Doutoramento em Alterações Climáticas e Políticas de Desenvolvimento Sustentável

Class 5 | 2nd April 2022 | Global energy and climate

Sofia G. Simoes

SEMINAR ENERGY & CLIMATE CHANGE

Climate Change and Sustainable Development Policies

LNEG

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CENSE center for environmental and sustainability research

1	04/03 6ª Feira	16h-18h	Session reserved for students meeting with the Scientific Committee on practical aspects of the PhD Program, and choice of tutors.	Comissão Científica
2	11/03 6ª Feira	16h-18h	ENERGY & CLIMATE CHANGE: A COMPLEX RELATION, PERENE AND INTERDISCIPLINARY. Framework and purpose of the course in the PDACPDS. Practicalities and seminar program. Basic concepts of the energy systems.	J. Seixas, FCT NOVA
3	18/03 6ª Feira	16h-18h	**Current state of the global energy system**: main energy carriers, energy production and consumption regions; energy access; concepts of energy and carbon intensity.	S. Simões
4	25/03 6ª Feira	14h-16h	**Global balance of CO_2 emissions** associated with energy and industrial processes. Estimates of the Global Carbon Budget (http://www.globalcarbonproject.org/) and its relationship to the global energy system and changes in land use. Future scenarios for greenhouse gas emissions: RCPs (Representative Concentration Pathways). Global emissions based on consumption vs. production.	S. Simões
5	02/04 Sábado	09h-11h	**Renewables**: Economic, environmental and energy security of endogenous vs. imported resources. Renewable technologies. Sustainability issues related with renewables. Land & water use, critical raw materials. Discussion: Where to place 7GW of solar PV in Portugal till 2030?	S. Simões
6	08/04 6ª Feira	16h-18h	**Energy concepts**: Primary/final energy; Sankey diagrams; energy efficiency; Energy services; Energy carriers; Final energy supply cost curves; learning curves of energy technologies. Definition and usefulness of LCOE. System value of Renewables. Global renewables' market.	S. Simões
7	22/04 6ª Feira	16h-18h	**Drawdown** - Climate Solutions for a New Decade	João P. Gouveia, FCT NOVA
8	30/04 Sábado	09h-11h	**Green hydrogen**: technological options, costs and the role for a carbon neutral energy system	P. Fortes, FCT NOVA
9	06/05 6ª Feira	18h-20h	**CARBON PRICING**. Regulatory framework in the European Union: 2020 - 2030 targets. Fit for 55. European low-carbon Roadmap 2050. Paris Agreement, and its implications.	S. Simões
10	13/05 6ª Feira	16h-18h	**Debate Como perspetivar o futuro da energia e alterações climáticas?** Baseado no artigo *An energy vision: the transformation towards sustainability — interconnected challenges and solutions*	students / S. Simões
11	21/05 Sábado	11h-13h	**Hands-on energy data**: access to energy databases, Portuguese and European (PORDATA, DGEG, EUROSTAT). i) How to find and explore energy statistics and emissions of greenhouse gas (GHG) emissions for Europe and Portugal; ii) How to make energy conversions; iii) How to build indicators and charts with added value; iii) How to analyze economic sectors, and interpret their performance in terms of energy consumption and greenhouse gas emissions.	S. Simões
12	27/05 6ª Feira	16h-18h	**Integrated assessment of energy systems**: The energy system addressed by the systems analysis approach. How to envisage the future energy system? Implications for the decision making in the medium and long term. Concept and formulation of cost-effectiveness within the integrated energy systems. Hands on Climate Mitigation Simulation	S. Simões
13	03/06 6ª Feira	16h-18h	Mentoring with each students' group: discussion on the approach and methods adopted by the students, expected results to be obtained with the final work; assessing preliminary results, if any.	S. Simões
14	17/06 6ª feira	18h-20h	**Smart and Sustainable cities**: concept, components and implications for the energy systems. The concept of Positive Energy Districts, and implications for future planning at the city level.	João P. Gouveia, FCT NOVA
	2 julho, 14h	14h-16h	Avaliações: apresentação dos trabalhos pelos alunos.	S. Simões / J. Seixas

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If you need to discuss topics related to the course, including the assignment, I am available on Fridays 10h-11h – send me an e-mail to book this slot at least 4 days before

Para discussão de assuntos relacionados com o seminário, incluindo o trabalho final, estou disponível às sextas 10h-11h – têm que enviar-me e-mail previamente (pelo menos 4 dias antes)

Às 5as feiras 12h-13h é dada aula complementar em Português (zoom) para quem tem mais dificuldades com o inglês

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PROGRAM & RESOURCES @
https://moodle.fct.unl.pt/course/view.php?id=7450

Climate Change and Sustainable Development Policies

Assignment

Challenge: Within the scope of your personal interests, select an economic activity:
Fashion I Communication I Food and BeverageI Industry I Health services I Mobility I Other

Assuming your country will be in the midst of a pathway to achieve a carbon neutral economy by 2050 (as stated in the Paris Agreement) or earlier, how do you envisage the selected activity will picture by 2030?

Team work I Think out of the box I Innovate

What is the challenge for the activity? Who are the challenge owners?
What do you envisage the activity must/should deliver in the future?

Assignment | How the work will be developed?

- **Groups of 3 students** (please send me an **email with the group members until end of march**)
- **Coaching session** to each group, on the work development (one class dedicated to this, end of May or early June maybe 3rd June??)
- **Oral presentation**: 30 min/group [15 min for oral presentation + 15 min Q&A] 2 July 2022, friday, 14:00h, ICS (tbd)
- **Deliverable**: at the day before the oral presentation at maximum, students will send to Julia Seixas the presentation by email.
  - Presentation in pdf format: maximum 10 slides + word document with 3 pages at maximum (only if needed for complementary information).

Assignment | Suggestion of script for development:

- firstly, **formulate (and detail) the problem** as far as you are able;
- characterize the **activity at present** [for example, production / import technologies| type of markets and consumers | competition from other markets? | energy consumption profile | indicators of carbon intensity]
- **envisage the activity up to 2030** [technological options | product change - green| change of consumers | energy consumption profile | indicators of carbon intensity]
- systematize **opportunities for the mitigation** of the selected activities (identify needs of R & D, act on consumption preferences, the product value chain, among others)
- identify and anticipate **constraints and barriers to the desired mitigation**, and explain how to overcome them.

Tips: Start now; try to be objective and quantify what is possible; do not try to be exhaustive (you can not do it within just one course); explore examples that already exist in other countries; be creative.

Assignment | GROUPS?

- Groups: 6 so far
- Locate yourself in a specific country
- Topics
  - Fashion
  - Decentralisation of energy/prosumer markets
  - MSW management Portugal
  - MSW management in Brasil
  - Agriculture's carbon neutrality in Portugal
  - Energy supply in megacities
  - Small scale retail
- Common suggestion – try to narrow down the topic, put yourself too in

Outline

- Recap SSPs and RCPs
- Renewables: Economic, environmental and energy security of endogenous vs. imported resources.
- Sustainability issues related with renewables - Land & water use, critical raw materials
- Discussion: Where to place 7GW of solar PV in Portugal till 2030?.

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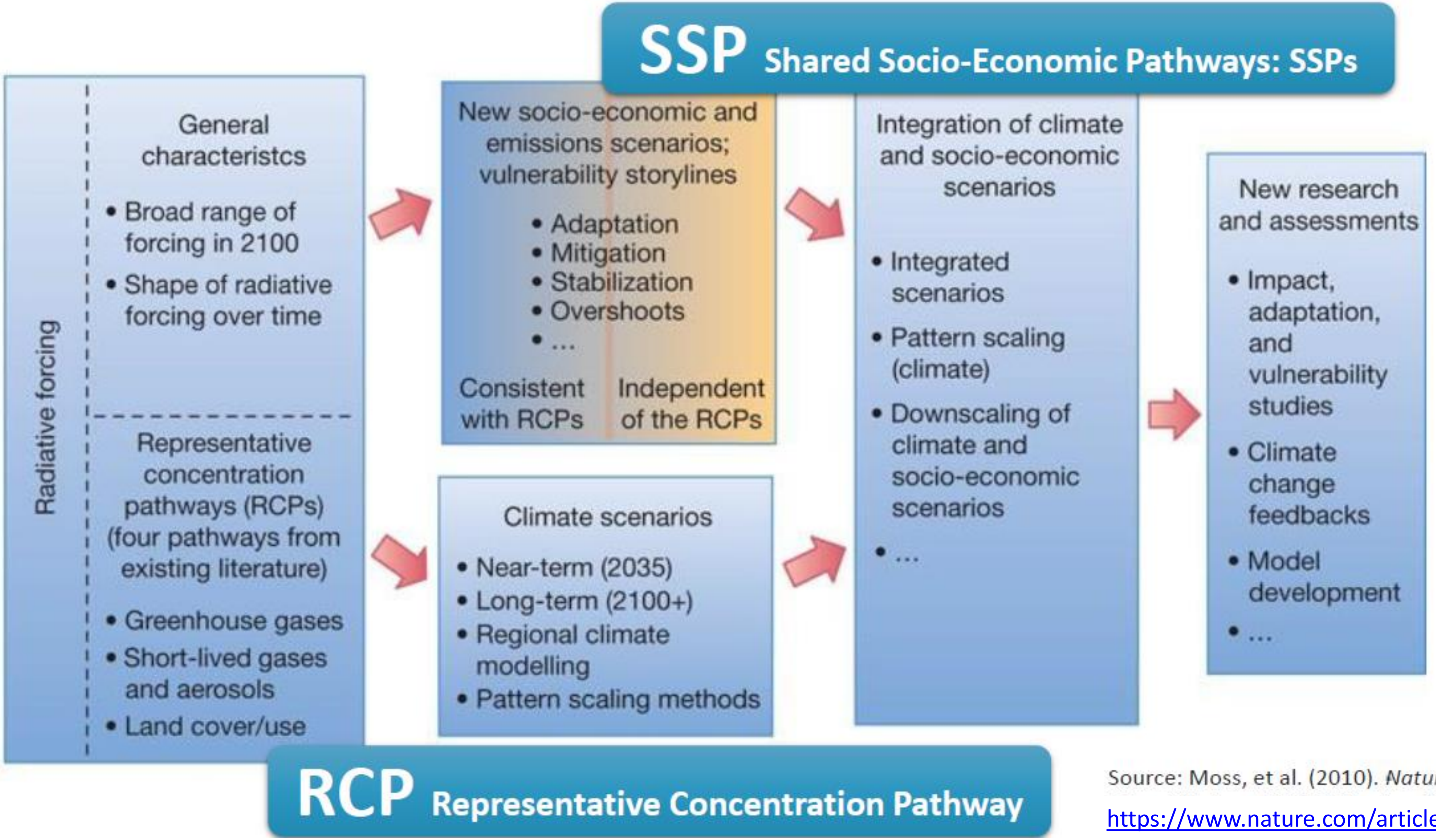
IPCC Climate Scenarios Design Framework



Source: Moss, et al. (2010). *Nature* **463,** 747–756

https://www.nature.com/articles/nature08823 https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change

RCP *vs* SSP

Representative Concentration Pathway (RCP): **descriptions of how the climate may evolve in the future** over the rest of the century – trajectories adopted by many scientific communities and IPCC (for its 5th Assessment Report (AR5)) **representing radiative forcing* from greenhouse gas concentration (not emissions).**

Originally there were **4 RCP** (IPCC 5th Assessment Report 2013/2014)
> After the adoption of the Paris Agreement **RCP 1.9** developed to represent mitigation pathways compatible with the 1.5 °C warming
> New **RCP7** – baseline outcome (IPCC 6th Assessment Report 2021/2022)

"Representative": each one of the RCPs represents a larger set of scenarios in the literature.

Paris Agreement (RCP 1.9 and 2.6)

RCP	Forcing	Temperature	Emission Trend
1.9	1.9 W/m2	~1.5 °C	Very Strongly Declining Emissions
2.6	2.6 W/m2	~2.0 °C	Strongly Declining Emissions
4.5	4.5 W/m2	~2.4 °C	Slowly Declining Emissions
6.0	6.0 W/m2	~2.8 °C	Stabilising Emissions
8.5	8.5 W/m2	~4.3 °C	Rising Emissions

Approximate radiative forcing levels were defined as ±5% of the stated level in W/m2 relative to preindustrial levels. Radiative forcing values include the net effect of all anthropogenic GHGs and other forcing agents

Shared Socio-economic Pathways (SSPs) define **5 narratives of world development characterized by different drivers** (e.g. population, economic activity, urbanization, technological development, etc.)
> SSPs consider the **absence of climate change and climate policy**
> They show that it would be much easier to mitigate and adapt to climate change in some versions of the future than in others

Source: O'Neill, et al. (2017). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Global Environmental Change, 42, 169-180, https://doi.org/10.1016/j.gloenvcha.2015.01.004

**Radiative forcing is the change in energy flux in the atmosphere caused by natural or anthropogenic factors of climate change as measured by watts / meter*

Climate Change and Sustainable Development Policies

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Outline

- Recap SSPs and RCPs
- **Renewables: economic, environmental and energy security of endogenous vs. imported resources.**
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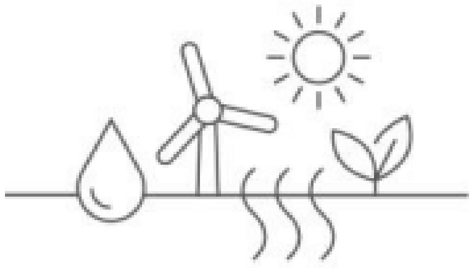
- Discussion: Where to place 7GW of solar PV in Portugal till 2030?.

Renewable energy technologies



Download:

- Full report: EN
- Key Messages for Decision Makers: EN
- Figures: EN
- Data pack: EN
- Presentation: EN
- Press releases: EN | DE | ES | FR | PT | ZH | JA | KO | EL | ID | VI | TR
- Country fact sheets: Argentina EN, ES | Australia EN | Brazil EN, PT | Canada EN | Chile EN, ES | China EN, ZH | France FR, EN | Germany DE, EN|

https://www.ren21.net/reports/global-status-report/

THE ONLY GLOBAL RENEWABLE ENERGY MULTI-STAKEHOLDER COMMUNITY

GOVERNMENTS
Afghanistan, Austria, Brazil, Denmark, Dominican Republic, Germany, India, Mexico, Norway, Republic of Korea, South Africa, Spain, UAE, USA

NGOs
CAN-I, CLASP, CCA, Club-ER, CC35, Energy Cities, EHP, FER, Global 100%RE, GFSE, Greenpeace Intl, GWNET, ICLEI, IEC, ISEP, JVE, MFC, Power for All, REEEP, REI, RGI, SCI, SLOCAT, SEforAll, WCRE, WFC, WRI, WWF

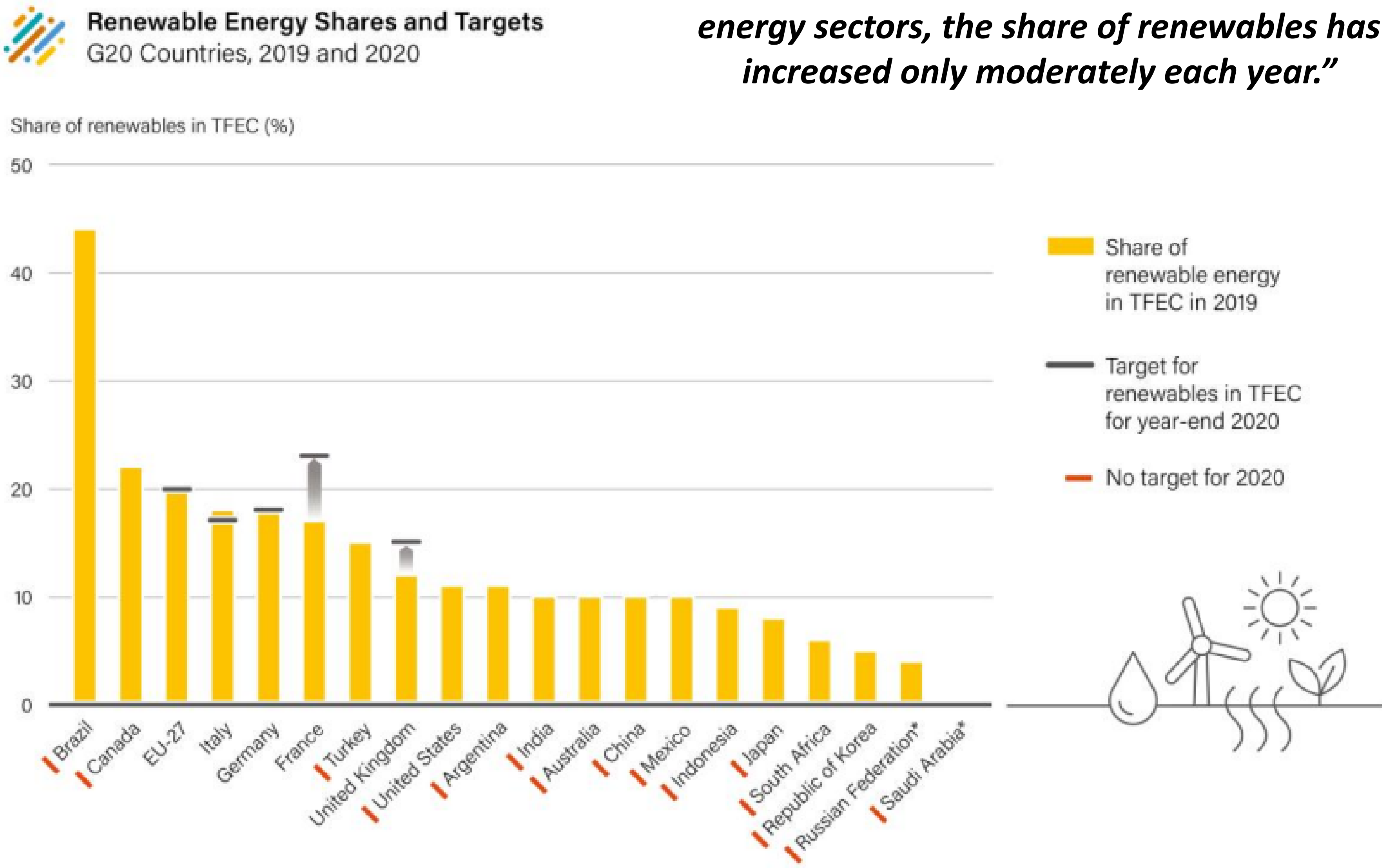
SCIENCE & ACADEMIA
AEE INTEC, CEEW, Fundacion Bariloche, Higher School of Economics (Russia), IIASA, ISES, NREL, SANEDI, TERI

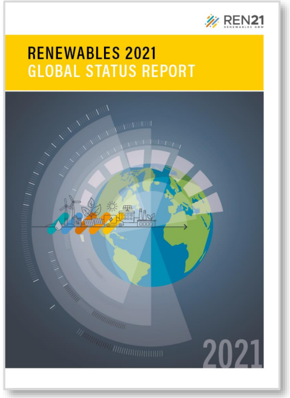
INTERGOVERNMENTAL ORGANISATIONS
ADB, APERC, ECREEE, EC, GEF, IEA, IRENA, IsDB, RCREEE, UNDP, UNEP, UNIDO, World Bank

INDUSTRY ASSOCIATIONS
ACORE, AMDA, ALER, ARE, APREN, CREIA, CEC, EREF, GOGLA, GSC, GWEC, IREF, IGA, IHA, RES4Africa, Solar Power Europe, WBA, WWEA

https://www.ren21.net/reports/global-status-report/

“Despite tremendous growth in some renewable energy sectors, the share of renewables has increased only moderately each year.”





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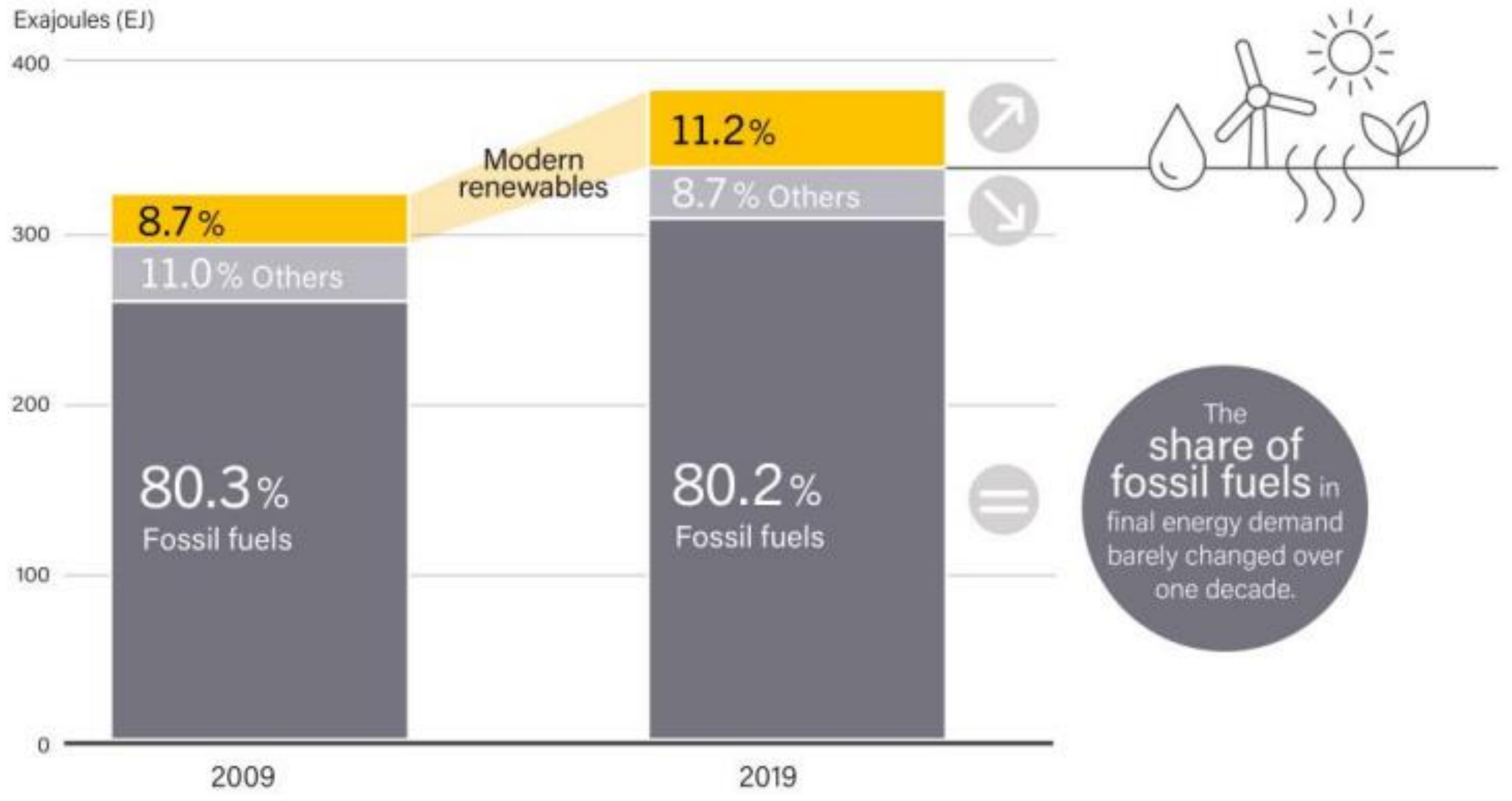
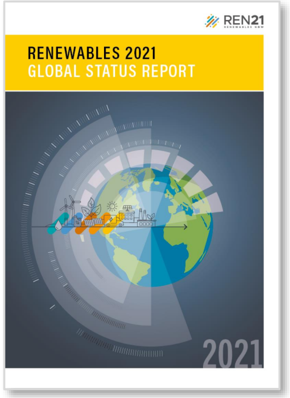
Estimated Renewable Share of Total Final Energy Consumption
2009 and 2019



Note: Totals may not add up due to rounding. This figure shows a comparison between two years across a 10-year span. The result of the economic recession in 2008 may have temporarily lowered the share of fossil fuels in total final energy consumption in 2009. The share in 2008 was 80.7%.

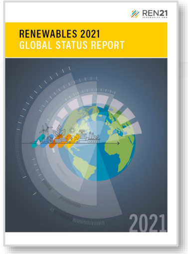
Source: Based on IEA data.



