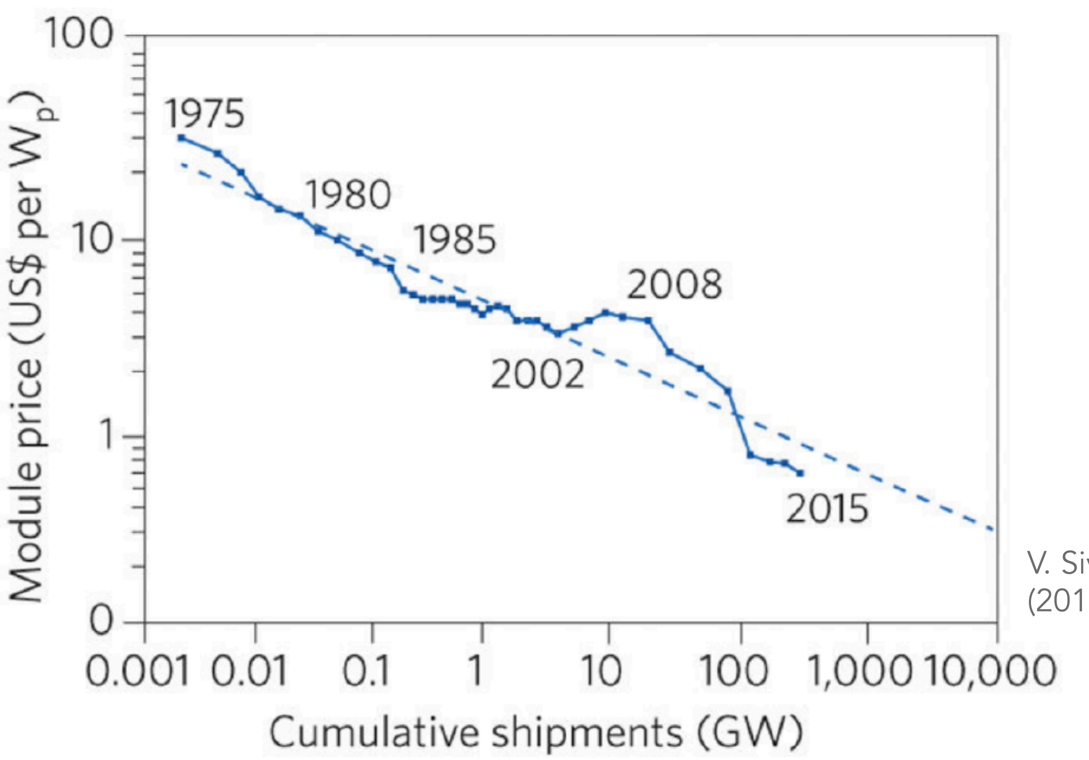
HOW TO ASSESS COST EVOLUTION OF A TECHNOLOGY?

Learning rate: expresses the constant percentage improvement (usually in terms of cost reductions) in a technology for each doubling of the technology's cumulative installed capacity

Figure 2 : Historical learning curve for PV modules.

From: Solar power needs a more ambitious cost target



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

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.