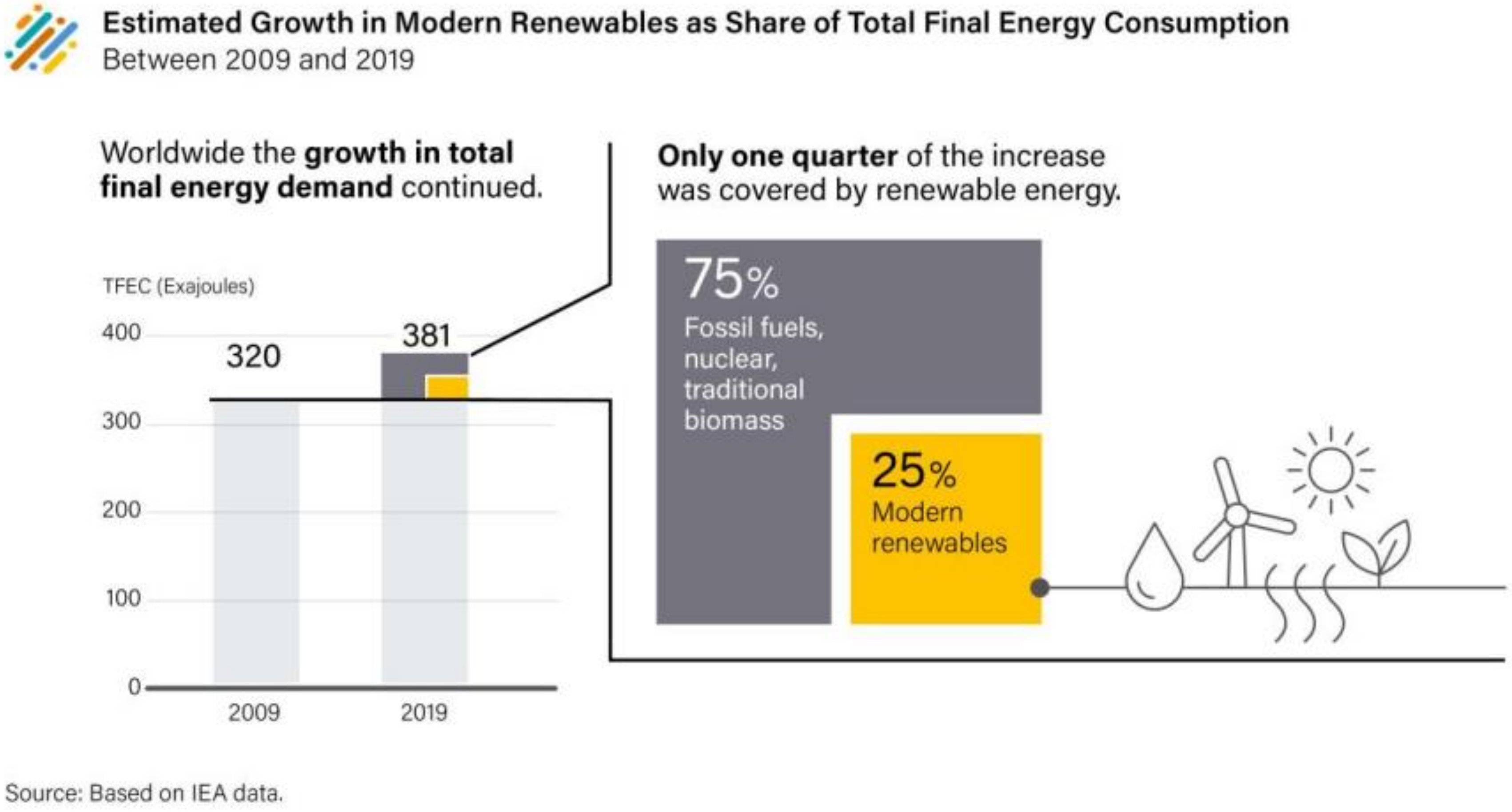
- Solar PV capacity
- Wind power capacity
- Hydropower capacity
- Geothermal power capacity
- Concentrating solar thermal power (CSP) capacity
- Solar water heating capacity
- Ethanol production
- Biodiesel production

https://www.ren21.net/reports/global-status-report/

RENEWABLES ARE GROWING FAST... BUT NOT FAST ENOUGH

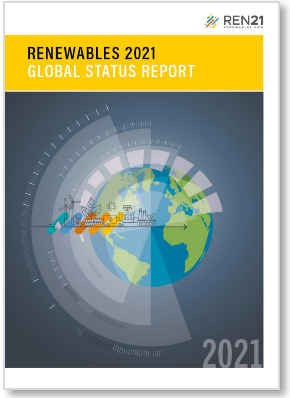


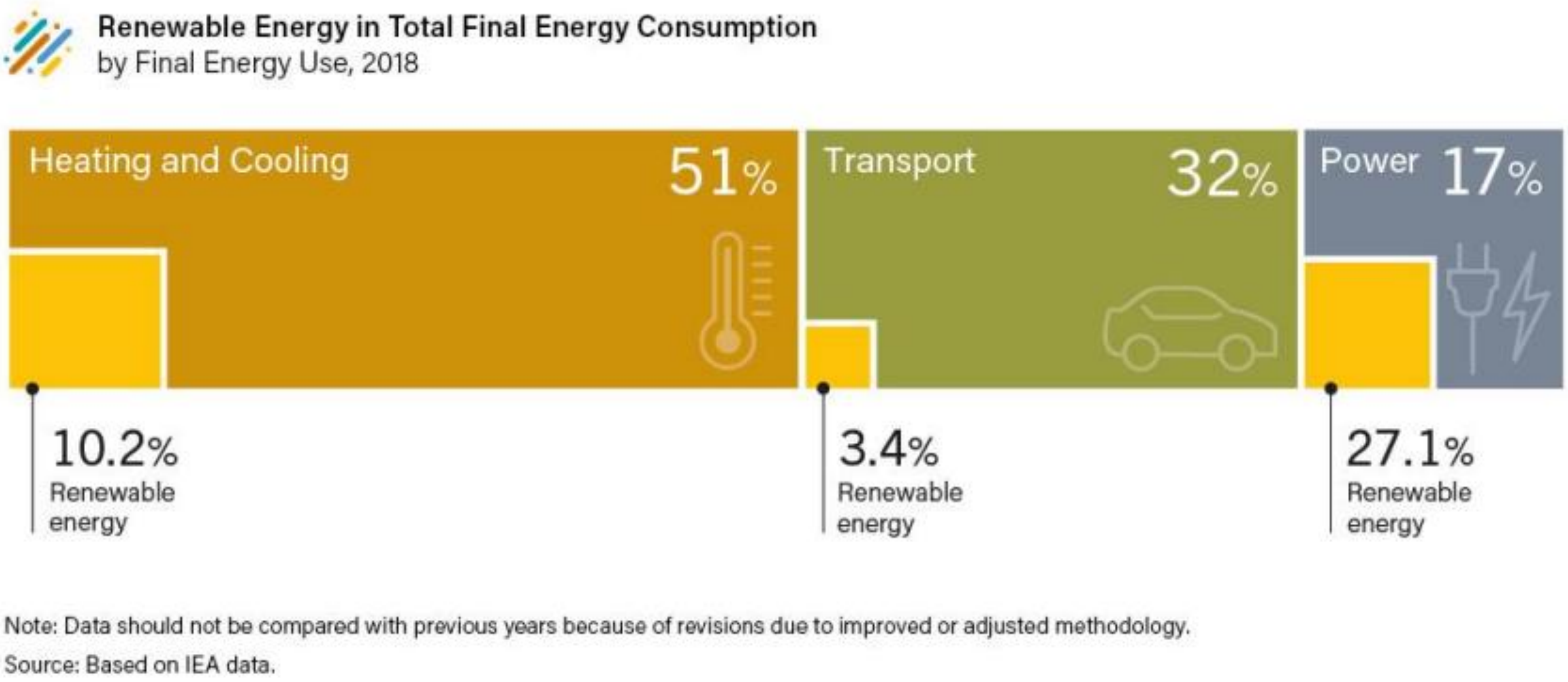
- Renewables grew two times faster than fossil fuels
- Renewable energy only accounted for 25% of demand growth
- Energy efficiency and renewables are complementary



https://www.ren21.net/reports/global-status-report/

MORE THAN 80% OF ENERGY FOR HEATING & TRANSPORT





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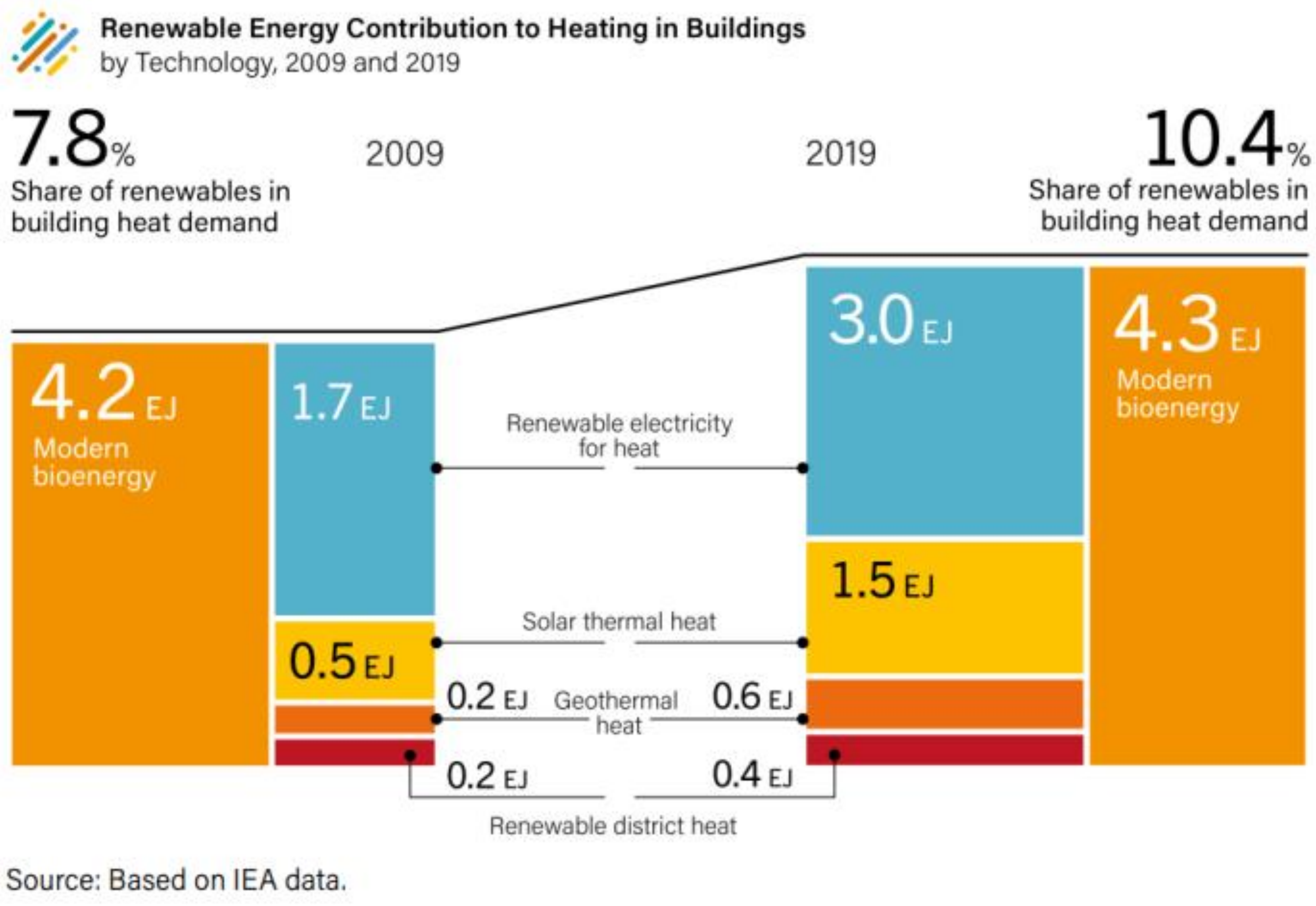
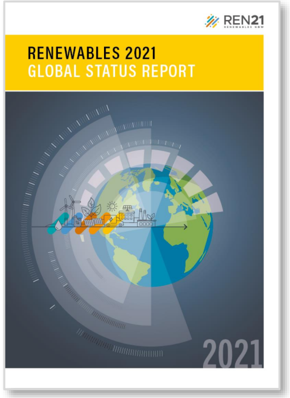
RENEWABLE HEAT IS GRADUALLY GROWING IN BUILDINGS





https://www.ren21.net/reports/global-status-report/

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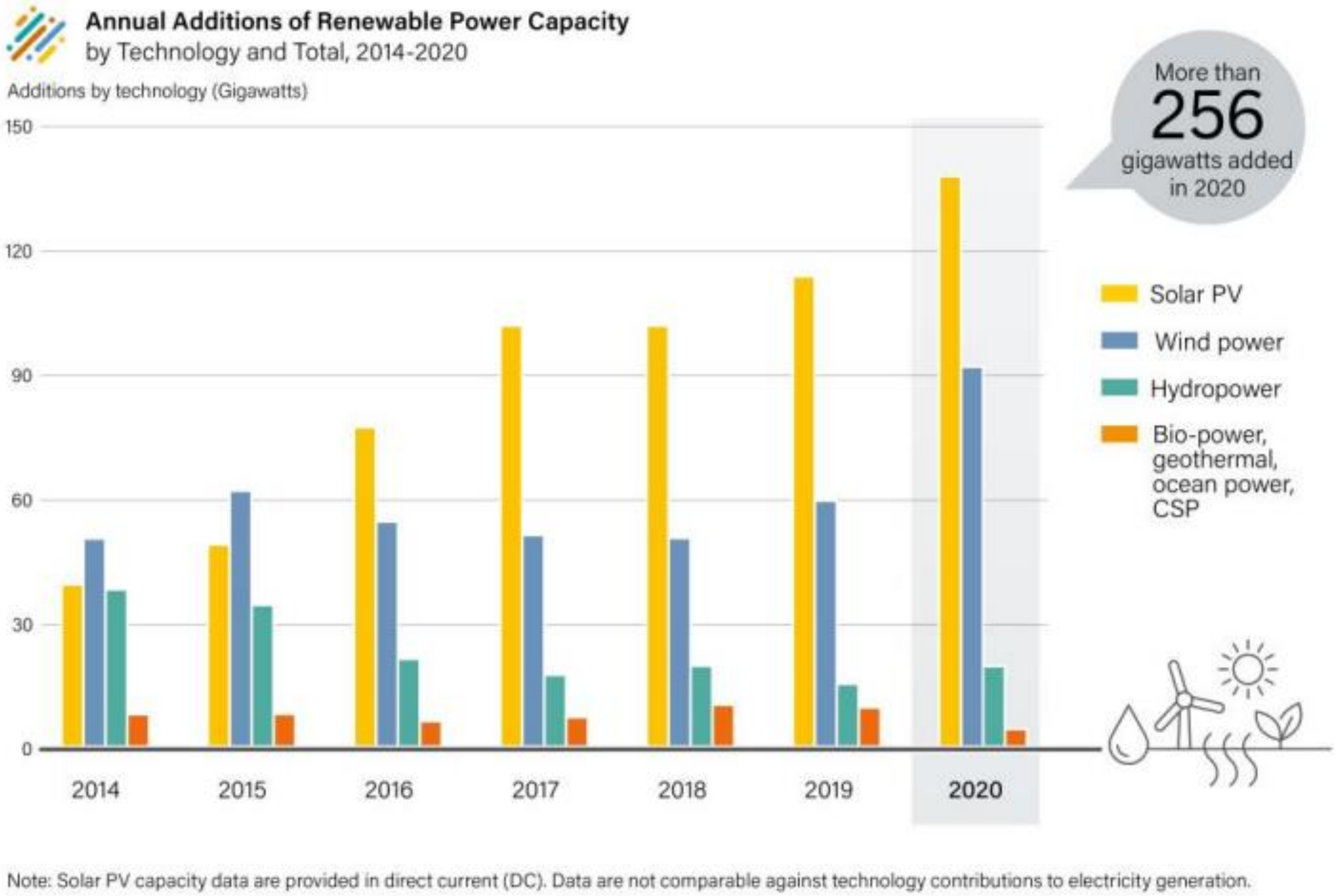
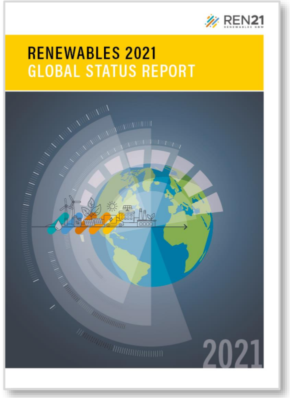
MORE THAN 250 GW OF RENEWABLE POWER ADDED



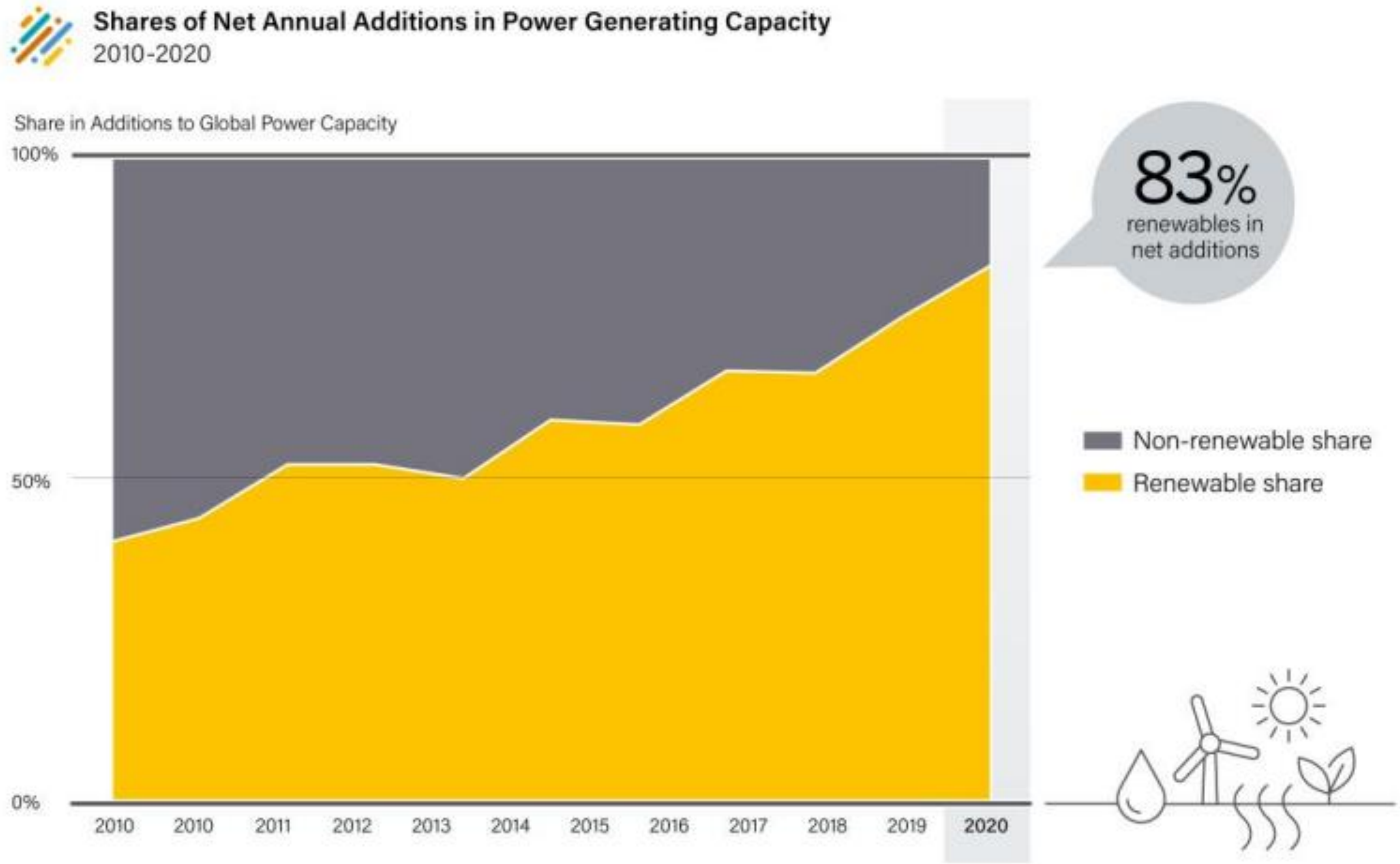


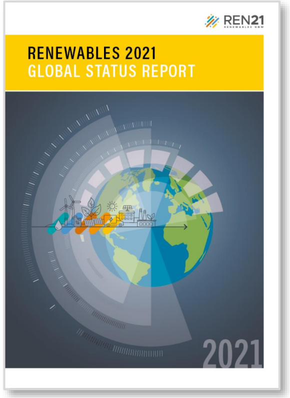
"New renewable power capacity hit a record increase globally"

https://www.ren21.net/reports/global-status-report/

Climate Change and Sustainable Development Policies

MORE RENEWABLE POWER ADDED THAN FOSSIL FUEL & NUCLEAR

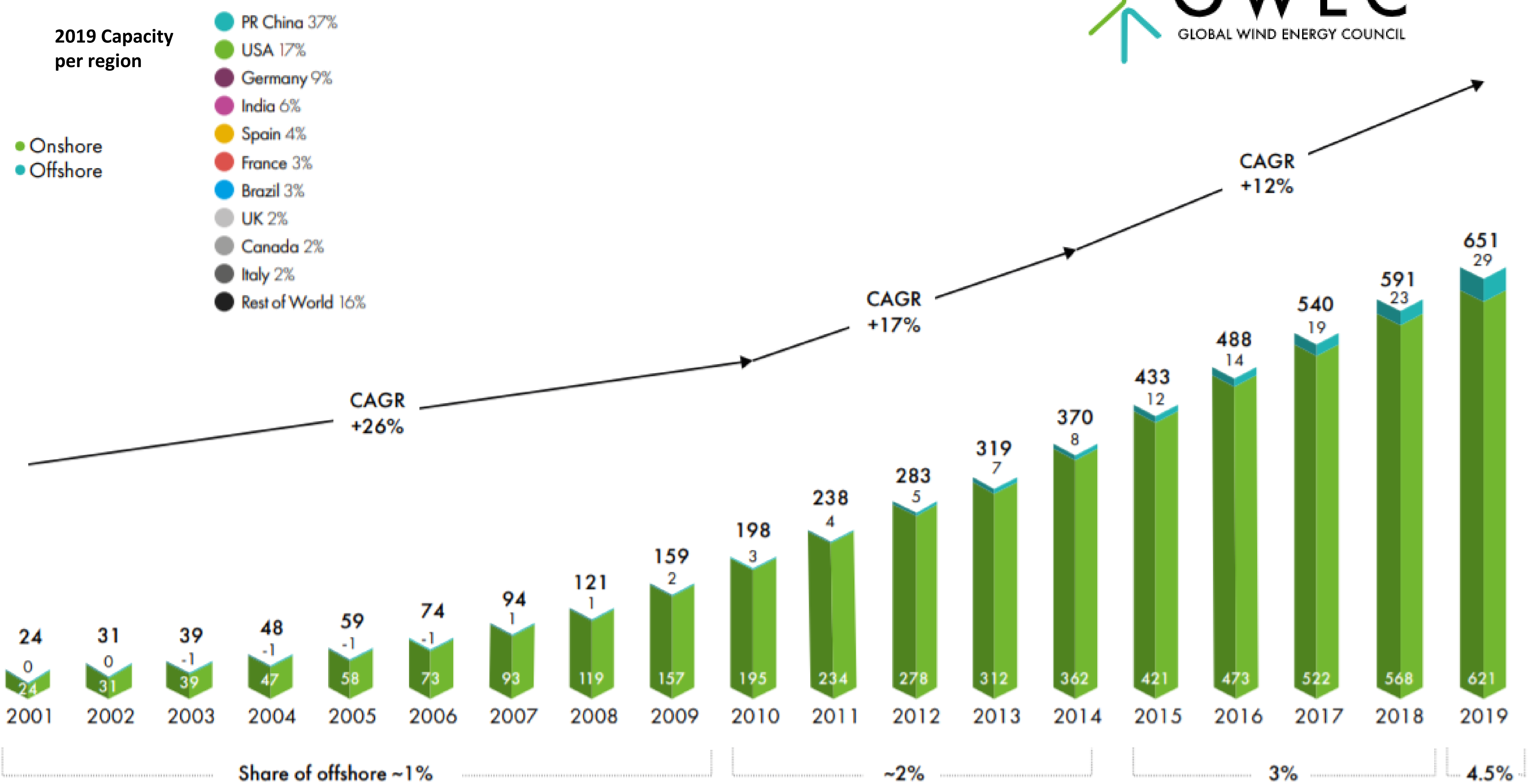




"Renewable power generation capacity additions remain ahead for the sixth year in a row."

https://www.ren21.net/reports/global-status-report/

WIND POWER GLOBAL INSTALLED CAPACITY (GW)