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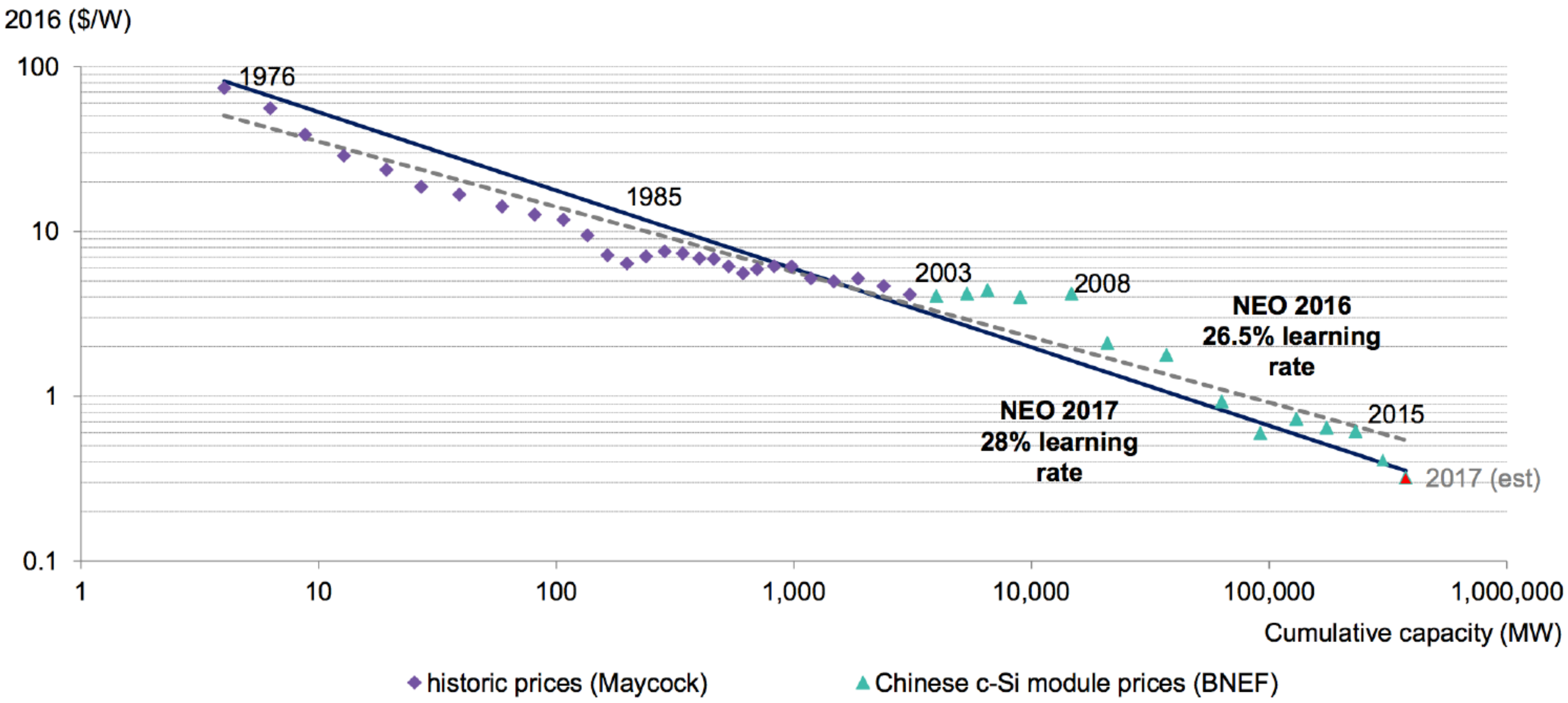
Solar technology is getting cheaper, faster