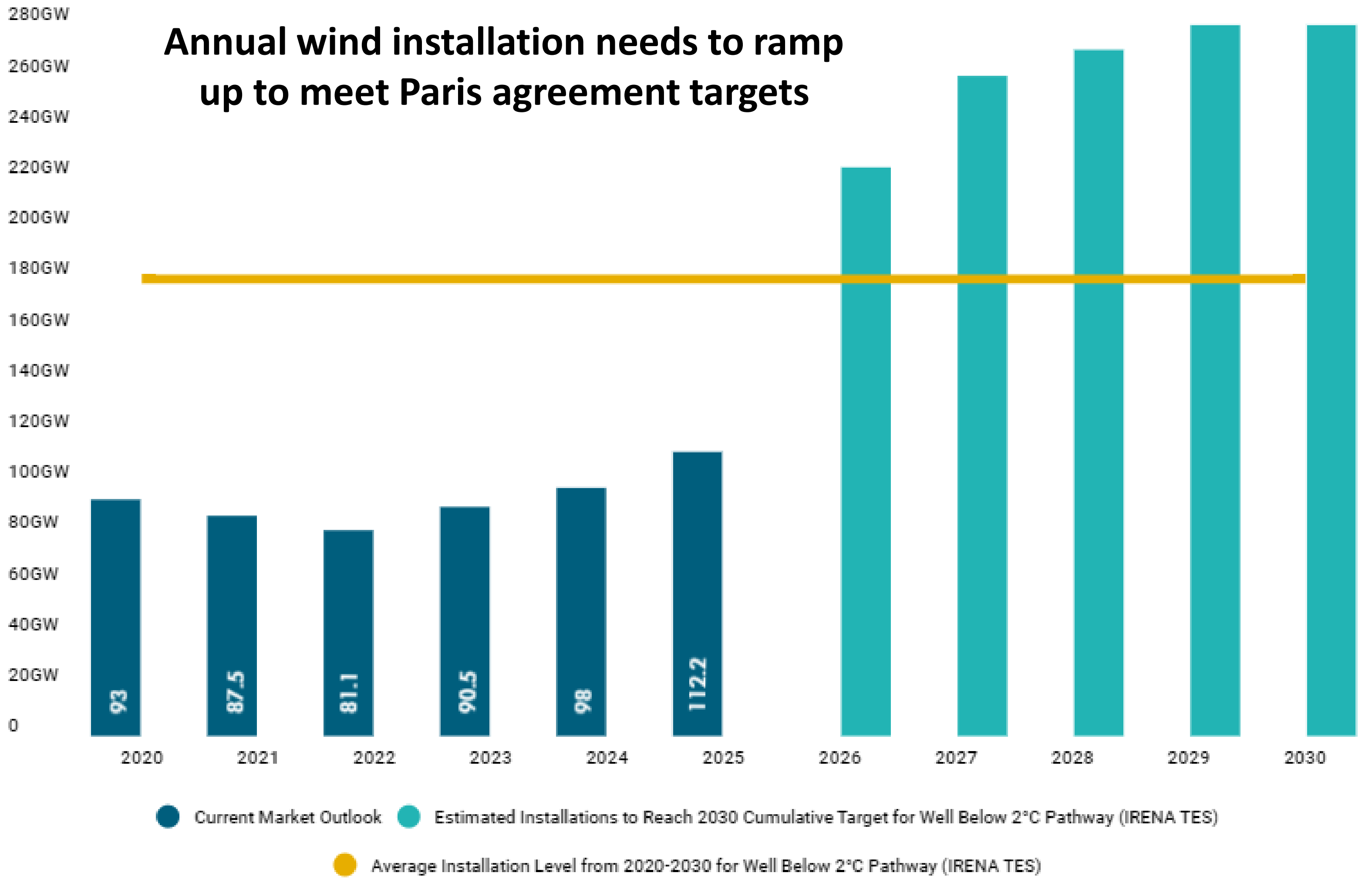


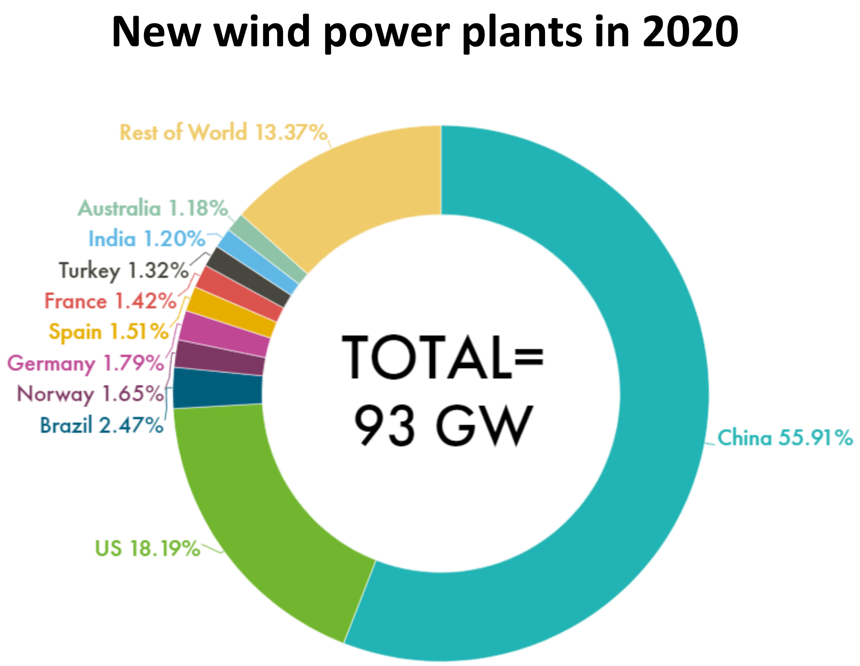
https://gwec.net/wp-content/uploads/2020/08/Annual-Wind-Report_2019_digital_final_2r.pdf

GWEC GLOBAL WIND REPORT 2019

2021: "A new record year for the wind industry. 93 GW of new wind power capacity was installed in 2020, driven by China and the US"

GWEC GLOBAL WIND ENERGY COUNCIL

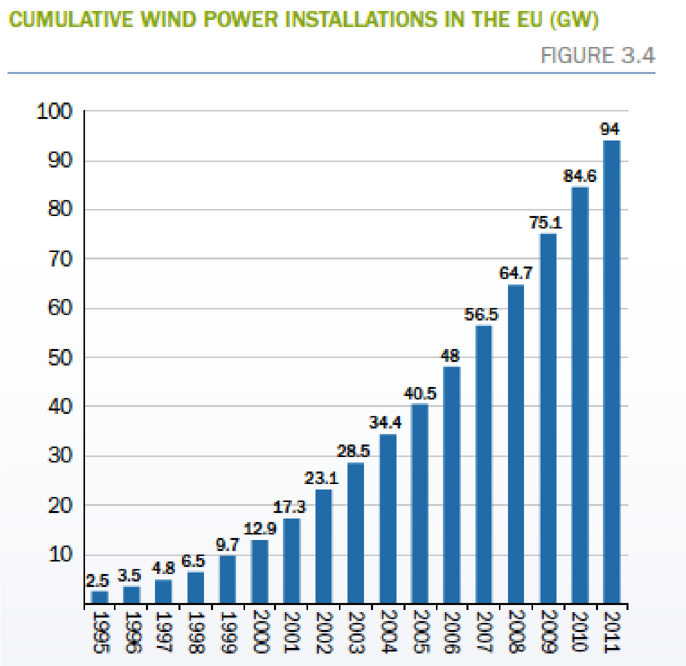




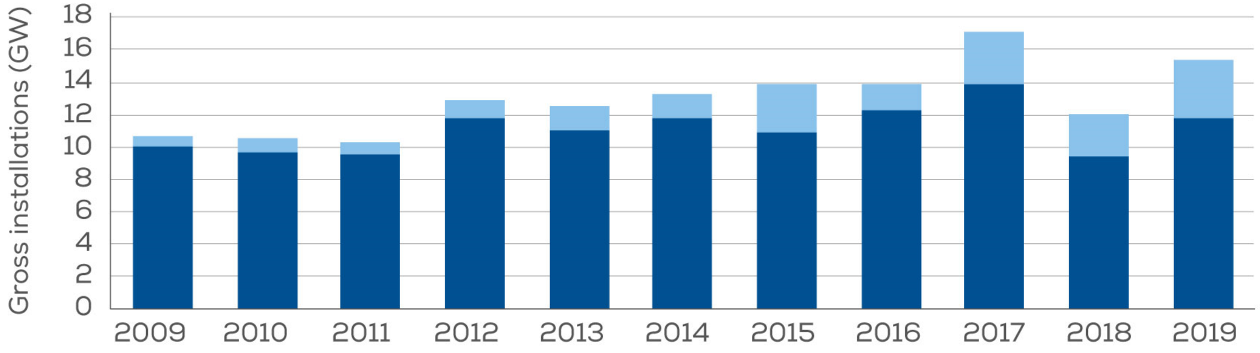
GWEC GLOBAL WIND REPORT 2021

https://gwec.net/global-wind-report-2021/

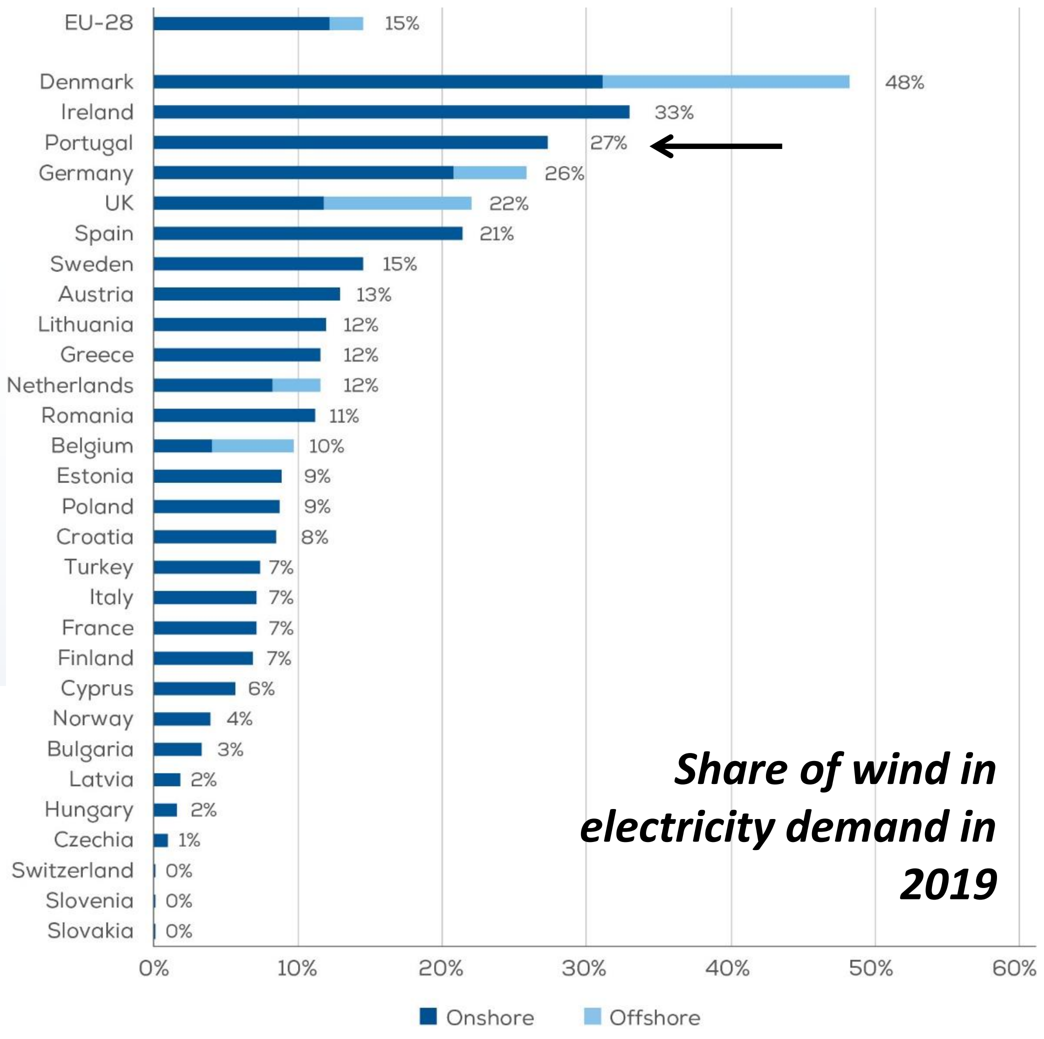
WIND POWER EUROPE



Source: The European Wind Energy Association, Feb 2012



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Offshore	0.6	0.9	0.8	1.2	1.5	1.5	3.0	1.6	3.2	2.7	3.6
Onshore	10.0	9.6	9.5	11.7	11.0	11.7	10.9	12.3	13.9	9.4	11.7
Total	**10.7**	**10.5**	**10.3**	**12.9**	**12.5**	**13.3**	**13.9**	**13.8**	**17.1**	**12.1**	**15.4**

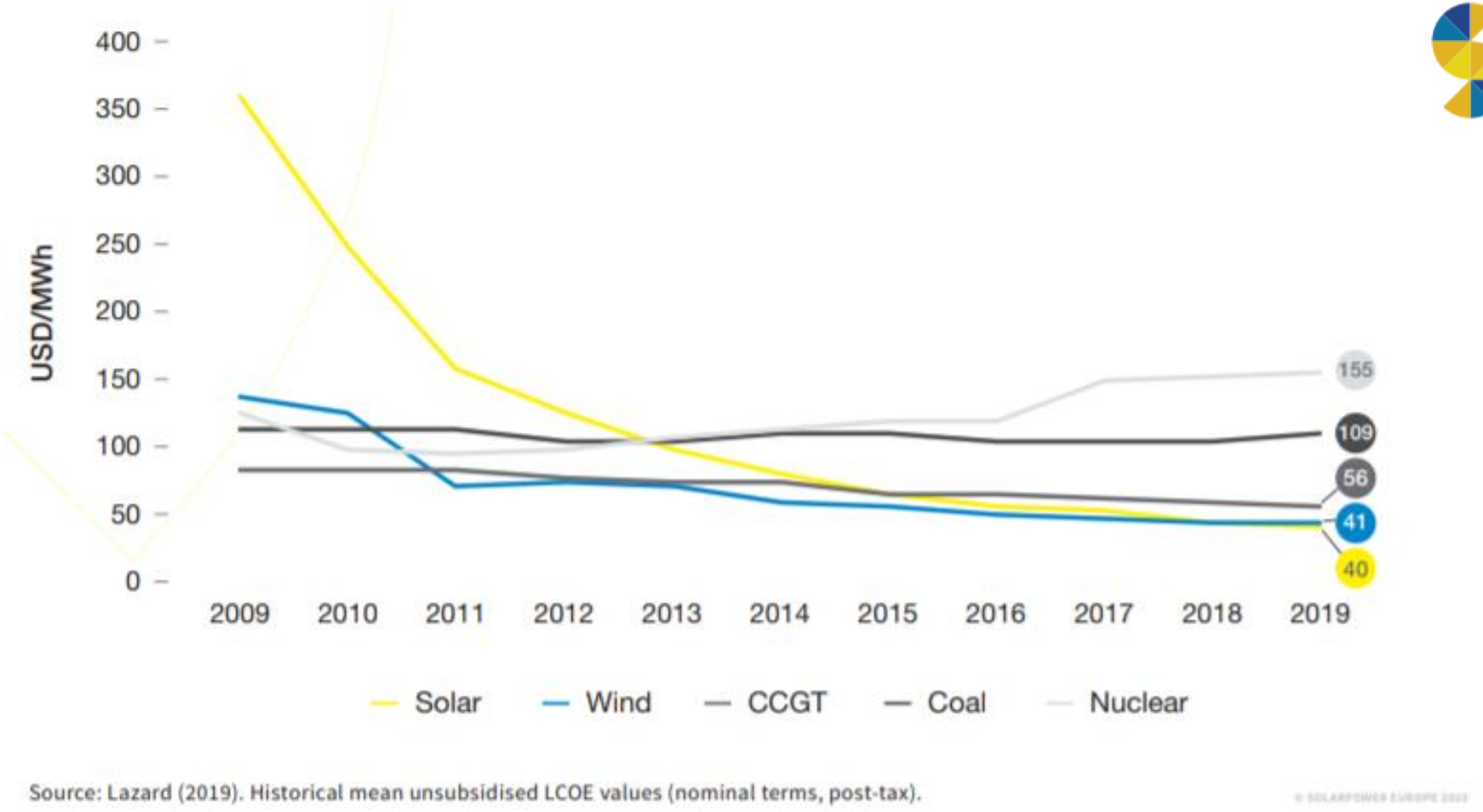


Share of wind in electricity demand in 2019

→ 2019 EU 170 GW onshore / 22 GW offshore

Climate Change and Sustainable Development Policies

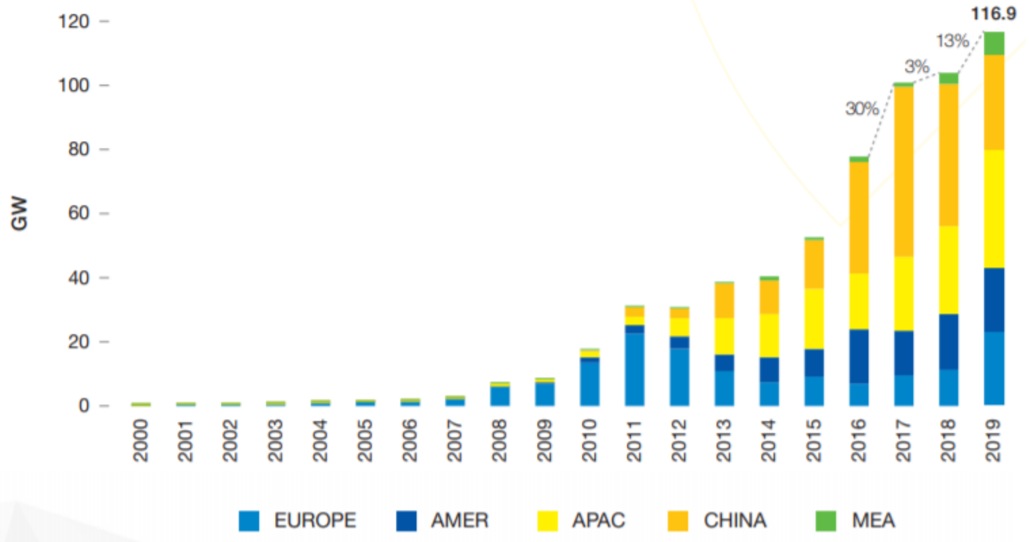
SOLAR ELECTRICITY GENERATION COST IN COMPARISON WITH OTHER POWER SOURCES 2009-2019

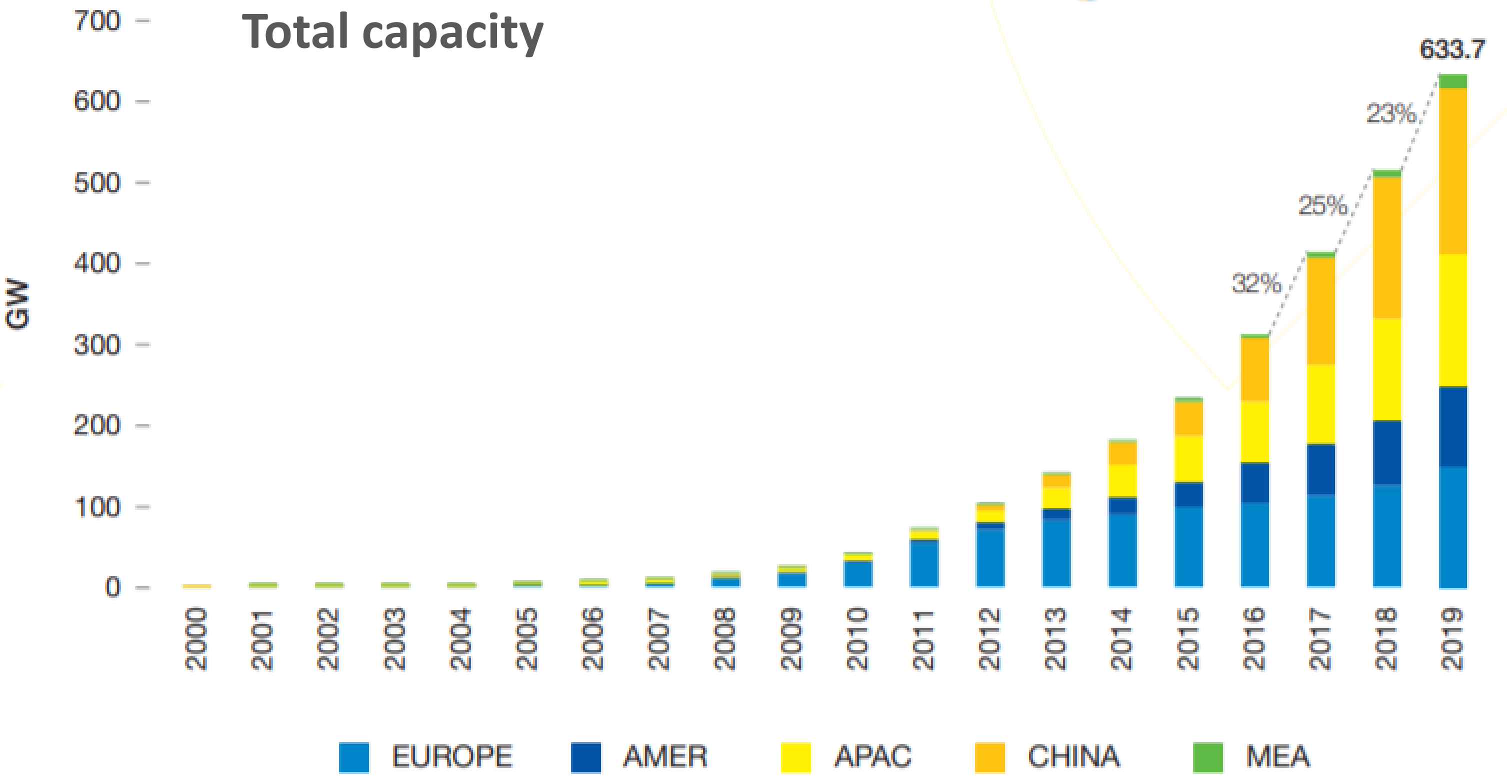


Source: SolarPower Europe, 2020 | https://www.solarpowereurope.org/global-market-outlook-2020-2024/

SOLAR POWER Evolution of global installed PV capacity annually

Annual capacity
(117 GW in 2019)





MEA - Middle East and African

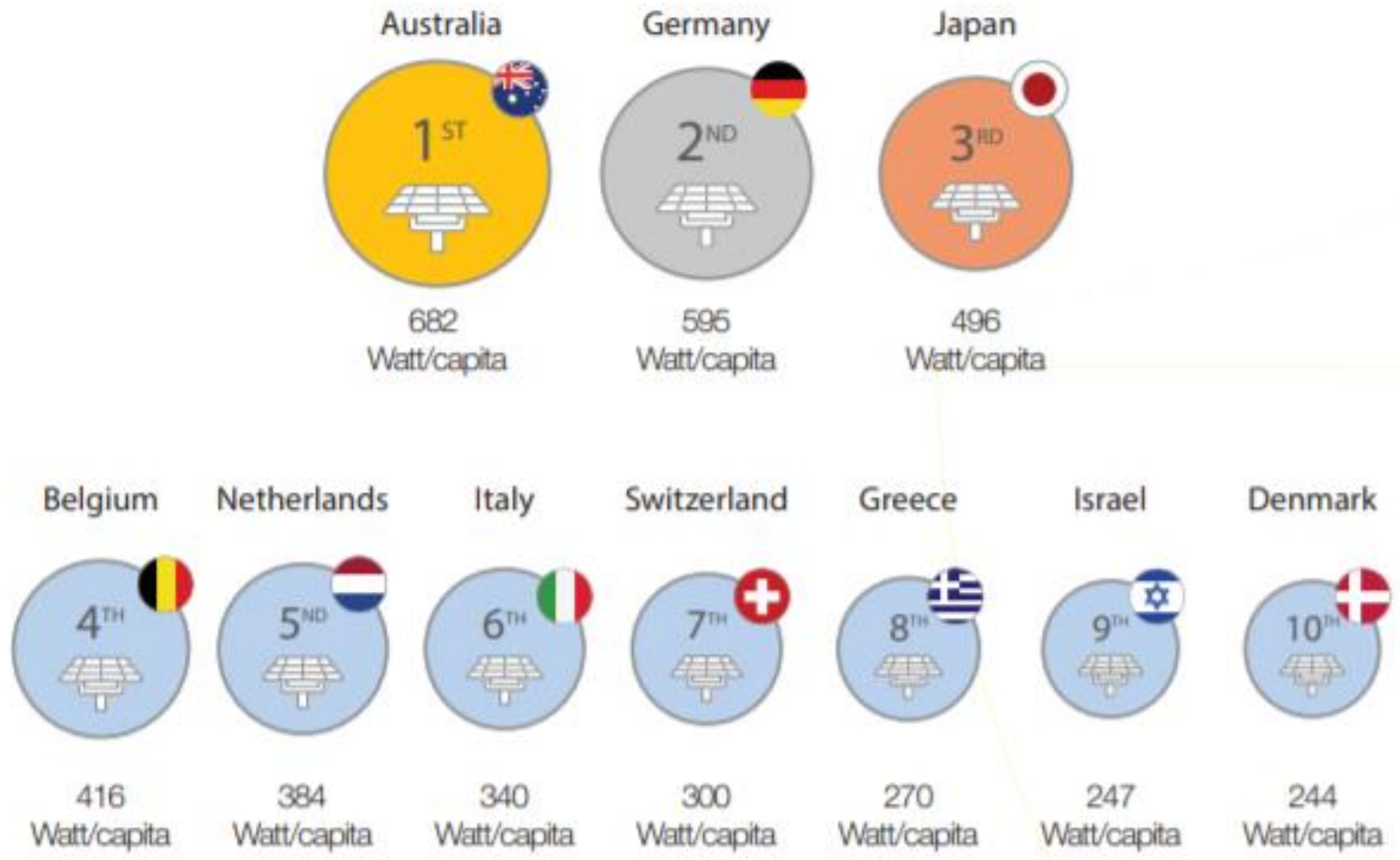
→ Europe leading in PV till 2015, currently replaced by China (205 GW, 32% world's total PV cumulative capacity, while EU has 24%)

→ Next in the ranking are USA (76 GW), Japan (63 GW), Germany (50 GW) and India (42GW)

Source: SolarPower Europe, 2020 | https://www.solarpowereurope.org/global-market-outlook-2020-2024/

WHICH COUNTRIES HAVE THE HIGHEST PV PRODUCTION PER CAPITA?