Source: Maycock, Bloomberg New Energy Finance

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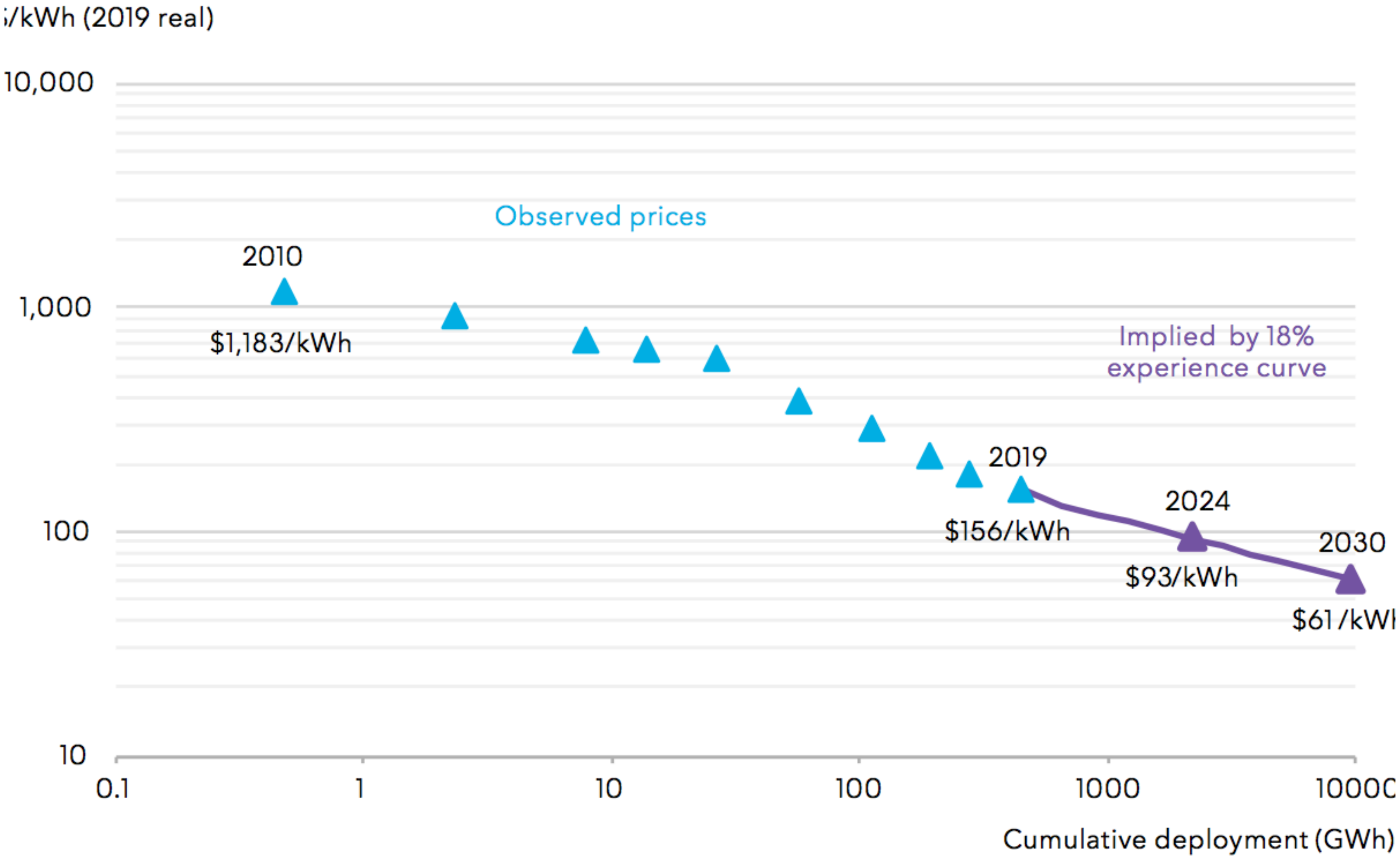
Bloomberg New Energy Finance

Learning Curves

Figure 3: Lithium-ion battery pack price outlook



Source: BloombergNEF
(NEO, 2020)

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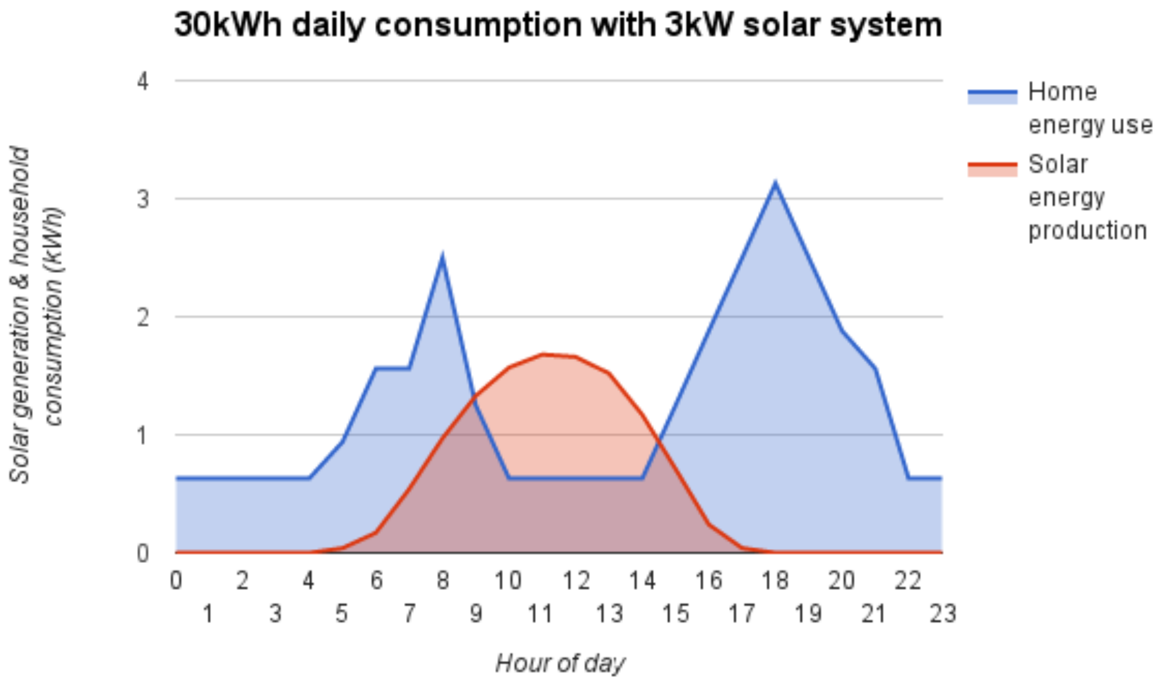
HOW TO MANAGE THE VARIABILITY OF RENEWABLES?

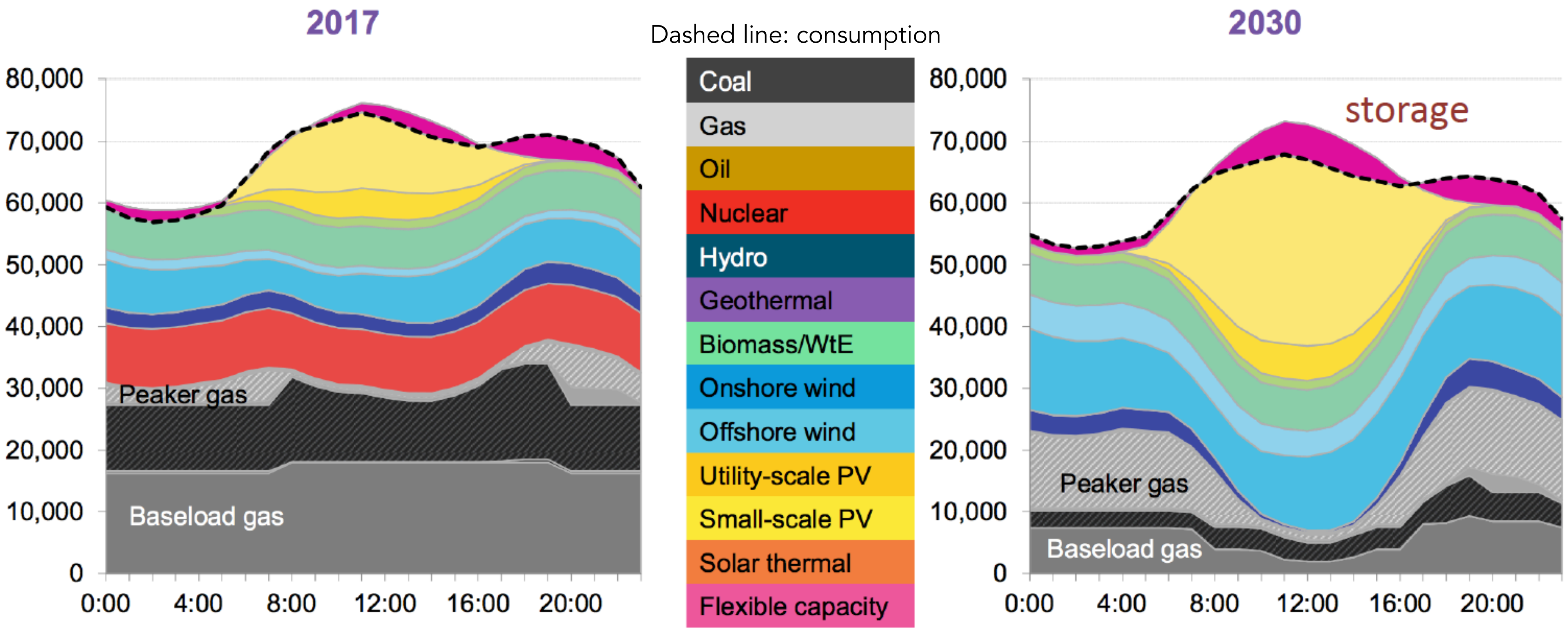
A dispatchable source of electricity refers to an electrical power system, such as a power plant, that can be turned on or off; in other words they can adjust their power output supplied to the electrical grid on demand. Most conventional power sources such as coal or nuclear power plants are dispatchable in order to meet the always changing electricity demands of the population.