SOLAR POWER - SOLAR PV- MARKET 2019

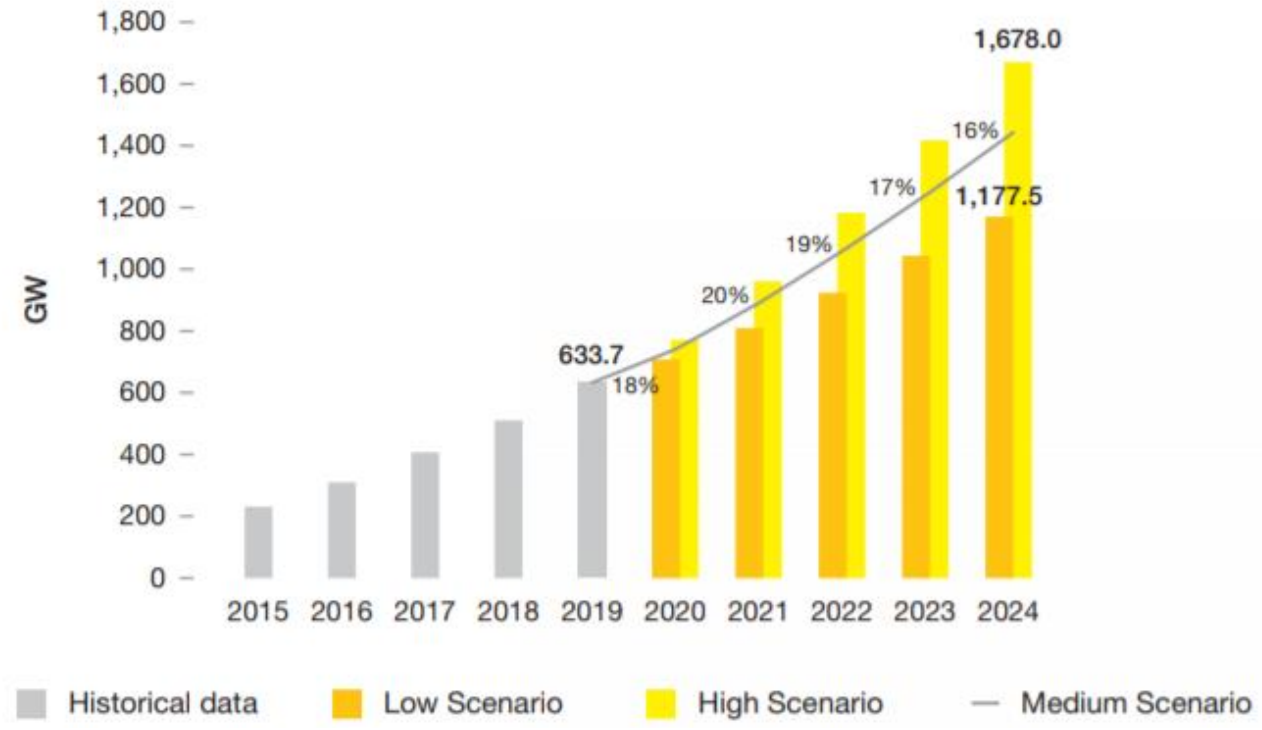


Source: SolarPower Europe, 2020 | https://www.solarpowereurope.org/global-market-outlook-2020-2024/

SOLAR POWER SOLAR PV MARKET SCENARIOS 2020-2024

SolarPower Europe

Annual capacity deployed in 2024: 129-255 GW/yr

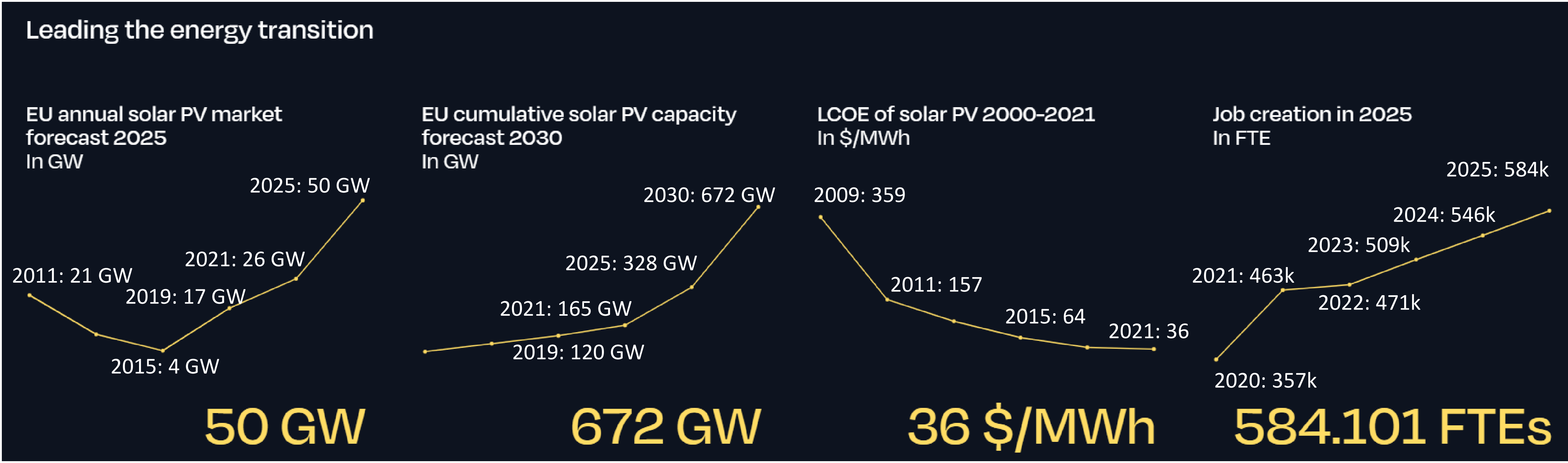


	2019 TOTAL CAPACITY (MW)	2024 TOTAL CAPACITY MEDIUM SCENARIO BY 2024 (MW)	2020 - 2024 NEW CAPACITY (MW)	2020 - 2024 COMPOUND ANNUAL GROWTH RATE (%)	POLITICAL SUPPORT PROSPECTS
China	205 187	485 987	280 800	19%	
United States	76 119	178 869	102 750	19%	
India	42 031	111 881	69 850	22%	
Japan	62 951	95 076	32 125	9%	
Germany	49 729	78 643	28 914	10%	
Australia	15 977	40 168	24 191	20%	
South Korea	10 872	28 456	17 584	21%	
Vietnam	6 458	23 720	17 262	30%	
Spain	10 641	27 734	17 093	21%	
Netherlands	6 559	23 495	16 936	29%	
France	9 874	22 033	12 159	17%	
Taiwan	4 151	15 977	11 826	31%	
Brazil	4 460	15 935	11 475	29%	
Italy	20 600	31 904	11 304	9%	
Turkey	5 994	13 139	7 145	17%	
Mexico	4 940	11 863	6 923	19%	
United Arab Emirates	2 009	8 789	6 780	34%	
Saudi Arabia	478	7 185	6 707	72%	
Ukraine	5 937	12 058	6 121	15%	
Israel	2 104	7 999	5 895	31%	

Source: SolarPower Europe, 2020 | https://www.solarpowereurope.org/global-market-outlook-2020-2024/

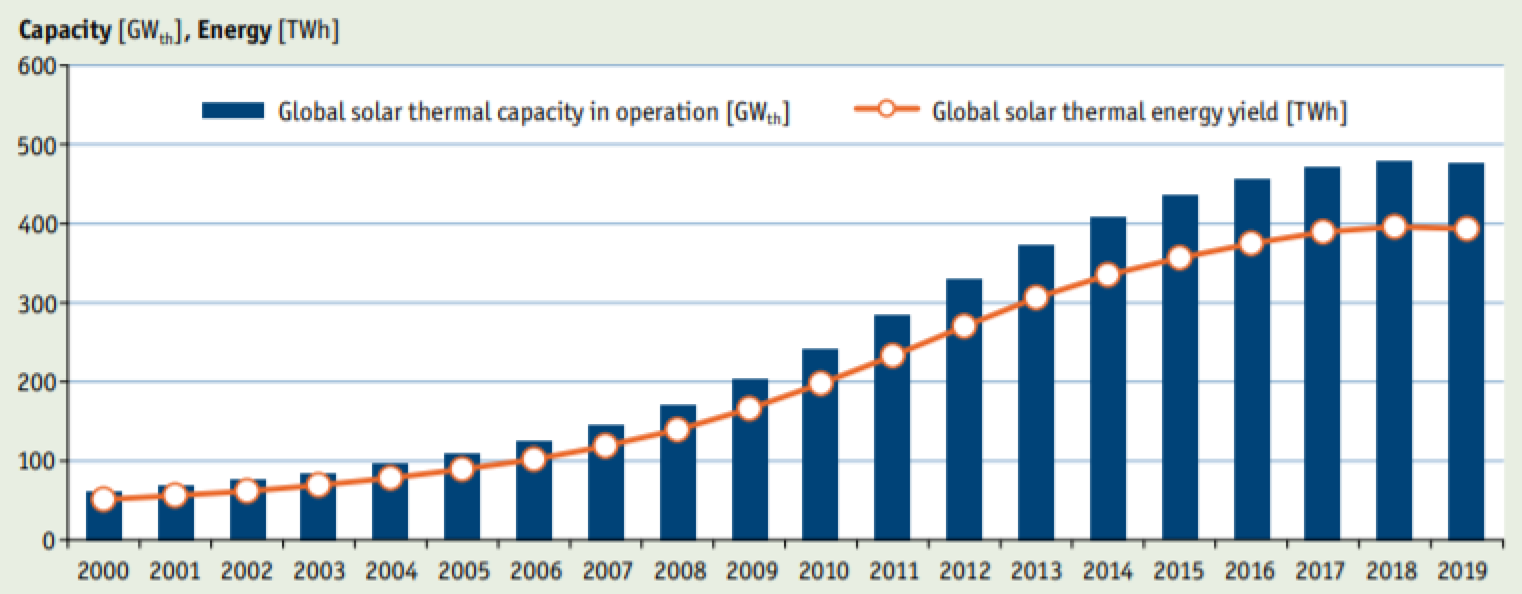
SOLAR POWER - SOLAR PV- MARKET 2022

"Despite the severe impact of the COVID-19 pandemic across the world in 2020, the year still saw 138.2 GW of solar installed, representing an 18% growth compared to 2019, yet another global annual installation record for the solar PV sector. This brings the global cumulative solar capacity to 773.2 GW, a 22% increase, and marks a new milestone for the solar sector by exceeding three quarters of a terawatt."



SolarPower Europe, 2020 | https://www.solarpowereurope.org/insights/market-outlooks/global-market-outlook-for-solar-power

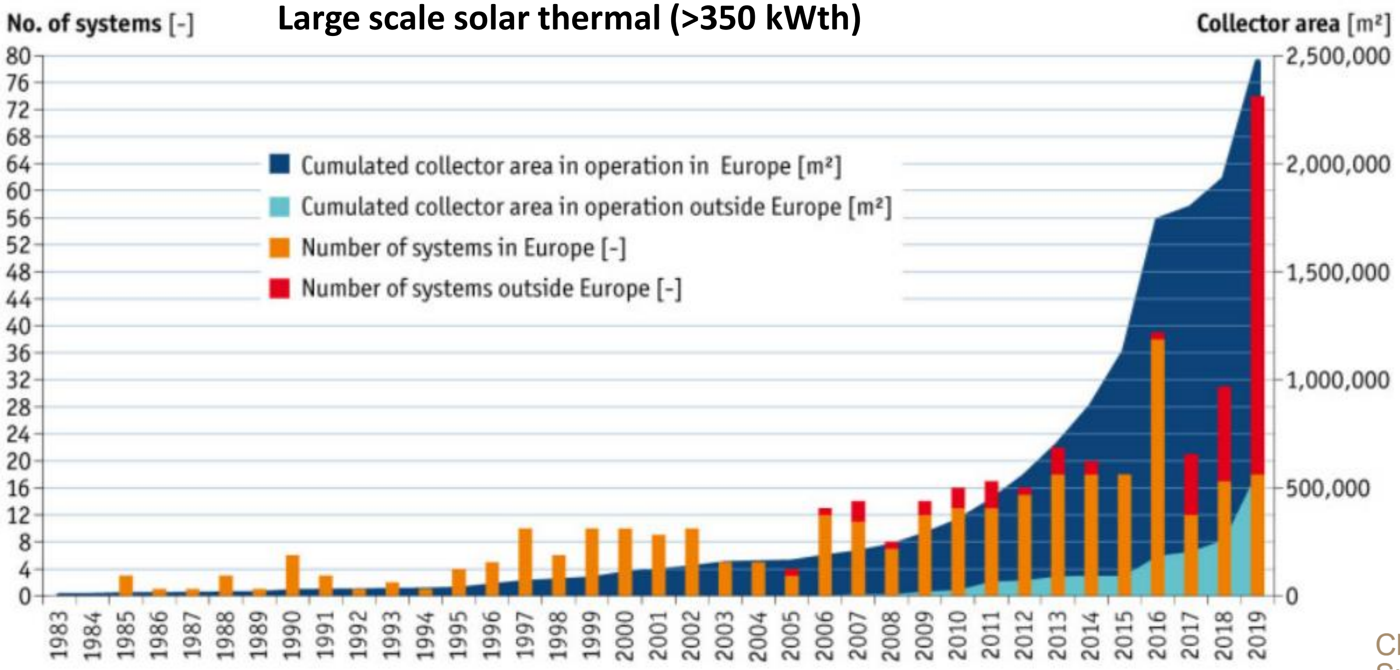
Solar Thermal



Source: https://www.iea-shc.org/solar-heat-worldwide

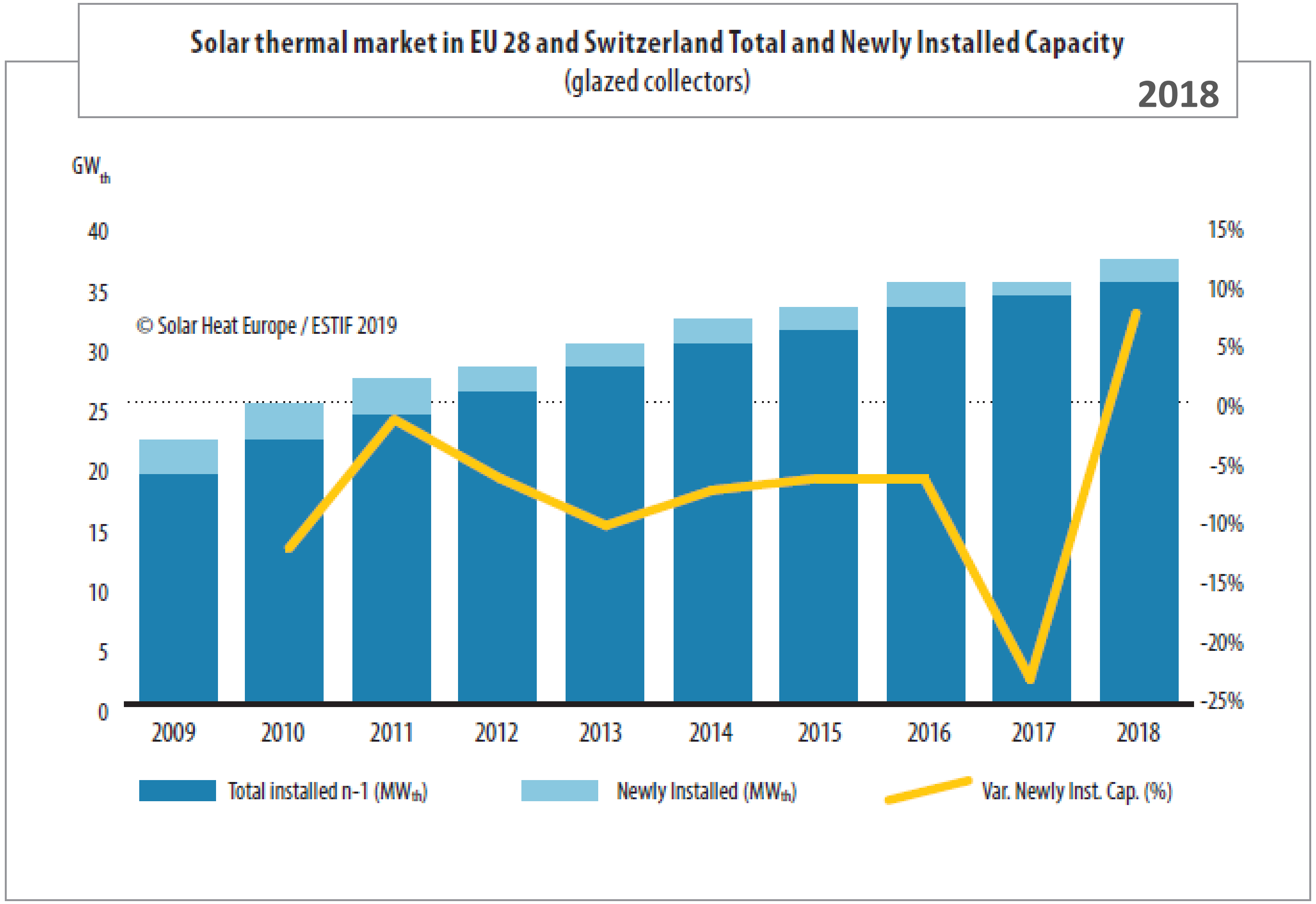
“Worldwide, in 2015, solar heat employed some **730 000 workers** and generated **a turnover of €21 billion**.”

Large scale solar thermal (>350 kWth)



Source: https://www.iea-shc.org/solar-heat-worldwide

→ Solar heat can contribute significantly to the global energy need for heat, meeting climate change and energy security objectives



http://solarheateurope.eu/publications/market-statistics/solar-heat-markets-in-europe/

"Heat represents almost half of the energy demand in Europe, and the vast majority of the energy bill of European households"

→ 36.1 GW_{th} total capacity in EU in 2018 (~10.1 million systems) capable to store circa 180 GWh and generating 1.5 GW_{th}

→ Germany leads with 28% of 2018 installed capacity in EU, followed by Greece (15%), Poland (14%), Spain (9%), Italy (8%), Austria (4%)

→ In per capita terms Cyprus, Austria, Greece, Denmark and Germany have highest solar thermal capacity in Europe

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

LCOE- levelized cost of energy (or electricity): a summary metric that combines the primary technology cost and performance parameters (i.e. capital expenditures, operations expenditures, and capacity factor). It is useful for discussing technology advances that yield future projections because it illustrates the combined effect of the primary cost and performance parameters in the technology innovation scenarios.
https://atb.nrel.gov/electricity/2021/definitions

Technology learning curve: A learning curve describes technological progress (measured generally in terms of decreasing costs for a specific technology) as a function of accumulating experience with that technology
http://pure.iiasa.ac.at/id/eprint/6787/1/RR-03-002.pdf

Capacity factor (recap): actual output /output at rated capacity for a certain period of time (normally 1 year), without curtailment for renewable generation. It is non-dimensional or sometimes expressed in %. In other words: the number of hrs in 1 year that the power plant operates / the total maximum possible number of hours in 1 year.

Dispatchability: 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.
https://energyeducation.ca/encyclopedia/Dispatchable_source_of_electricity

Energy system value: reflects other attributes that add value to the system such as reliability, energy security, sustainability. Etc.

LCOE formulation – the details

$$\sum_{t=0}^{T} \frac{C_t + M_t}{(1+r)^t} = \sum_{t=0}^{T} \frac{LCOE \times Q_t}{(1+r)^t} = LCOE \sum_{t=0}^{T} \frac{Q_t}{(1+r)^t}$$

C_t represents all capital costs incurred in year t (these may be zero except during the first few years of the project)
M_t represents all operational costs incurred in year t
Q_t represents the total output of the project in year t.

The term $C_t + M_t$ represents the ***annual costs* of the proj**ect (which may include payments on capital, fuel, labor, land leases and so forth).
The term Q_t represents the **annual energy output of the plant**.

https://www.e-education.psu.edu/eme801/node/560

Climate Change and Sustainable Development Policies

LCOE allows to compare costs of different technologies

PennState

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)*

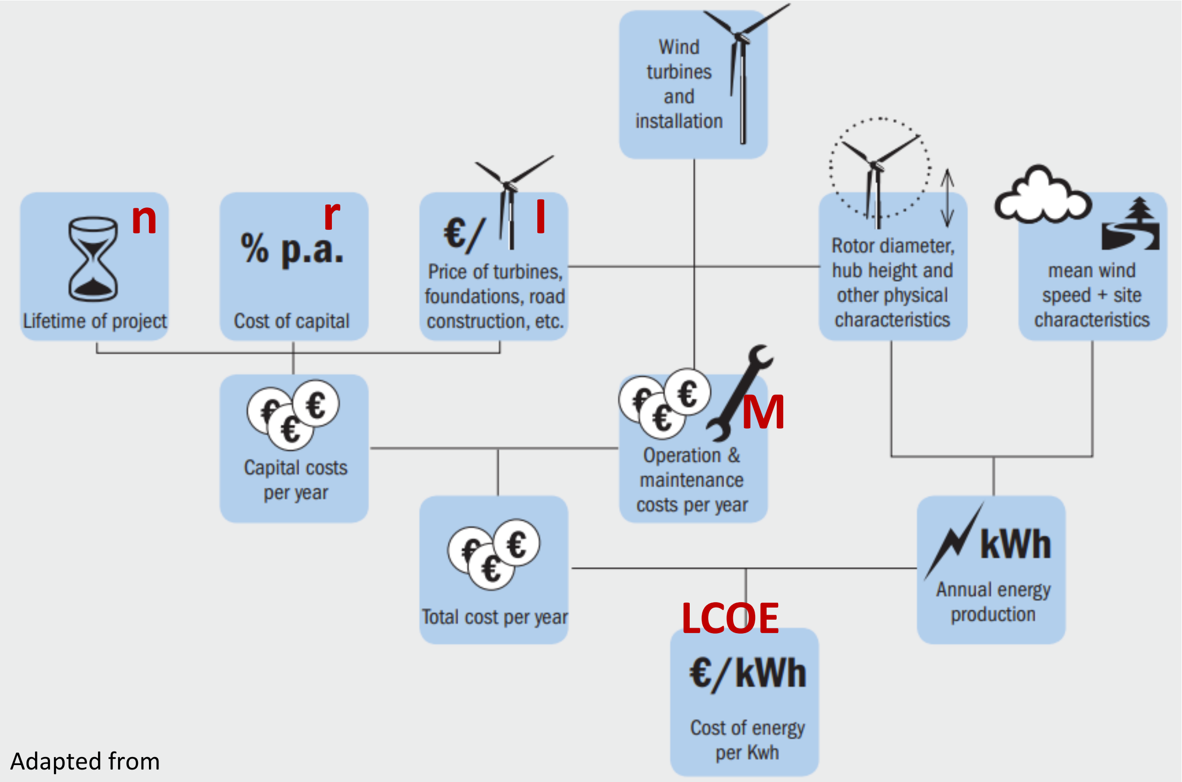
Technology	Capital Cost ($/kW)	Operating Cost ($/kWh)
Coal-fired combustion turbine	$500 — $1,000	0.02 — 0.04
Natural gas combustion turbine	$400 — $800	0.04 — 0.10
Coal gasification combined-cycle (IGCC)	$1,000 — $1,500	0.04 — 0.08
Natural gas combined-cycle	$600 — $1,200	0.04 — 0.10
Wind turbine (includes 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

“In general, central station generators face a tradeoff between capital and operating costs. Those types of plants that have higher capital costs tend to have lower operating costs. Further, generators which run on fossil fuels tend to have operating costs that are extremely sensitive to changes in the underlying fuel price.”