In contrast, **<u>many renewable energy sources are intermittent and non-dispatchable</u>**, such as wind power or solar power which can only generate electricity while their energy flow is input on them.

Read more here



Germany hourly dispatch



Source: Bloomberg New Energy Forecast *Source: Bloomberg New Energy Finance*

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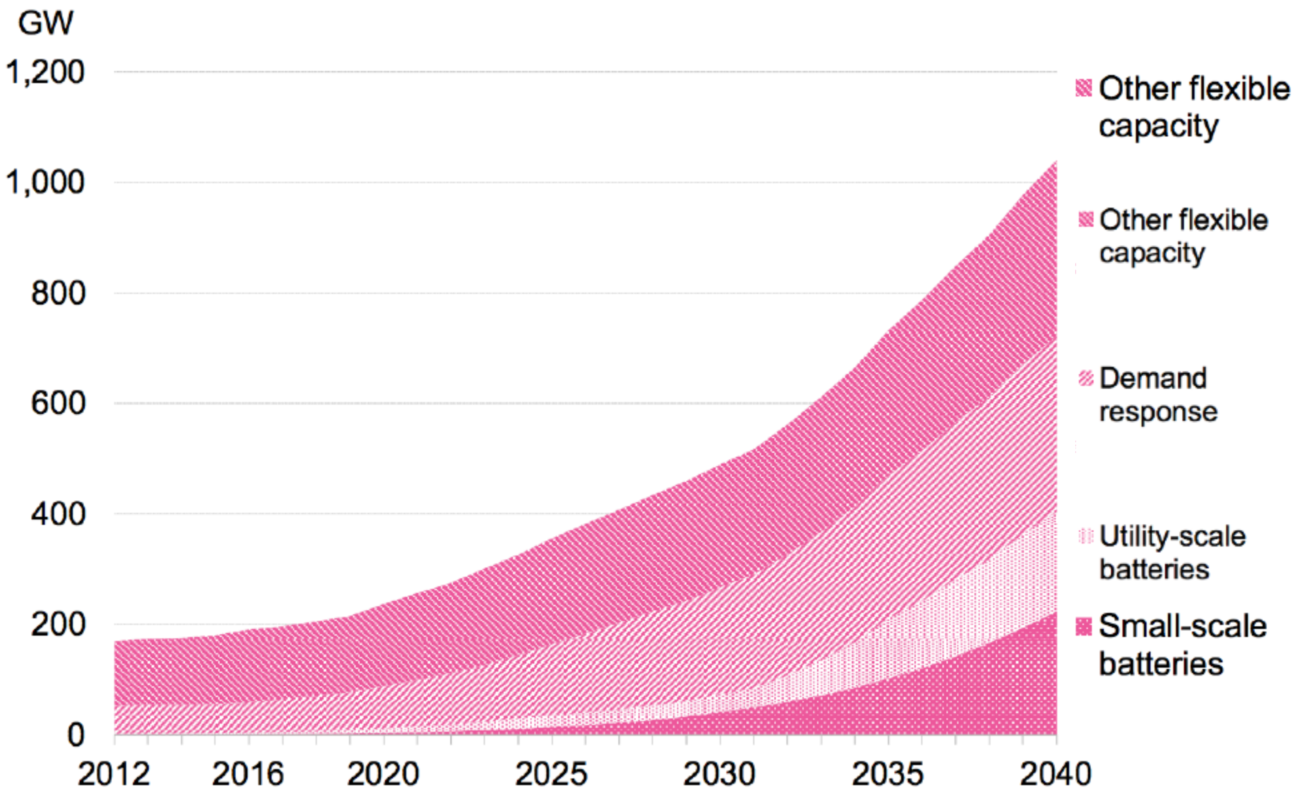
Demand response and batteries help meet peak demand and help balance the grid