Slide adapted from Júlia Seixas materials

https://www.e-education.psu.edu/eme801/node/560

LCOE - how it works



https://www.ewea.org/fileadmin/files/library/publications/reports/Economics_of_Wind_Energy.pdf

$$\text{LCOE} = \frac{\text{NPV of total costs over lifetime}}{\text{NPV of electrical Energy produced over lifetime}}$$

- Measure **lifetime costs divided by energy production**
- Calculates (net) **present value (NPV)** 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) with **different characteristics**: life spans, project size, different capital costs, risk, return and capacities

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)

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

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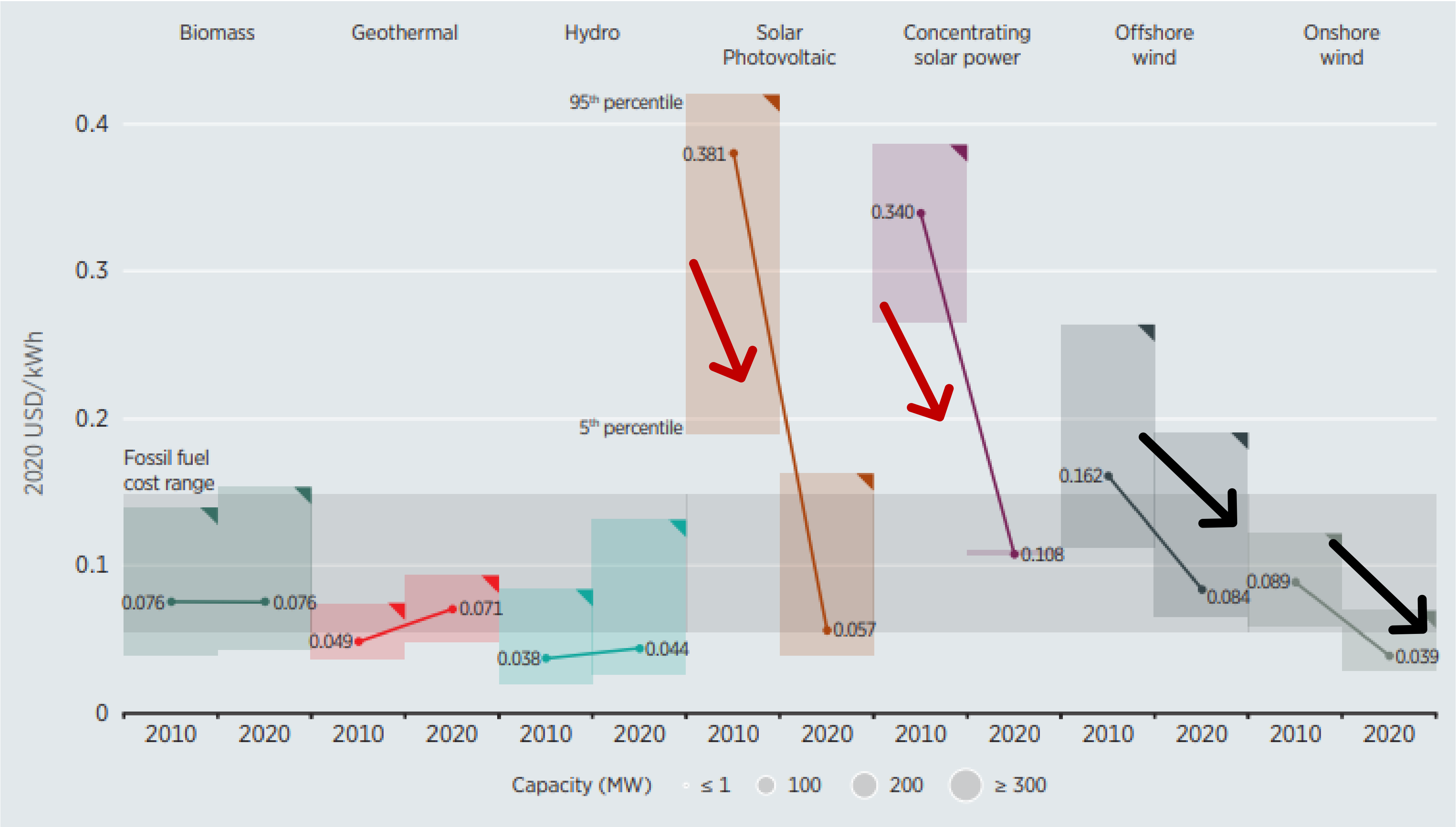
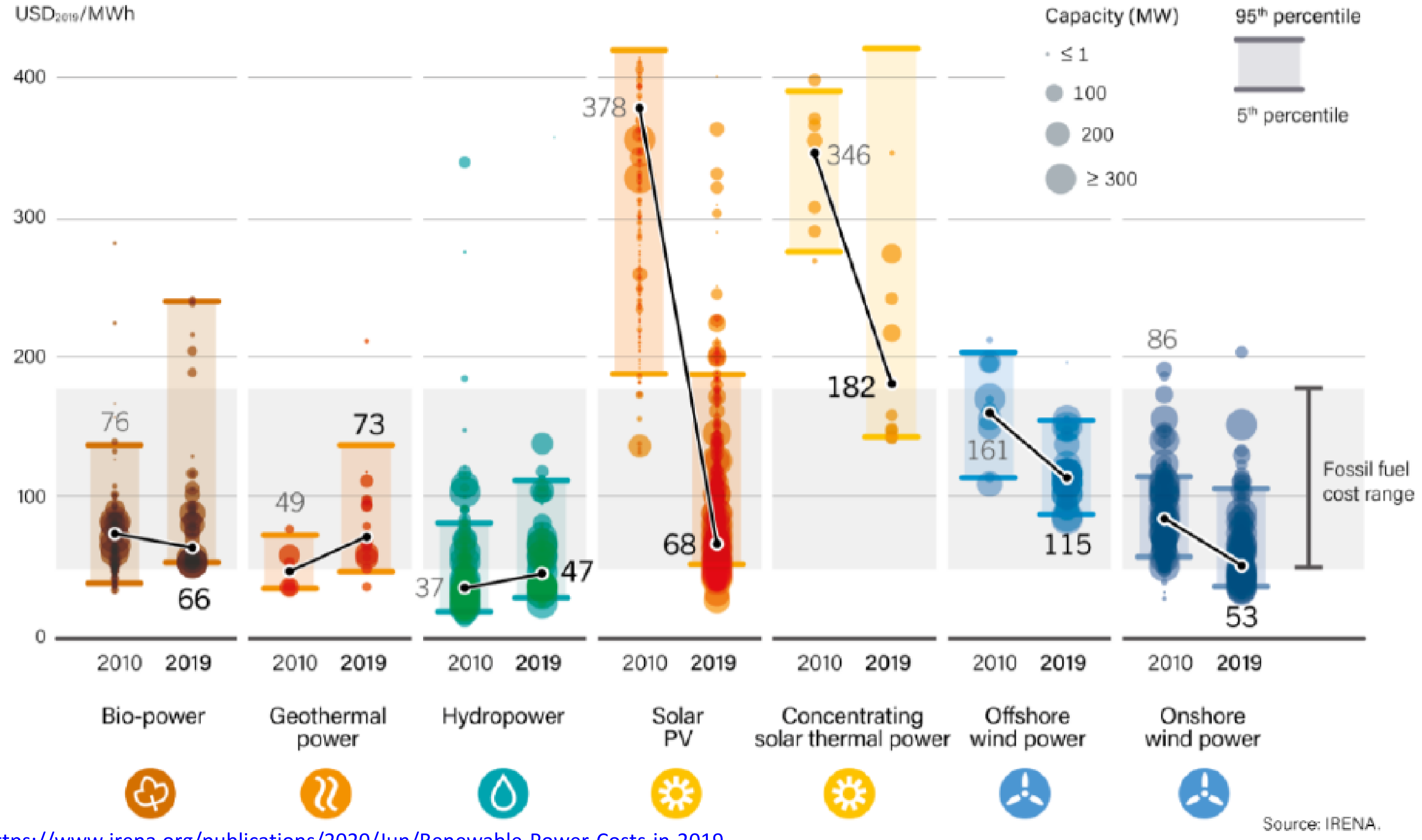
Renewable power costs keep falling

Global LCOEs from newly commissioned, utility-scale renewable power generation technologies, 2010-2020



https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jun/IRENA_Power_Generation_Costs_2020.pdf

Renewable power costs keep falling – but they also vary across countries and regions

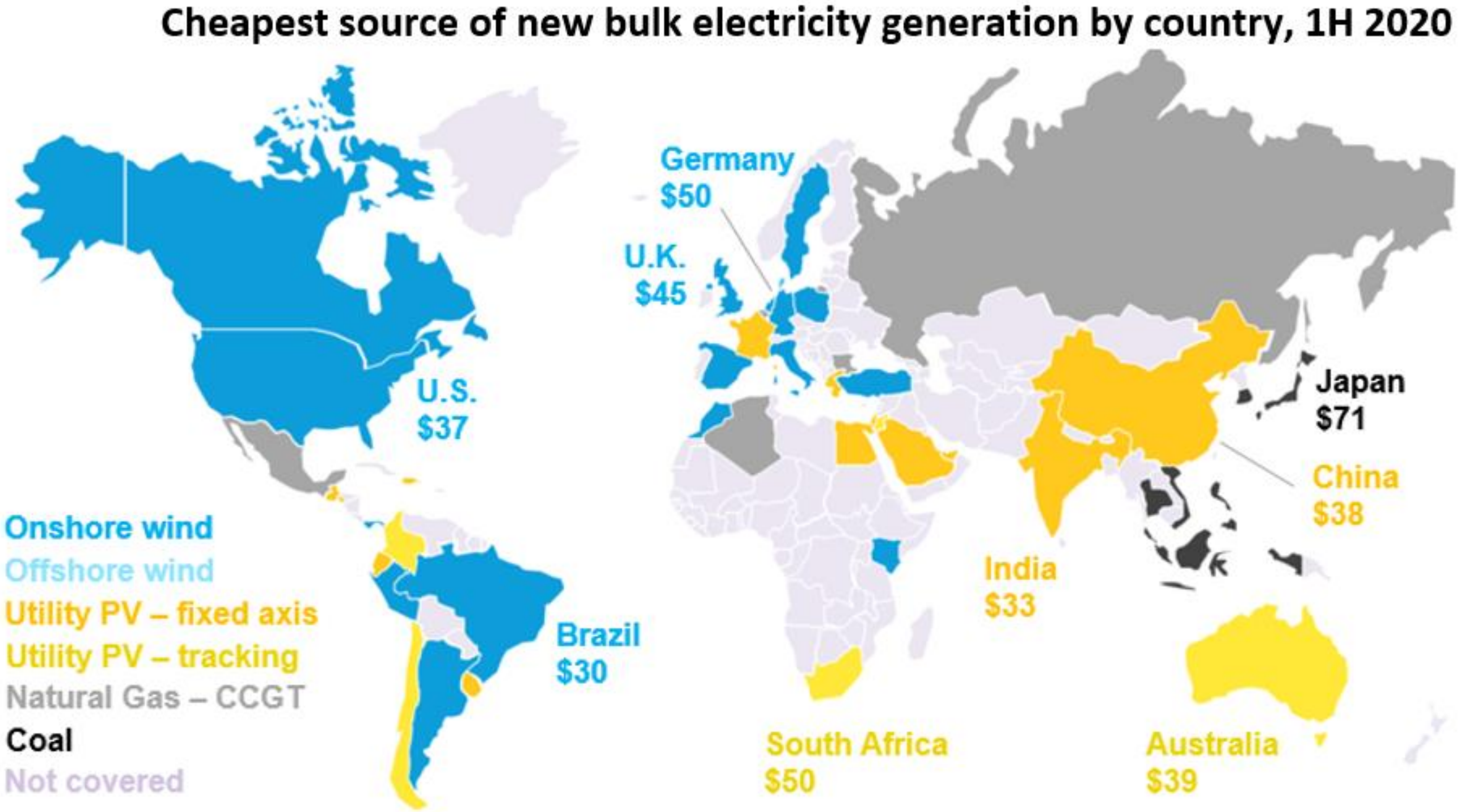


Global LCOEs from newly commissioned, utility-scale renewable power generation technologies, 2010-2019

https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019

Slide adapted from Júlia Seixas materials

LCOE across countries

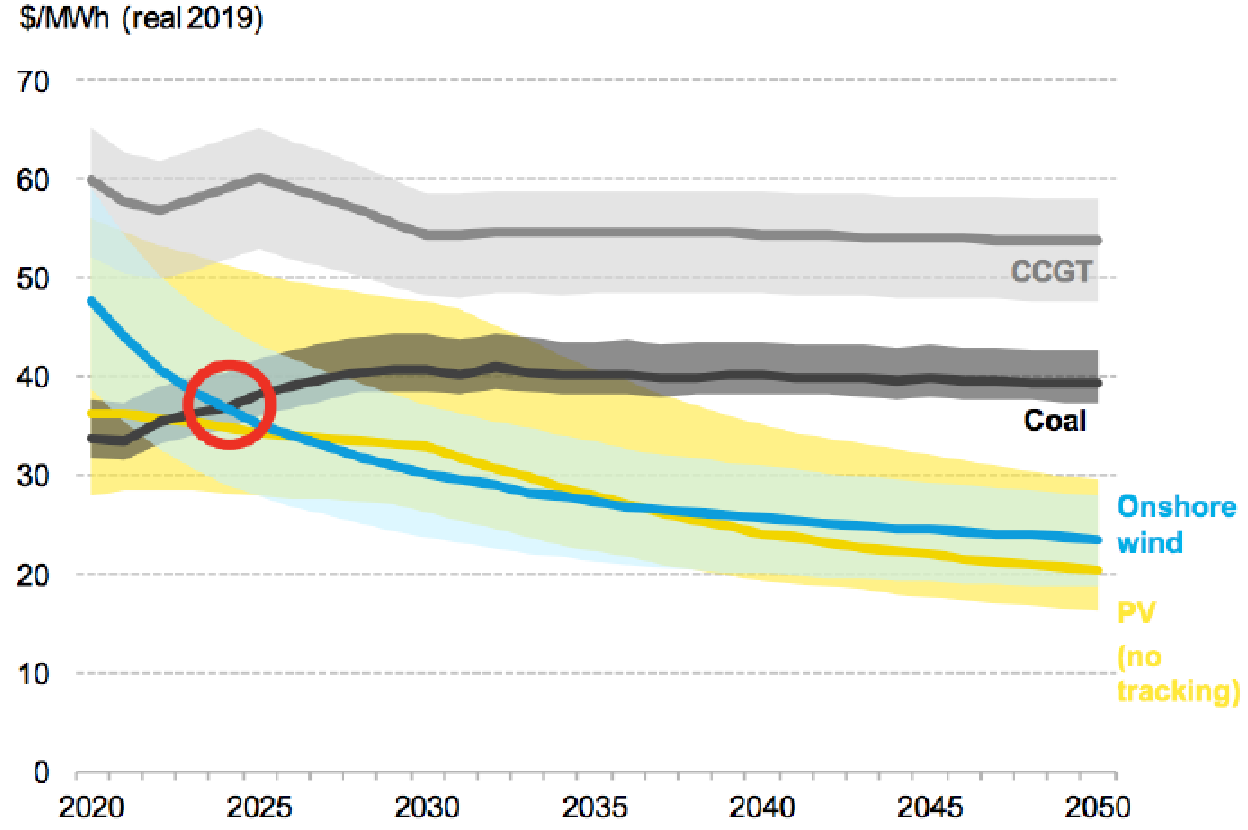


Source: BloombergNEF. Note: LCOE calculations exclude subsidies or tax-credits. Graph shows benchmark LCOE for each country in $ per megawatt-hour. CCGT: Combined-cycle gas turbine.

https://about.bnef.com/blog/scale-up-of-solar-and-wind-puts-existing-coal-gas-at-risk/

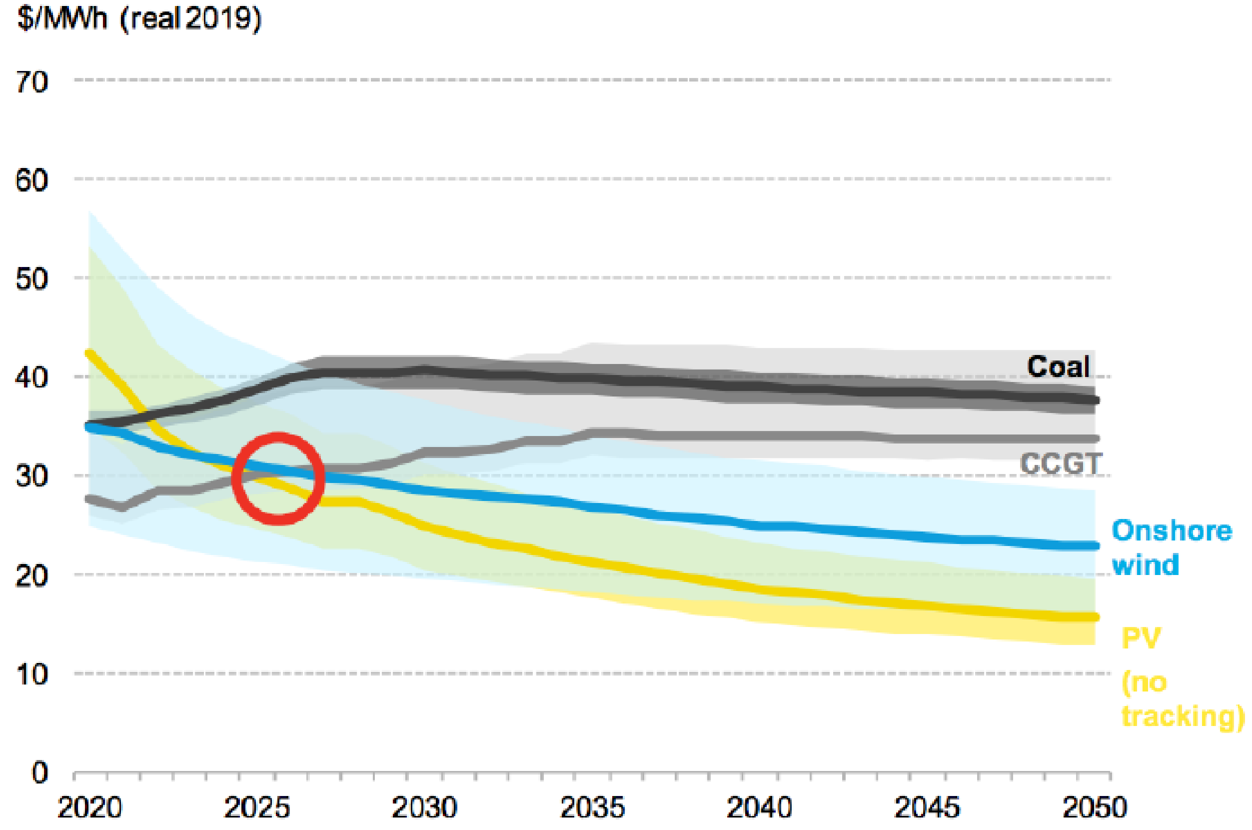
In the next 5 years, wind & PV are on track to be cheaper than running existing coal and gas

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



Source: BloombergNEF

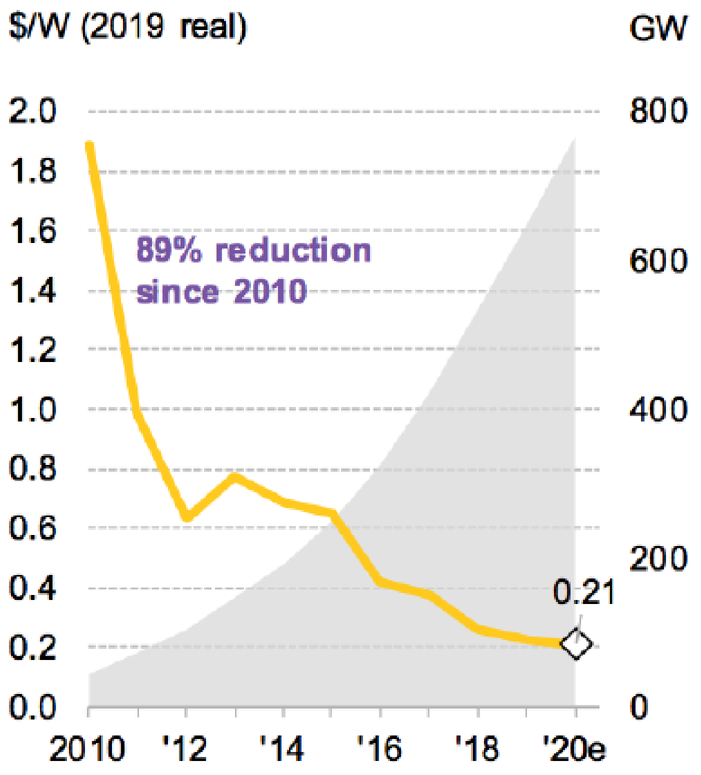
United States: new wind and PV vs. existing coal & gas



Source: BloombergNEF

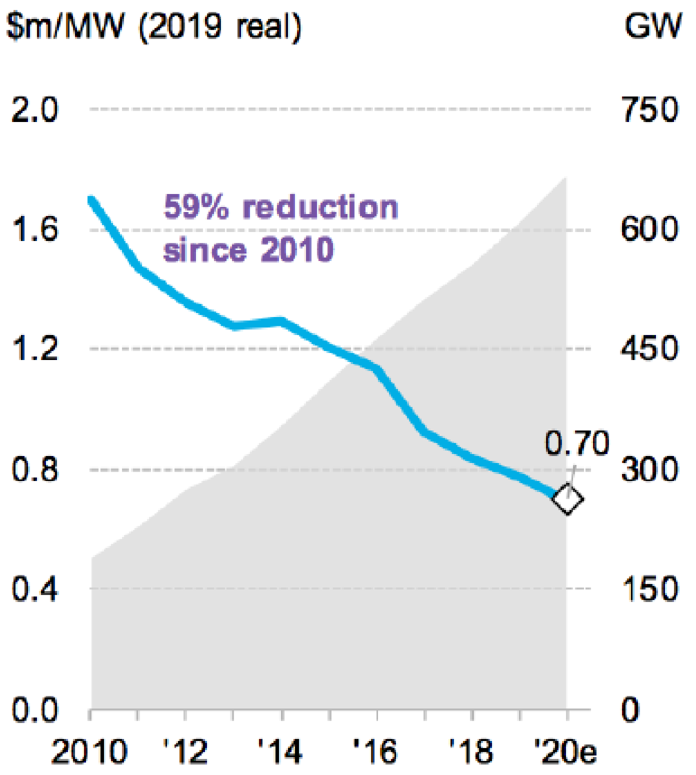
Innovation and scale have driven down the costs of renewable technology…

PV module price and cumulative installed capacity



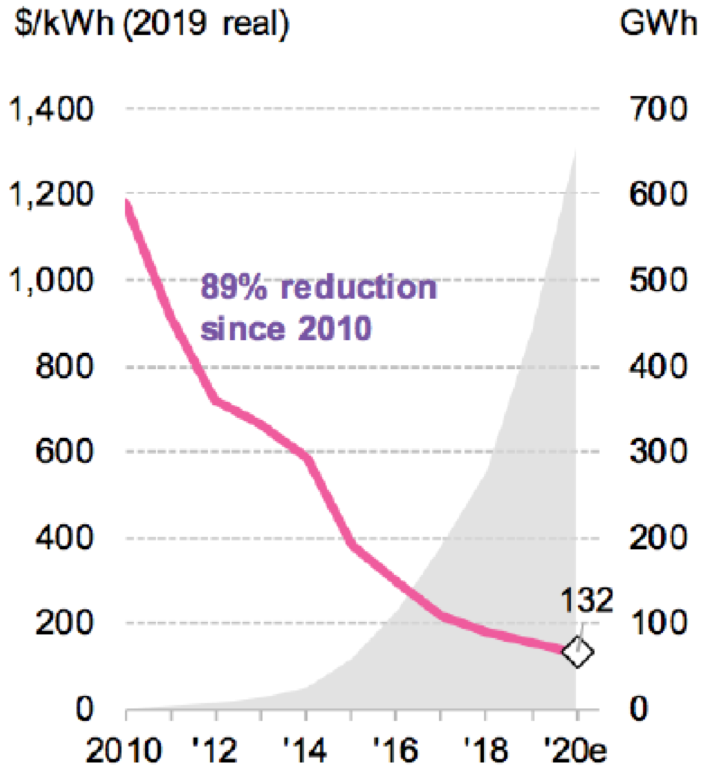
Source: BloombergNEF

Onshore wind turbine price and cumulative installed capacity



Source: BloombergNEF

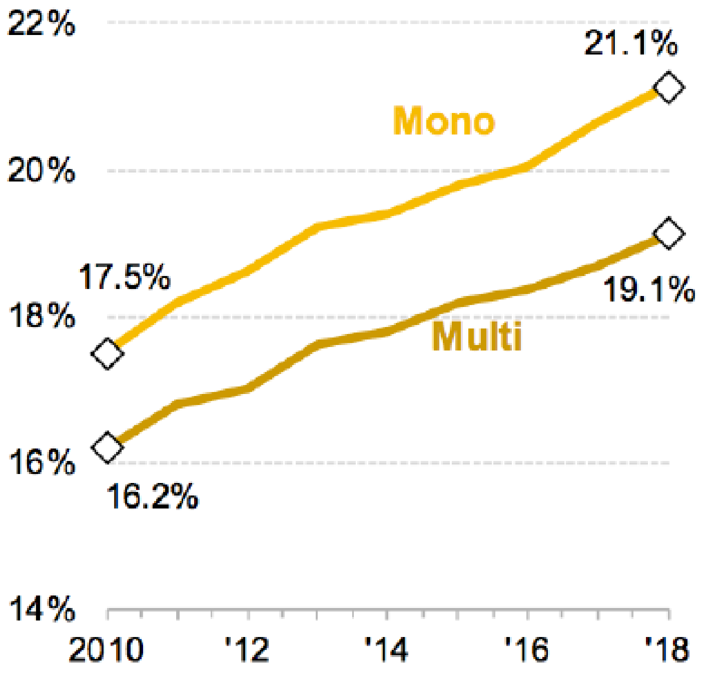
Li-ion battery pack price and demand



Source: BloombergNEF

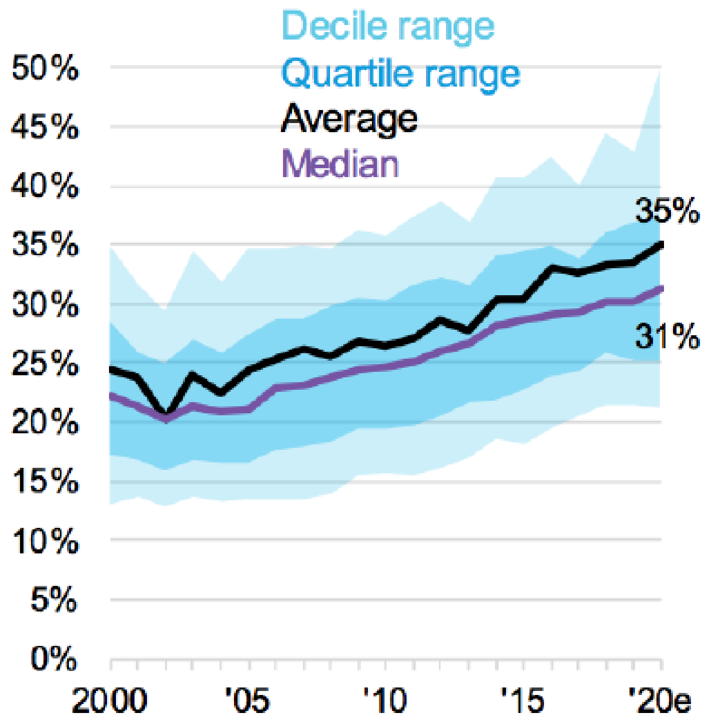
…and at the same time the technology keeps getting better

PV module efficiency



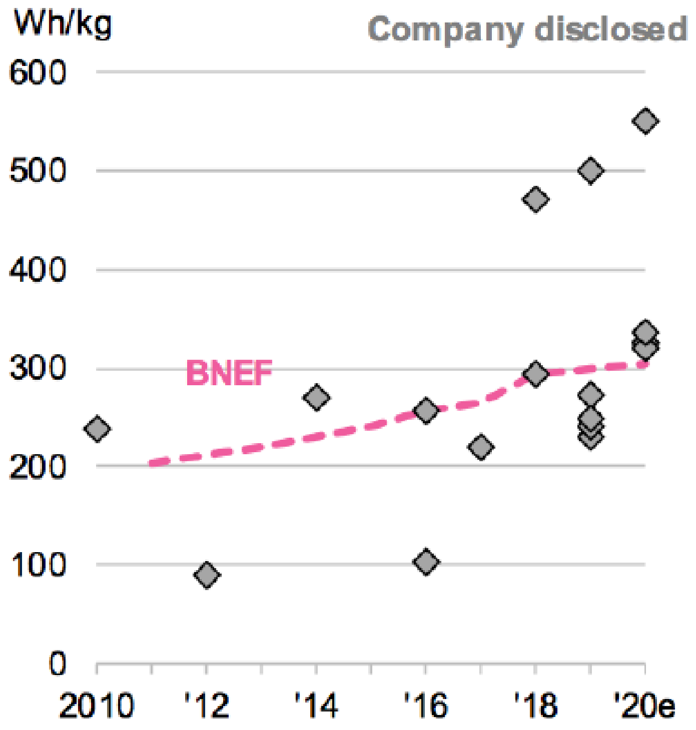
Source: BloombergNEF

Onshore wind capacity factors



Source: BloombergNEF

Battery cell energy density



Source: BloombergNEF, public announcements, company interviews

Climate Change and Sustainable Development Policies

LNEG NOVA SCHOOL OF SCIENCE & TECHNOLOGY CENSE center for environmental and sustainability research

Slide adapted from Júlia Seixas materials

LCOE Simulator

2016 | 2030 | 2050 | 2016 | 2030 | 2050

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

The NREL simulator is available online in a simplified version where the user can introduce its ow assumptions

For the same technology LCOE can become lower over the years as the investment cost decrease and efficiency increase

In this website, it is possible to explore the different cost and efficiency assumptions: https://atb.nrel.gov/electricity/2021/index

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

https://www.nrel.gov/analysis/tech-lcoe.html

Slide adapted from Júlia Seixas materials

Capacity factor (CF)

CF is estimated by dividing the actual output by theoretical output at rated capacity for a certain period of time (normally 1 year). It can be expressed as a ratio (e.g. 0.9 or 0.13) or as a %.
In other words: CF can be calculated by dividing the generated electricity in the number of hrs in 1 year that the power plant operates by the total maximum electricity generated if the plant would operate in all in 1 year. (8760hr)

The amount of electricity generated by one given technology along the year depends on:
- number and duration of stops for maintenance
- if there are accidents and generation has to stop
- in the case of renewables, the availability of the renewable resources (water, solar irradiation, wind). The availability can be seasonal (hydro) or daily (solar) and varies across locals

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

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

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: the higher the CF, the more electricity is produced

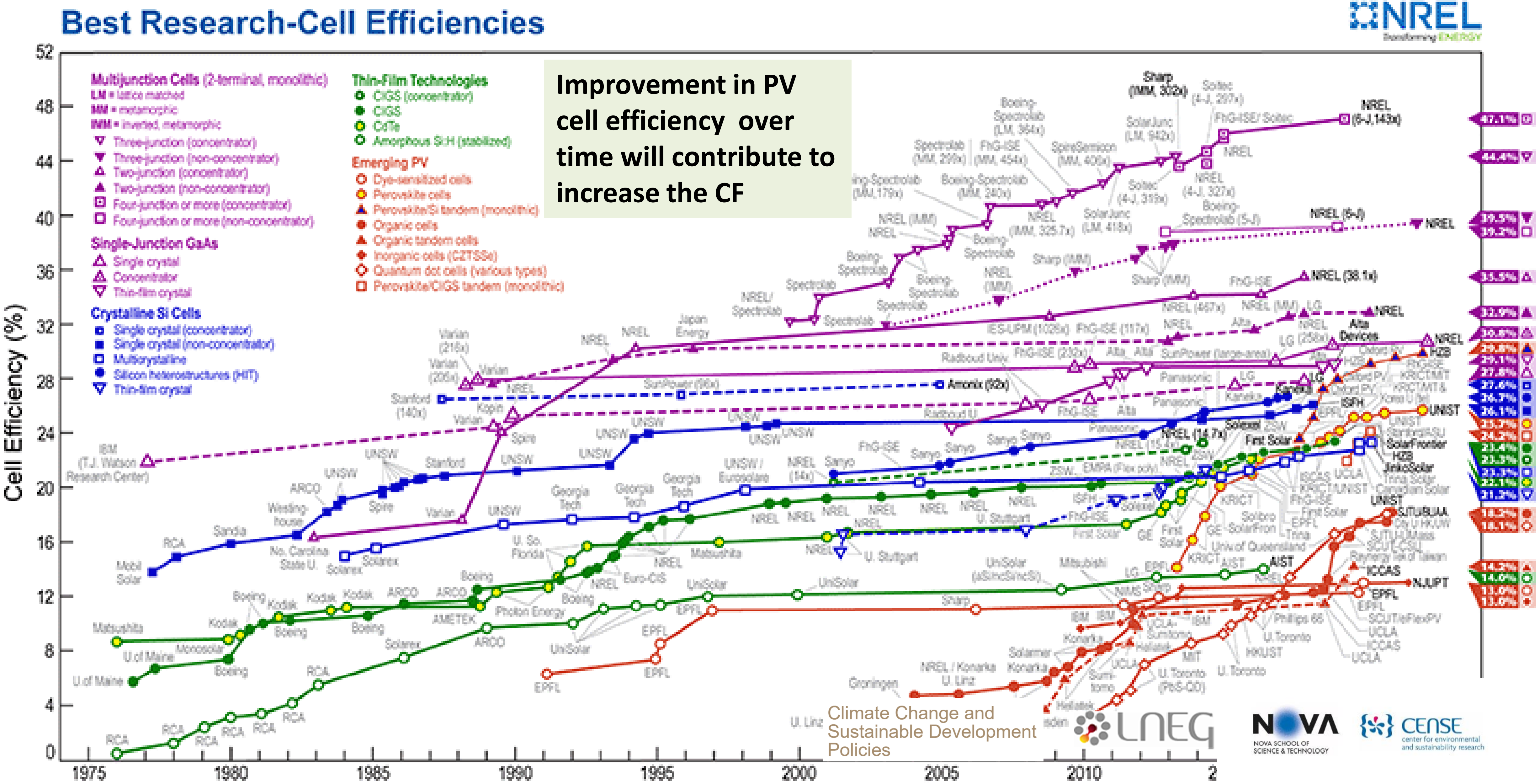
Capacity factor in the USA – vary across technologies, years and countries

Capacity Factors for Utility Scale Generators Primarily Using Non-Fossil Fuels

	Geothermal		Hydroelectric		Nuclear		Other Biomass		Other Gas		Solar				Wind		Wood	
Year/Month											Photovoltaic		Thermal					
	Time Adjusted Capacity	Capacity Factor	Time Adjusted Capacity	Capacity Factor	Time Adjusted Capacity	Capacity Factor	Time Adjusted Capacity	Capacity Factor	Time Adjusted Capacity	Capacity Factor	Time Adjusted Capacity	Capacity Factor	Time Adjusted Capacity	Capacity Factor	Time Adjusted Capacity	Capacity Factor	Time Adjusted Capacity	Capacity Factor
Annual Data																		
2012	2,531.8	68.3%	78,296.6	39.6%	101,166.0	86.6%	4,639.7	63.3%	1,802.8	59.6%	1,527.1	20.4%	476.0	23.6%	49,458.0	31.8%	7,089.1	61.3%
2013	2,509.5	71.8%	78,873.5	38.8%	99,006.8	90.8%	4,949.7	62.3%	2,171.6	55.9%	3,525.2	24.5%	552.1	17.4%	59,175.6	32.4%	7,887.9	59.0%
2014	2,513.3	72.0%	79,582.8	37.2%	98,569.3	91.7%	5,114.6	62.7%	1,994.0	54.0%	6,555.6	25.6%	1,445.3	18.3%	60,587.8	34.0%	8,319.7	60.0%
2015	2,523.0	71.9%	79,650.8	35.7%	98,614.6	92.3%	5,104.5	62.6%	2,527.7	60.8%	9,521.6	25.5%	1,697.3	21.7%	67,106.2	32.2%	9,024.5	59.3%
2016	2,516.6	71.6%	79,806.0	38.2%	99,364.8	92.3%	5,099.5	62.7%	2,458.8	64.8%	14,161.4	25.0%	1,757.9	22.1%	74,162.7	34.5%	8,979.8	58.3%
2017	2,460.4	73.2%	79,698.8	43.0%	99,619.5	92.3%	5,125.6	61.8%	2,375.8	62.8%	21,940.9	25.6%	1,757.9	21.8%	83,355.6	34.6%	8,807.5	60.2%
2018	2,391.5	76.0%	79,771.9	41.9%	99,605.2	92.5%	5,059.0	61.8%	2,543.9	65.4%	27,143.3	25.1%	1,757.9	23.6%	89,228.5	34.6%	8,760.2	60.6%
2019	2,535.2	69.6%	79,838.0	41.2%	98,836.7	93.4%	4,786.5	62.5%	2,504.1	67.4%	31,840.8	24.3%	1,758.1	21.2%	97,564.8	34.4%	8,485.0	59.0%
2020	2,561.5	69.1%	79,810.4	40.7%	97,238.3	92.4%	4,653.8	62.5%	2,275.2	64.6%	39,458.1	24.2%	1,747.9	20.6%	107,387.7	35.3%	8,327.2	57.8%
2021	2,588.5	71.0%	79,995.7	37.1%	95,747.9	92.7%	4,561.8	63.5%	2,264.7	62.4%	51,047.1	24.6%	1,631.0	20.5%	123,937.5	34.6%	8,199.4	59.5%

https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_b https://www.nrel.gov/pv/cell-efficiency.html

Capacity factor /efficiency



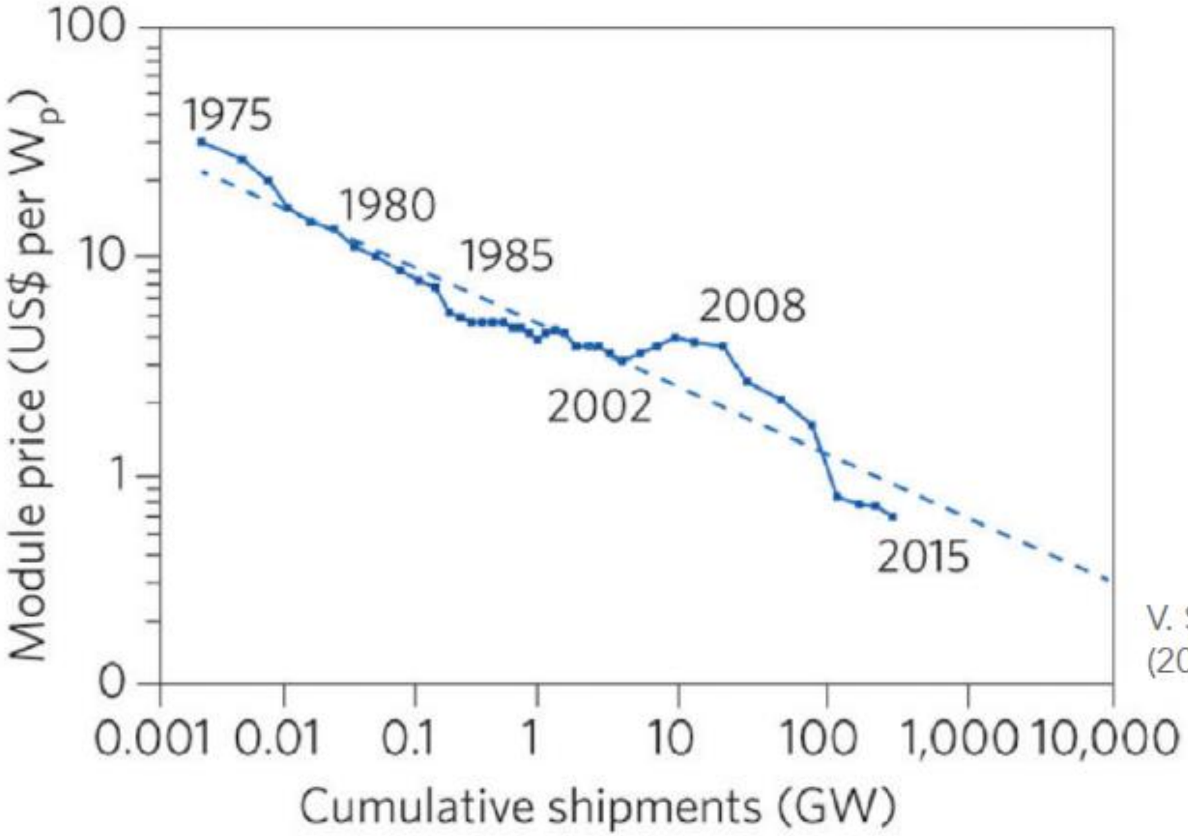
Improvement in PV cell efficiency over time will contribute to increase the CF

Climate Change and Sustainable Development Policies

(Technology) Learning curves

Are used to extrapolate how the technology costs will evolve.

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



V. Sivaram & S. Kann (2016), Nature Energy
https://www.nature.com/articles/nenergy201636

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.

More on learning curves for solar and wind here:

https://www.oxfordenergy.org/wpcms/wp-content/uploads/2021/02/A-critical-assessment-of-learning-curves-for-solar-and-wind-power-technologies-EL-43.pdf

http://pure.iiasa.ac.at/id/eprint/6787/1/RR-03-002.pdf

Variability of renewables (VRES) and dispatchability

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

VRES intermittent electricity sources as solar and wind do not produce consistent electricity, therefore their power output cannot be controlled. Although they provide valuable electricity, they do not provide **guaranteed electricity**, therefore dispatchable sources are required when they are not meeting their production demands.

Dispatch times vary for different types of power plants:

Fast (seconds)

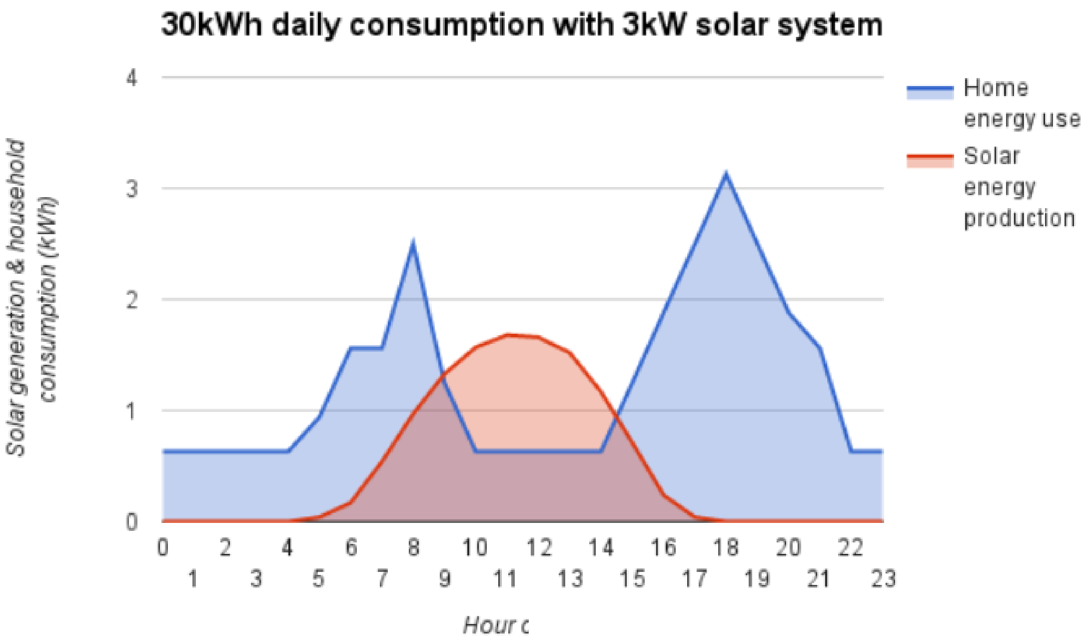
Capacitors (milliseconds), as the energy stored is already electrical – in other types of power storage as chemical batteries the power must be converted into electrical energy. Hydropower facilities are also able to dispatch extremely quickly.

Medium (minutes)

Natural gas turbines are a very common dispatchable source and can generally be ramped up in minutes. Solar thermal power plants can utilize efficient thermal energy storage, that can ramp um in minutes.

Slow (hours)

Biomass, nuclear and coal require hours to ramp up/down, They are typically regarded as only providing baseload power, but they often have some flexibility.



https://energyeducation.ca/encyclopedia/Dispatchable_source_of_electricity

Climate Change and Sustainable Development Policies

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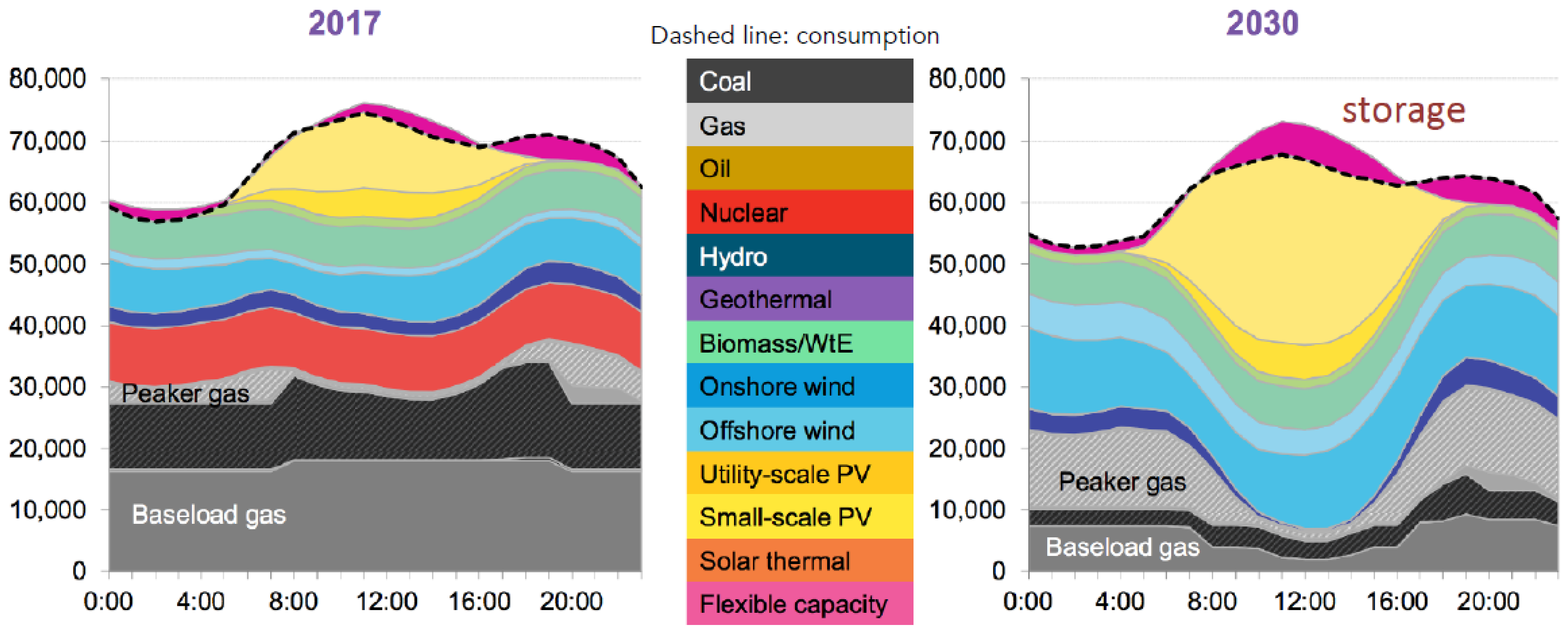
Germany hourly dispatch