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

Source: Bloomberg New Energy Finance

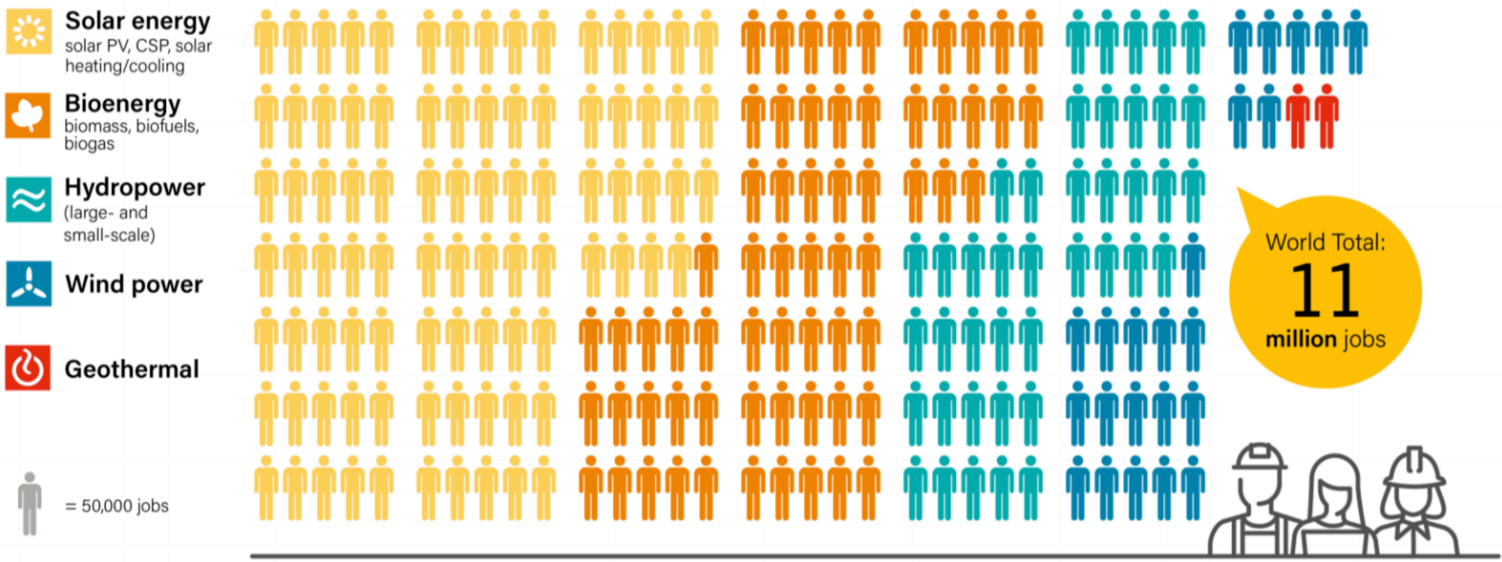
IS LCOE ENOUGH TO CAPTURE THE VALUE OF RENEWABLES?

FROM COST TO VALUE:
Renewable energy can make a contribution to energy, environmental and economic benefits:
1) **energy security** (not depending from volatile international markets);
2) **reduction of carbon dioxide** (CO_2) 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

Read more here

Jobs in Renewable Energy, 2018



Source: IRENA.