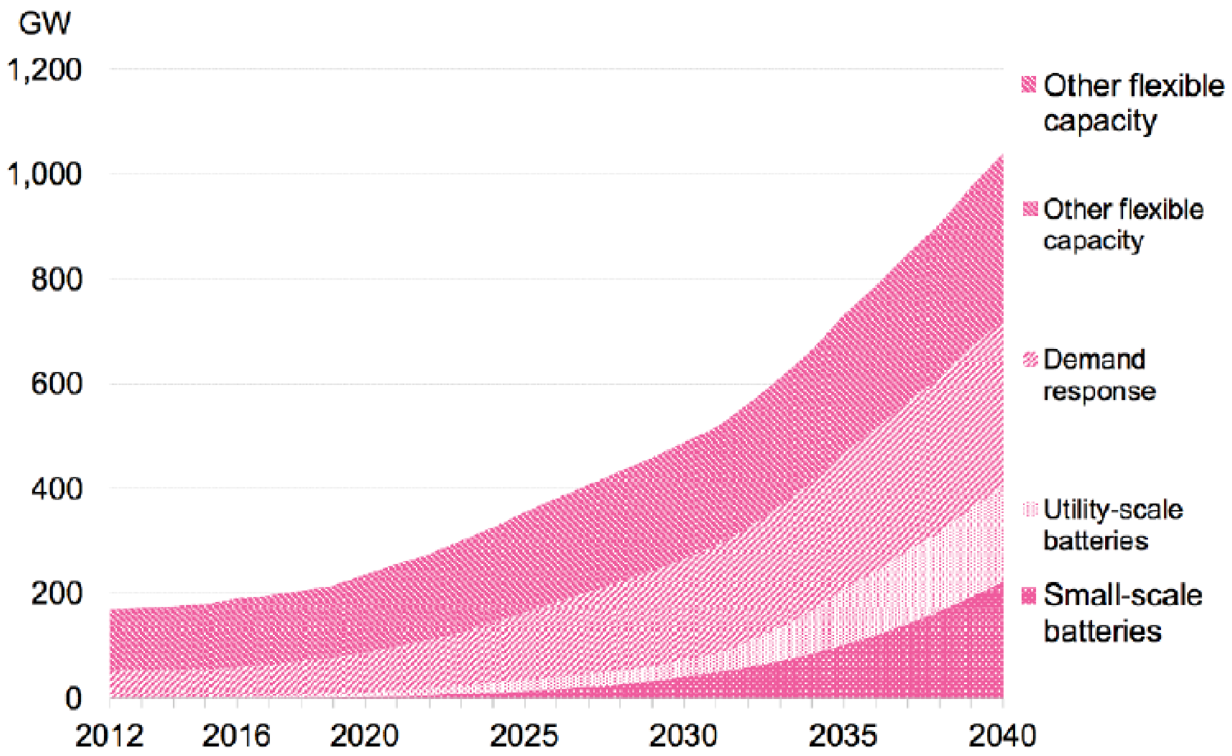


Source: Bloomberg New Energy Forecast

Source: Bloomberg New Energy Finance

Variability of renewables

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



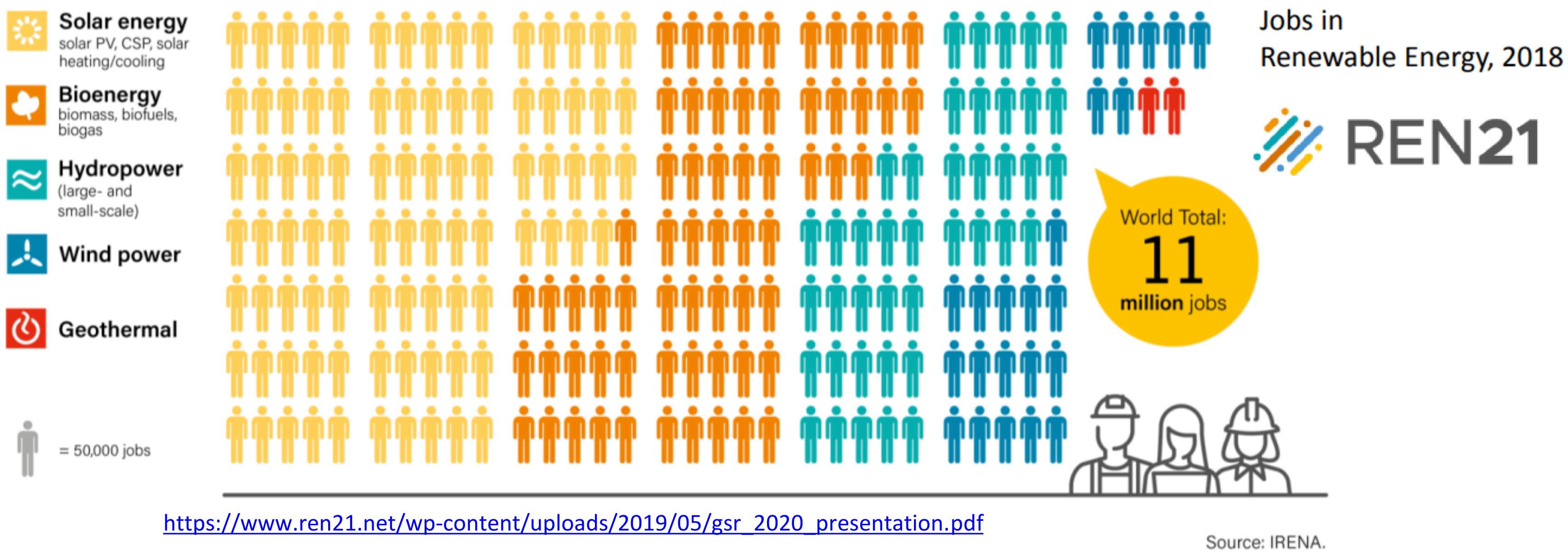
Top 5 markets in 2040	
China	343GW
U.S.	200GW
India	127GW
Japan	62GW
Germany	30GW

Source: Bloomberg New Energy Finance

Why talking about system value

LCOE is not 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**)



https://www.ren21.net/wp-content/uploads/2019/05/gsr_2020_presentation.pdf

Climate Change and Sustainable Development Policies

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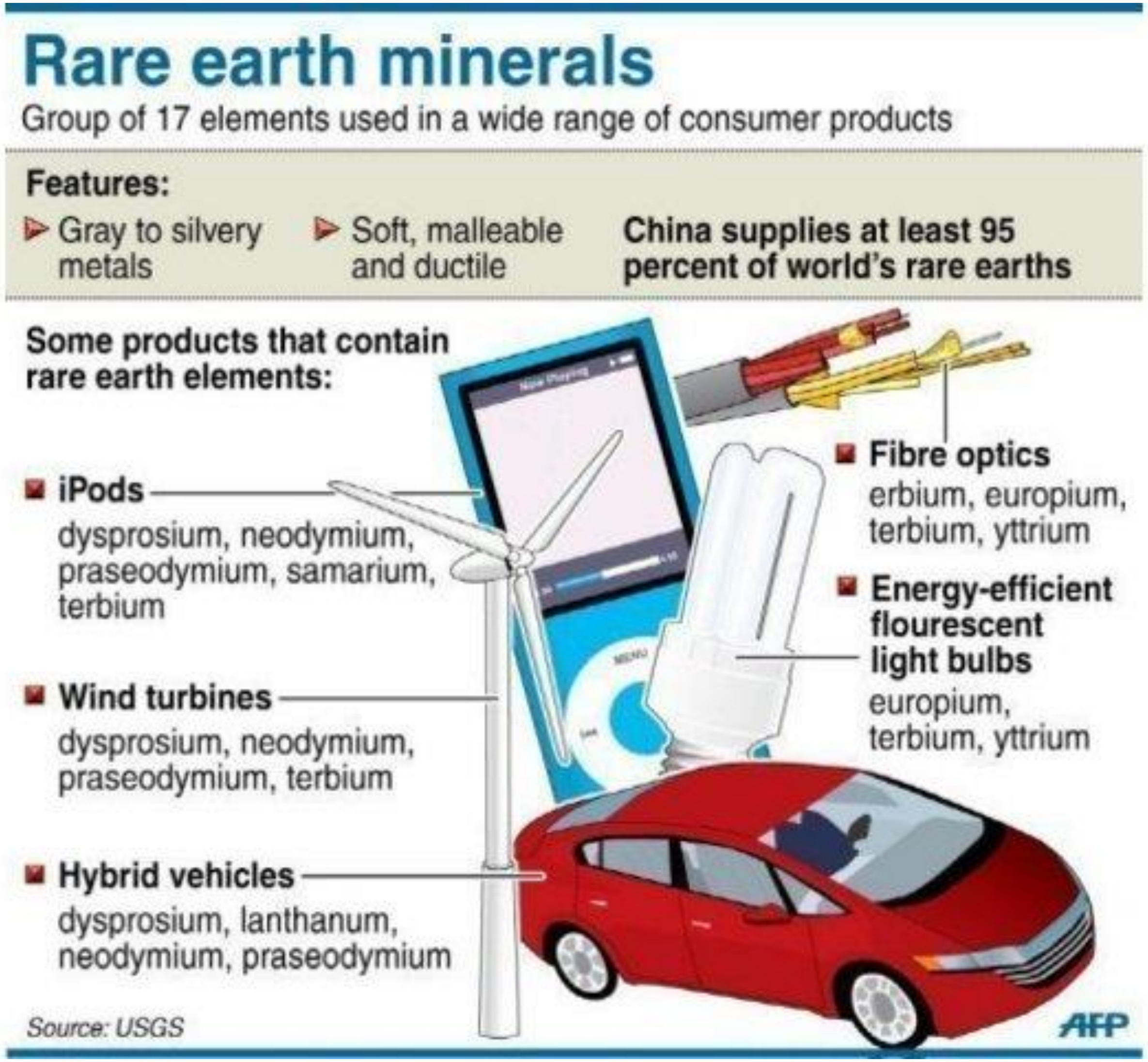
Outline

- Recap SSPs and RCPs
- Renewables: economic, environmental and energy security of endogenous vs. imported resources
- **Sustainability issues related with renewables - Land & water use, critical raw materials**
- Discussion: Where to place 7GW of solar PV in Portugal till 2030?.

Critical (and rare earth) metals



Reference: USGS – United States Geological Service

In 2013 - 14 metals identified as "likely to be needed in significant quantities for the deployment of low carbon energy technologies in Europe":

Cadmium (Cd), Hafnium (Hf), Molybdenum (Mo), Nickel (Ni), Silver (Ag)

Niobium (Nb), Selenium (Se), Tin (Sn), Vanadium (V)

Tellurium (Te), Indium (In), Gallium (Ga). Neodymium (Nd), Dysprosium (Dy)

R. Moss, E. Tzimas, P. Willis., J. Arendorf, and L. T. Espinoza. **Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector. Assessing Rare Metals as Supply-Chain Bottlenecks in Low-Carbon Energy Technologies**. JRC Scientific and Policy Report EUR 25994 EN." Luxembourg. 2013 https://setis.ec.europa.eu/sites/default/files/reports/JRC-report-Critical-Metals-Energy-Sector.pdf

Critical raw materials (Matérias Primas Críticas)

European Commission

several EU lists

2011 (14)

↓

2014 (20)

↓

2017 (27)

↓

2020 (30)

Raw materials are crucial to Europe's economy. They form a strong industrial base, producing a broad range of goods and applications used in everyday life and modern technologies. Reliable and unhindered access to certain raw materials is a growing concern within the EU and across the globe. To address this challenge, the European Commission has created a list of critical raw materials (CRMs) for the EU, which is subject to a regular review and update. CRMs combine raw materials of high importance to the EU economy and of high risk associated with their supply.

Why critical raw materials are important

- **Link to industry** - non-energy raw materials are linked to all industries across all supply chain stages
- **Modern technology** - technological progress and quality of life rely on access to a growing number of raw materials. For example, a smartphone might contain up to 50 different kinds of metals, all of which contribute to its small size, light weight and functionality.
- **Environment** – raw materials are closely linked to clean technologies. They are irreplaceable in solar panels, wind turbines, electric vehicles, and energy-efficient lighting.

https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

4th EU list of 30 Critical Raw Materials – CRM (sept. 2020)

Antimony (Sb)**	Hafnium (Hf)*	Phosphorus (P)
Baryte (mineral $BaSO_4$)	Heavy Rare Earth Elements	Scandium (Sc)*
Beryllium (Be)*	Light Rare Earth Elements	Silicon metal (Si)**
Bismuth (Bi)*	**Indium (In)***	Tantalum (Ta)*
Borate (BO_3 or BO_4 compounds)	Magnesium (Mg)*	Tungsten or wolfram (W)*
Cobalt (Co)*	Natural Graphite (C)	Vanadium (V)*
Coking Coal (C)	Natural Rubber	***Bauxite rock (Al & Ga)***
Fluorspar (CaF_2)	Niobium (Nb)*	***Lithium (Li)****
Gallium (Ga)*	Platinum Group Metals*	***Titanium (Ti)****
Germanium (Ge)**	Phosphate rock	***Strontium (Sr)****

*Italic – new materials in 2020 CRM list; * metal (or transition metal);** metalloid; purple – materials in 2013 JRC study for energy technologies*

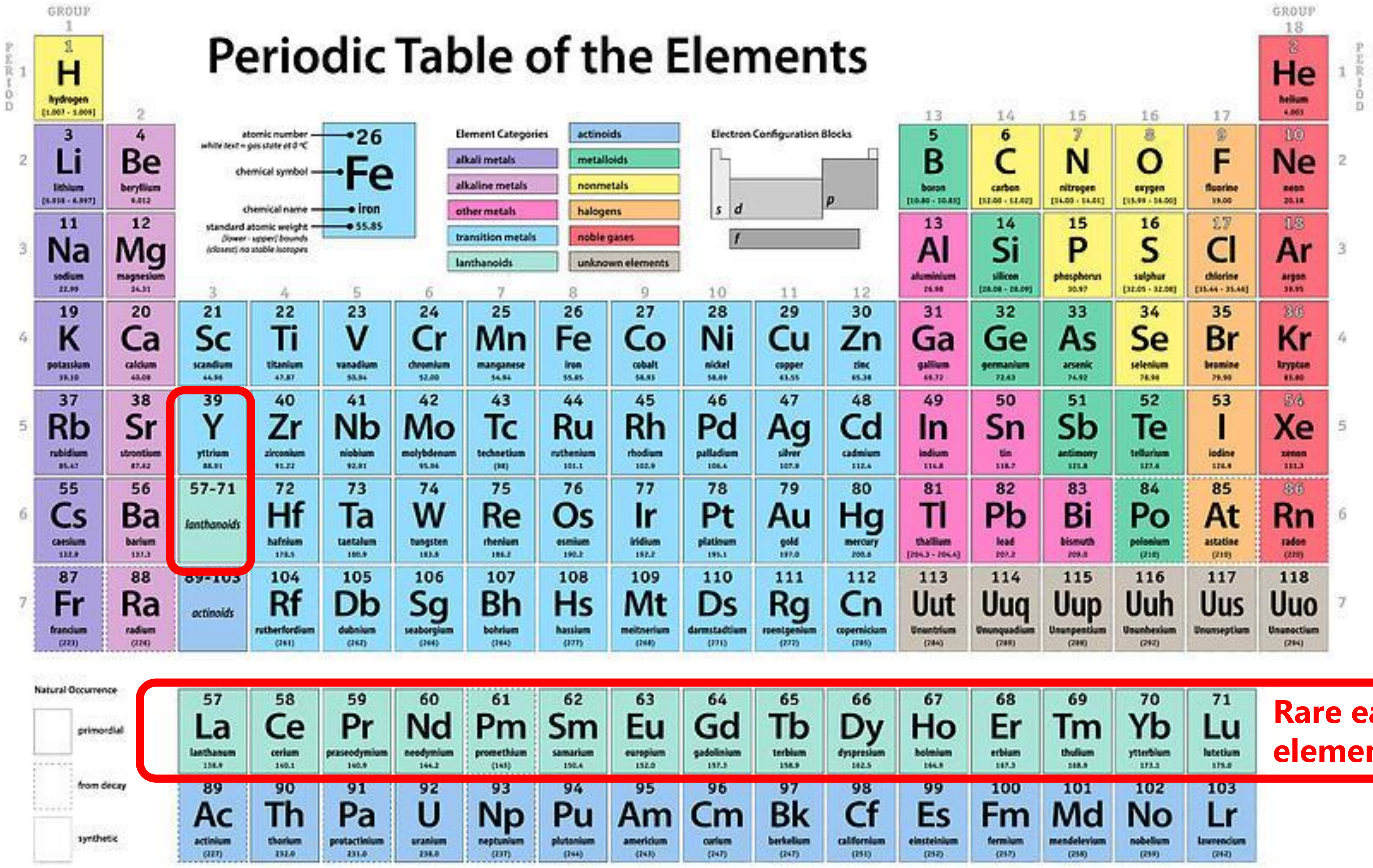
Heavy Rare Earth Elements: yttrium (Y)*, europium (Eu), gadolinium(Gd). terbium (Tb), **dysprosium (Dy),** holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu)

Light Rare Earth Elements: lanthanum (La), cerium (Ce), praseodymium (Pr), **neodymium (Nd)**, promethium (Pm), samarium (Sm)

Not on CRM list, yet relevant for energy technologies:

Tellurium (Te), Cadmium (Cd), Molybdenum (Mo), Nickel (Ni), Silver (Ag), Selenium (Se), Tin (Sn)

Platinum Group Metals: ruthenium (Ru), rhodium (Rh), palladium (Pd), osmium (Os), iridium (Ir), platinum (Pt)



Rare earth elements

https://elementsandtheperiodictable.weebly.com/groups-and-periods-of-the-periodic-table-------------------metals-nonmetals-and-metalloids.html

Materials use per low carbon technologies

Ocean	Fe, Cu, Al, Cr, Ni, Mo, Ti **[#7]**
Carbon Capture	Mn, Pr, Cr, Nb, Va, Mo, Co **[#7]**
Batteries	Bauxite, Co, Fe, Li, Mn, Ni, Graphite, Cu **[#8]**
Geothermal	Fe, Ni, Cr, Al, Mo, Mn, Cu, Ti, Nb, Ta **[#10]**
Hydropower	Fe, Cu, Ni, Cr, Zn, Pb, Mo, Mn, Magnesite, Sn **[#10]**
Solar PV	Al, Cu, Sn, Pb, Magnesite, Zn, Ag, Cd, Te, Se, In, Ga **[#12]**
Concentrated Solar	Fe, Al, Mn, Cr, Cu, Ni, Zn, Mo, Nb, Ag, Ti, Va **[#12]**
Onshore Wind	Fe , Zn, Cr, Cu, Al, Mn, Ni, Mo, Nd, Pr, Dy, Tb, Pb **[#13]**
Offshore Wind	Fe, Cu, Zn, Pb, Mn, Al, Cr, Ni, Nd, Mo, Pr, Dy, Tb **[#13]**
Nuclear	Cr, Ni, Mo, Cu, Zr, Ag, W, Pb, Ti, Nb, In, Va, Cd, Yt **[#14]**
Electric vehicles	Al, B, Ce, Co, Cu, Dy, Ga, Ge, Au, Graphite, In, Fe, La, Pb, Li, Mn, Nd, Ni, Pd, Pr, Sm, Ag, Tb, Ti **[#24]**

Literature review

JRC (2011, 2013, 2016)
Garcia - Olivares et al. (2012)
Ashby, Attwood and Lord, (2012)
B.Guezuraga (2012)
Corona et al. (2017)
Elshkaki & Graedel (2013)
Gamesa, (2014)
Kavlak (2015)
Kleijn and Voet (2010)
Kleijn et al, (2018)
Ohrlund (2012)
Pihl,_et al (2012)
Primard, Pierre (2015)
Till Zimmermann (2013)
USGS (2011)
Vestas, (2012)
World Bank (2017)
Zimmermann (2013

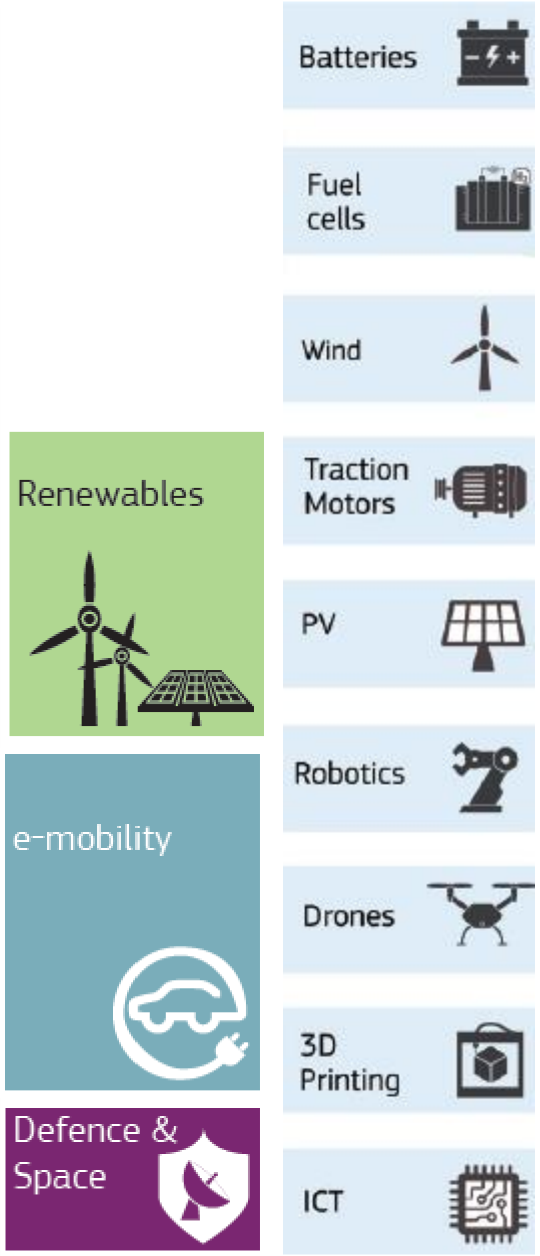
Em Português

Ag (prata), Al (alumínio), B (boro), Cd (cádmio), Ce (cério), Co (cobalto), Cr (crómio), Cu (cobre), Dy (disprósio), Fe (ferro), Ga (gálio), Ge (germânio), In (índio), La (lantânio), Mg (magnésio), Mn (manganês), Mo (molibdénio), Nb (nióbio), Nd (neodímio), Ni (níquel), Pb (chumbo), Pd (paládio), Pr (praseodímio), Se (selénio), Sm (samário), Sn (estanho), Ta (tântalo), Tb (térbio), Te (telúrio), Ti (titânio), Va (vanádio), Yt (ítrio), W (tungsténio), Zn (zinco), Zr (zircónio).

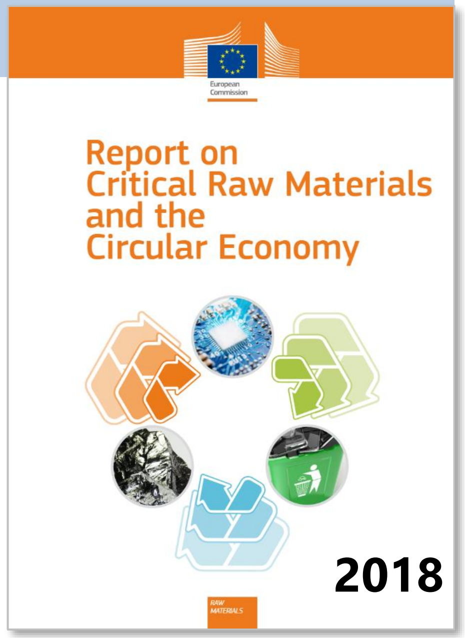
Stilwell, T., Simoes, S.G. (n.d.) Mapping necessary resources for the transition to a low carbon energy system. *(in preparation)*

Sep 2020

https://ec.europa.eu/docsroom/documents/42881



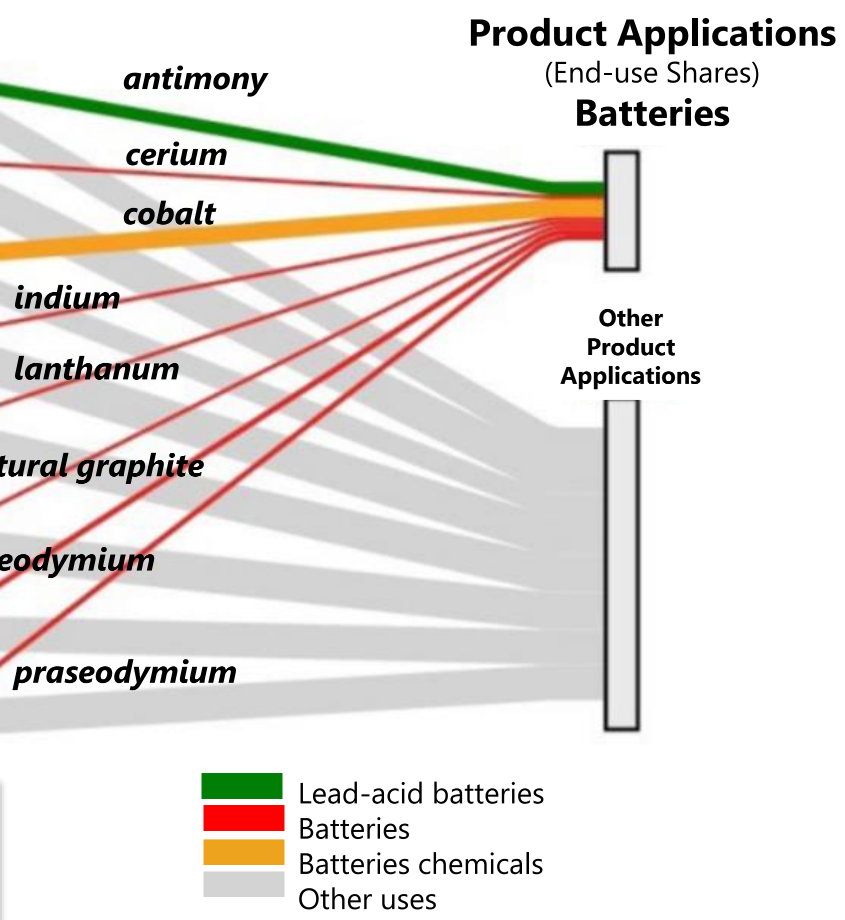
Electric and electronic equipment
Batteries
Automotive sector
Renewable energy
Defence industry
Chemicals and fertilisers

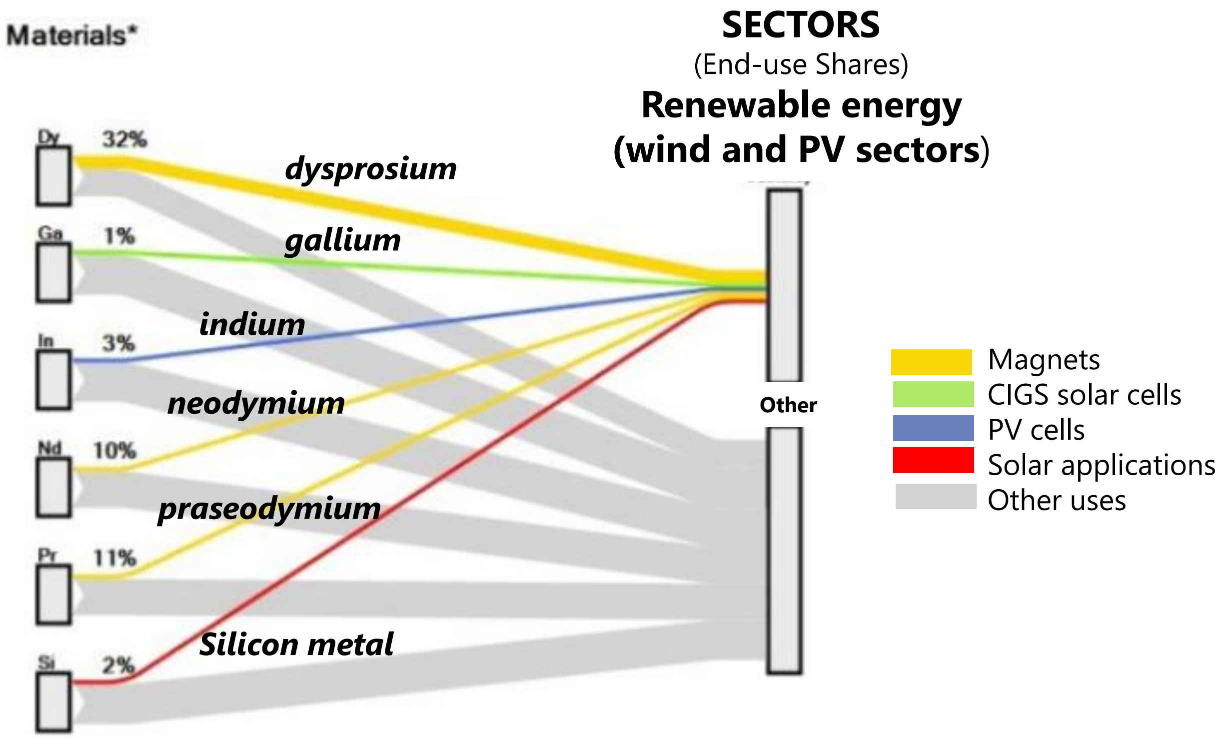


2018

https://ec.europa.eu/commission/publications/report-critical-raw-materials-and-circular-economy_en

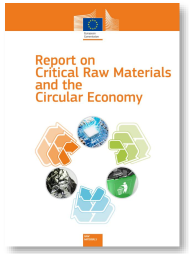
CRMs demand for batteries and solar and wind





* Only a subset of all CRMs used in renewable energy sector is included.

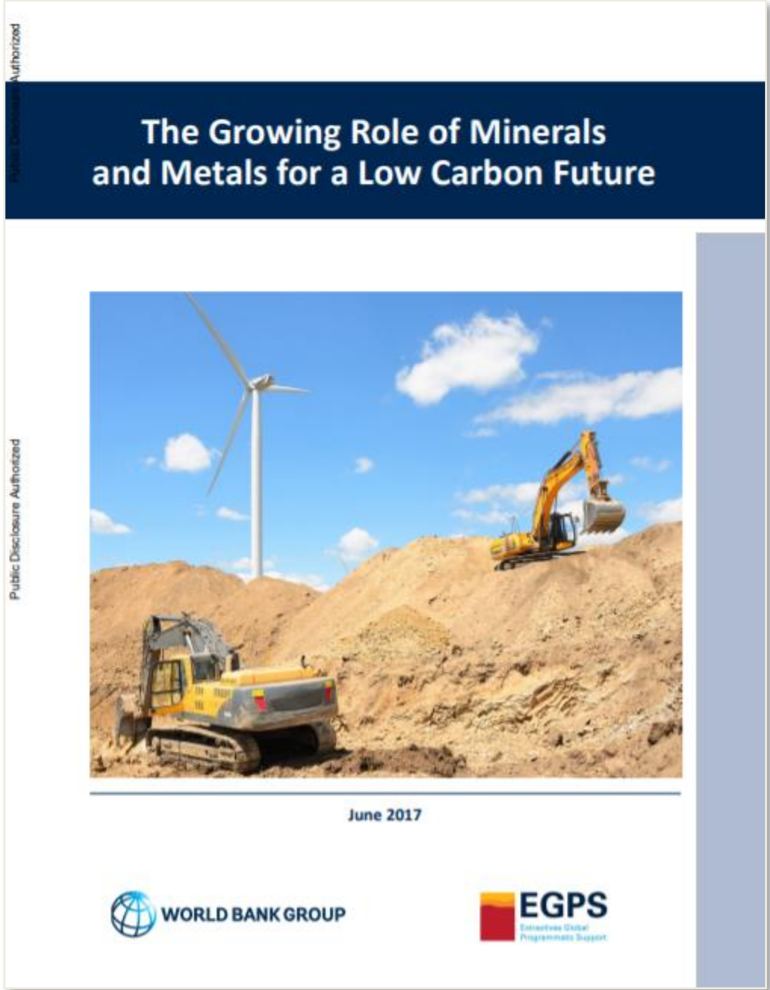
CIGS – copper indium gallium selenide solar cells (thin film PV)



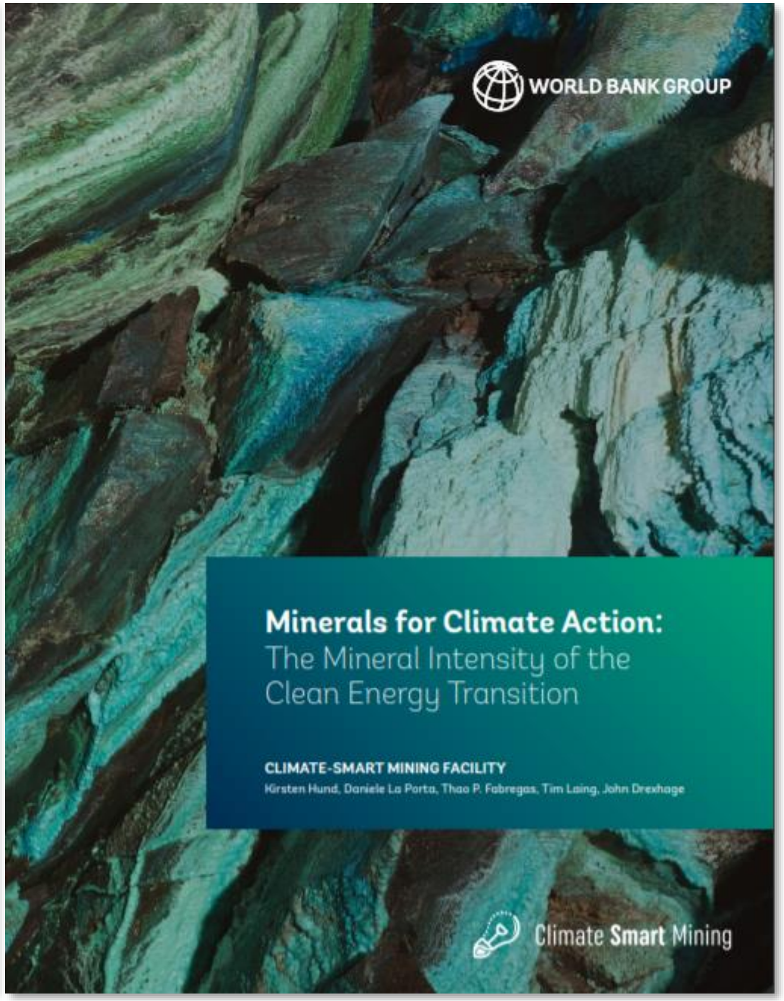
https://ec.europa.eu/commission/publications/report-critical-raw-materials-and-circular-economy_en

Minerals & Metals for low carbon energy

THE WORLD BANK
IBRD • IDA



July 2017
http://documents1.worldbank.org/curated/en/207371500386458722/pdf/117581-WP-P159838-PUBLIC-ClimateSmartMiningJuly.pdf



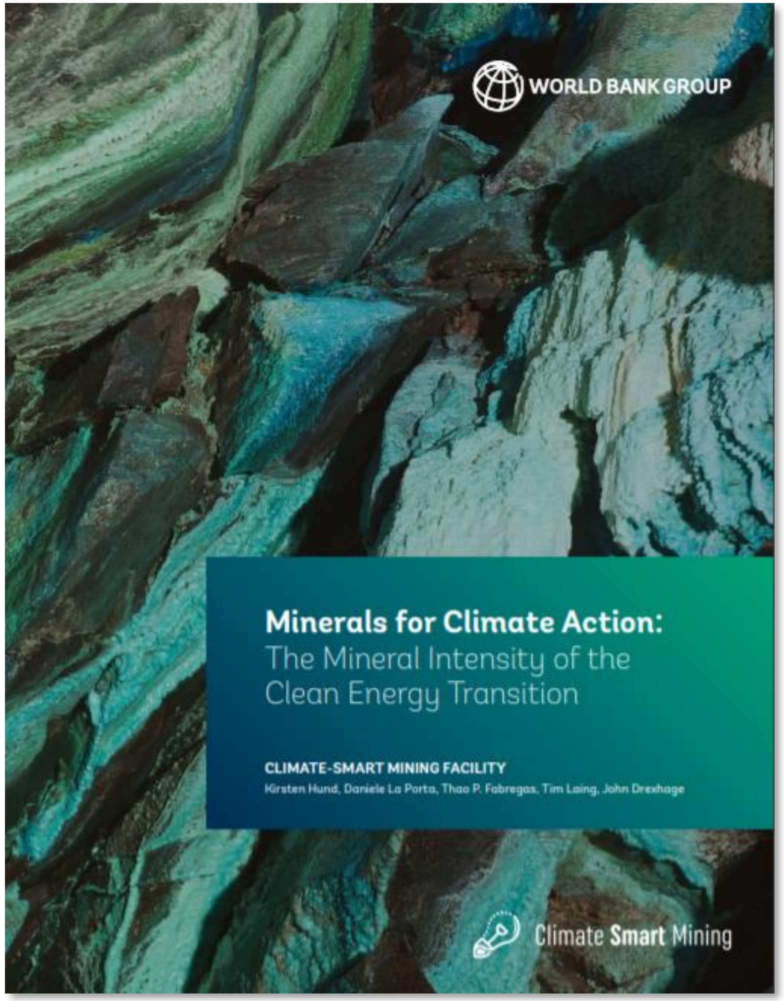
2020
https://www.worldbank.org/en/topic/extractiveindustries/brief/climate-smart-mining-minerals-for-climate-action

Minerals for climate action

"the production of minerals, such as graphite, lithium and cobalt, could **increase by nearly 500% by 2050** to meet the growing demand for clean energy technologies. It is estimated that over 3 billion tons of minerals and metals will be needed to deploy wind, solar and geothermal power, as well as energy storage, required for achieving a below 2°C future"

Highest growth for: Graphite, Lithium, Cobalt (in % of current demand) and Aluminium (in total terms)

"While the growing demand for minerals and metals provides economic opportunities for resource-rich developing countries and private sector entities alike, significant challenges will likely emerge if the climate-driven clean energy transition is not managed responsibly and sustainably."

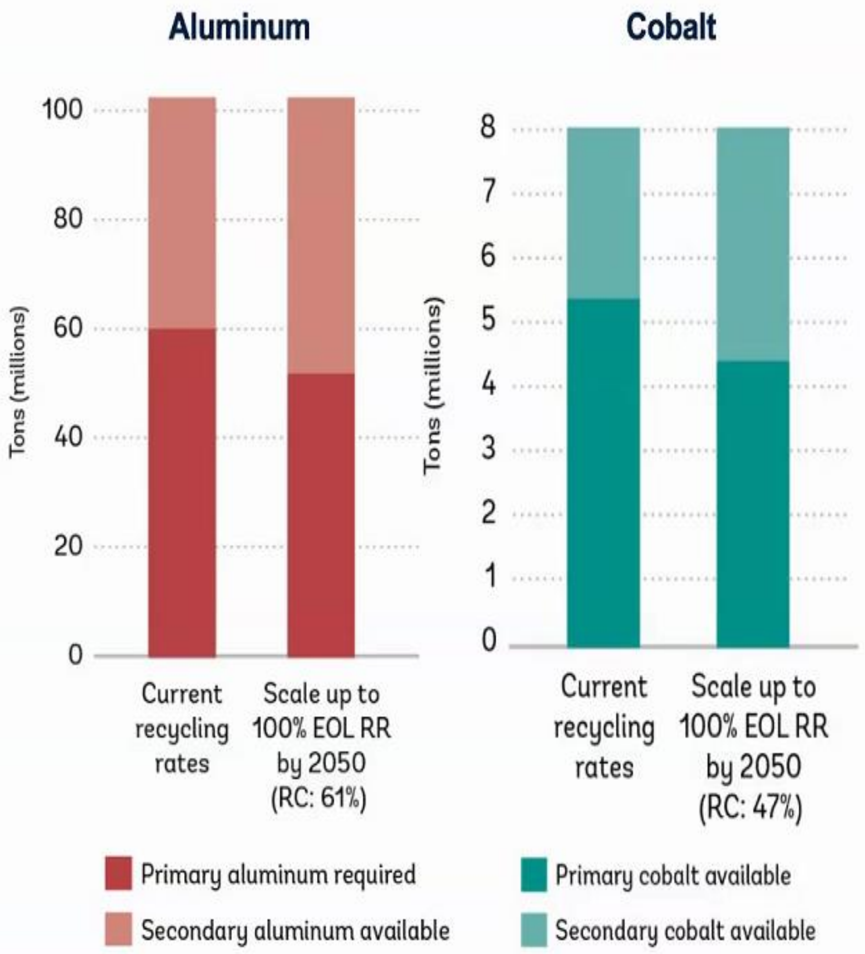


http://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf

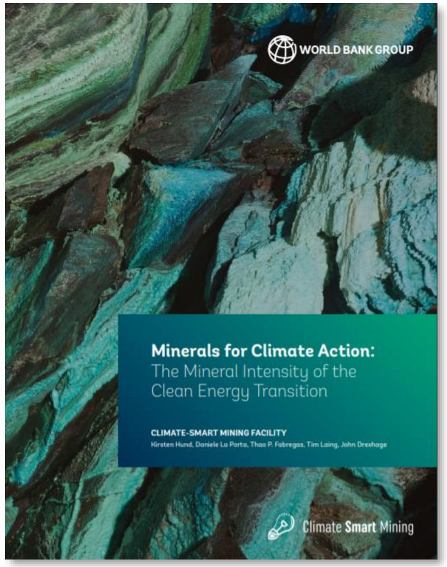
LNEG

NEW FINDINGS:
THE ROLE OF RECYCLING IN MEETING DEMAND UNDER 2DS

- **Current recycling rates** refer to how many minerals are recycled at the end of a product's life (**EOL RR**)
- **Recycled content** refers to secondary minerals, which is the amount of recycled mineral that is used in new products
- Even if aluminum and copper from current products are recycled at **EOL at 100%**, it still wouldn't be enough to meet mineral demand under a 2DS
- While recycling can play an important role in meeting demand, **primary production** will still be needed



Note: 2DS = 2-degree scenario.



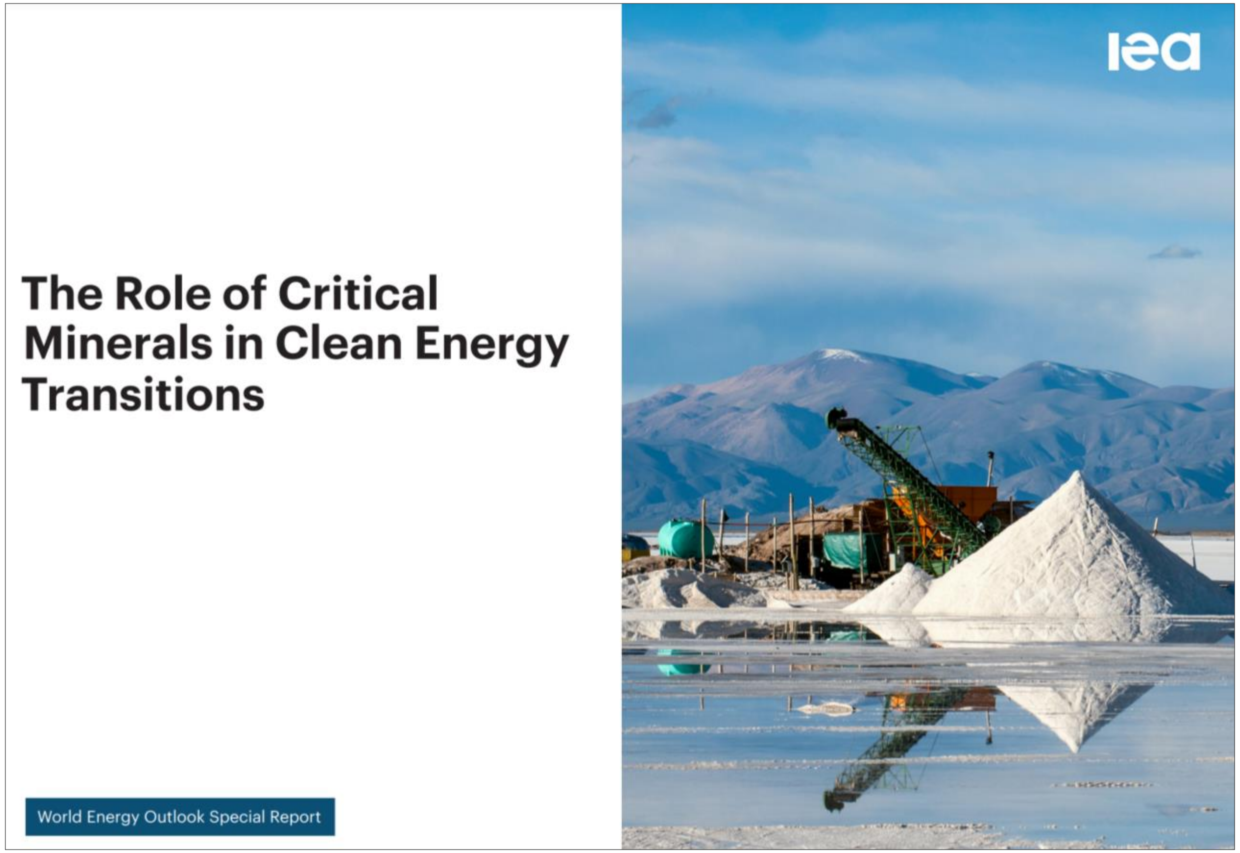
http://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf

Minerals in Clean Energy Transitions

International
Energy Agency

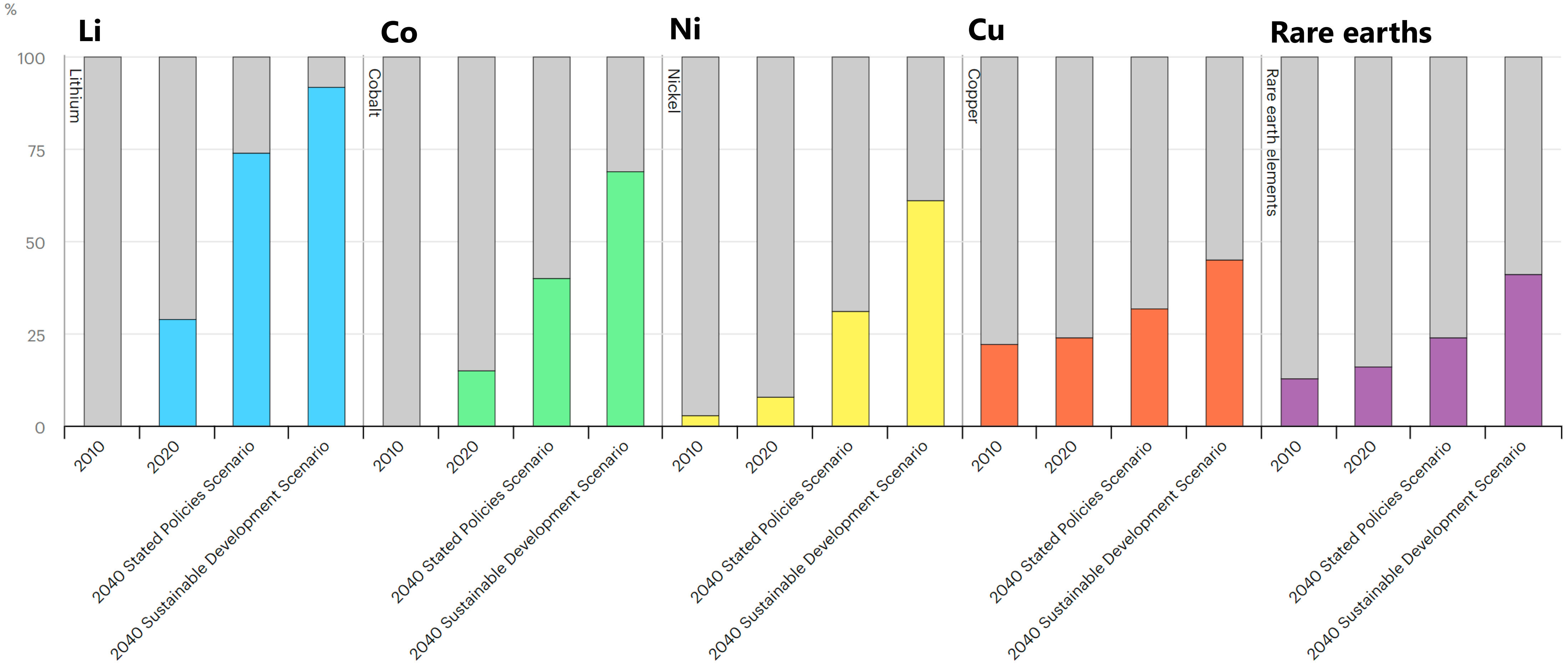
"A typical **electric car** requires **six times** the mineral inputs of a conventional car and an **onshore wind** plant requires **nine times** more mineral resources than a gas-fired plant. **Since 2010 the average amount of minerals needed for a new unit of power generation capacity has increased by 50%"**

"The shift to a clean energy system is set to drive a huge increase in the requirements for these minerals, meaning that **the energy sector is emerging as a major force in mineral markets**."



July 2021
IEA (2021), *The Role of Critical Minerals in Clean Energy Transitions*, IEA, Paris
https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

Share of minerals consumption by the energy system over total global mineral markets



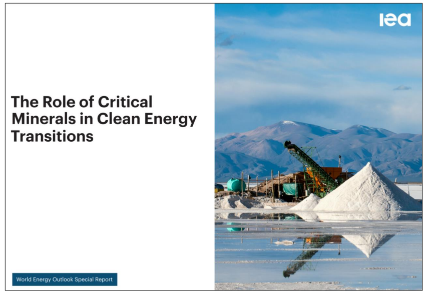
% of total global minerals demand for the energy system will rise significantly over the next two decades up to more:

> **40% for copper and rare earth elements,**

> **60-70% for nickel and cobalt**

> **almost 90% for lithium**

https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions



Key information you should have apprehended after the class

- Overview of RES markets globally and in Europe, especially for solar PV and wind
- LCOE
- Capacity factor
- Costs and efficiency evolution of renewables
- VRES
- Dispatchability, System value of renewables
- Critical raw materials for energy
- Minerals for low carbon energy
- Importance of the energy sector in global mineral markets