



**UNIVERSITÀ
DEGLI STUDI
DI TRIESTE**



Dipartimento di
**Ingegneria
e Architettura**

La Transizione Energetica

Elettrotecnica

A.A. 2024 - 2025

Prof. Alessandro Massi Pavan – apavan@units.it

La transizione energetica

- L'elettrotecnica comprende due principali tipi di applicazioni: applicazioni per l'informazione e applicazioni per l'**energia**
- Queste ultime sono oggi al centro di una transizione epocale che riguarda le risorse primarie utilizzate:
fonti fossili → fonti rinnovabili
- Una seconda transizione riguarda il vettore energetico energia elettrica: **generazione centralizzata**
→ **generazione ibrida centralizzata/distribuita**

La transizione energetica

- Questa seconda transizione vede un'elettrificazione sempre più spinta dei consumi energetici
- Sempre più utilizzatori sono elettrici:
veicoli, pompe di calore, fornelli a induzione, ...
- Nuovi generatori distribuiti entrano nelle nostre case
- Le tecnologie ICT sono fondamentali per abilitare la transizione
- Così come il nuovo mercato elettrico in cui tutto è in divenire

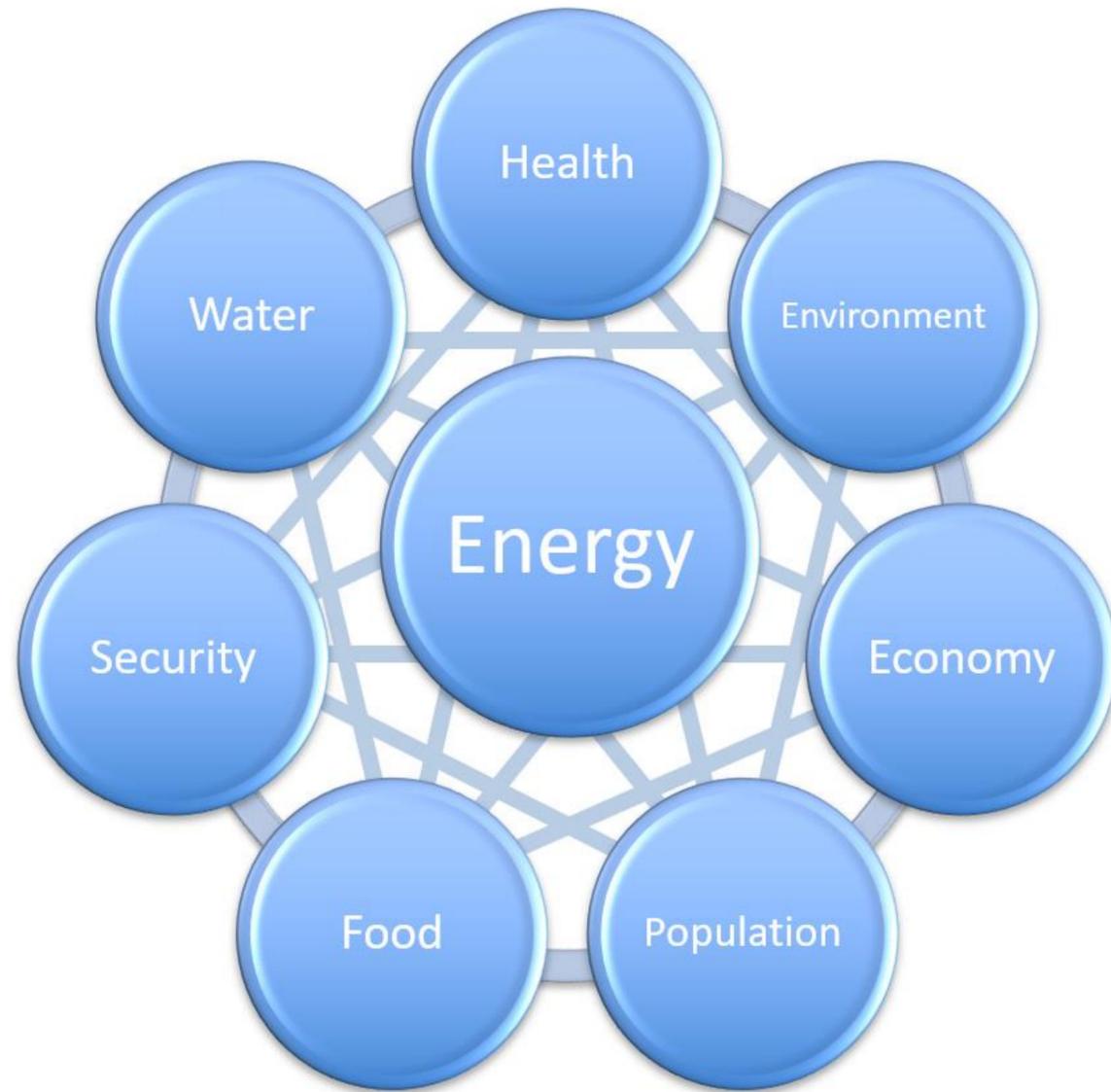
Definizioni

- **Fonti energetiche primarie** sono quelle direttamente reperibili in natura: combustibili fossili, radiazione solare, vento, acqua
- Possono essere utilizzate direttamente o trasformate in **vettori energetici**: energia elettrica, combustibili benzina, kerosene), idrogeno
- **Fonti rinnovabili**: fonti energetiche che non si esauriscono in quanto reintegrate più velocemente rispetto al loro consumo
- **Fonti alternative**: energia prodotta senza l'utilizzo dei combustibili fossili

Complessità del sistema energetico



Complessità del sistema energetico



Complessità del sistema energetico



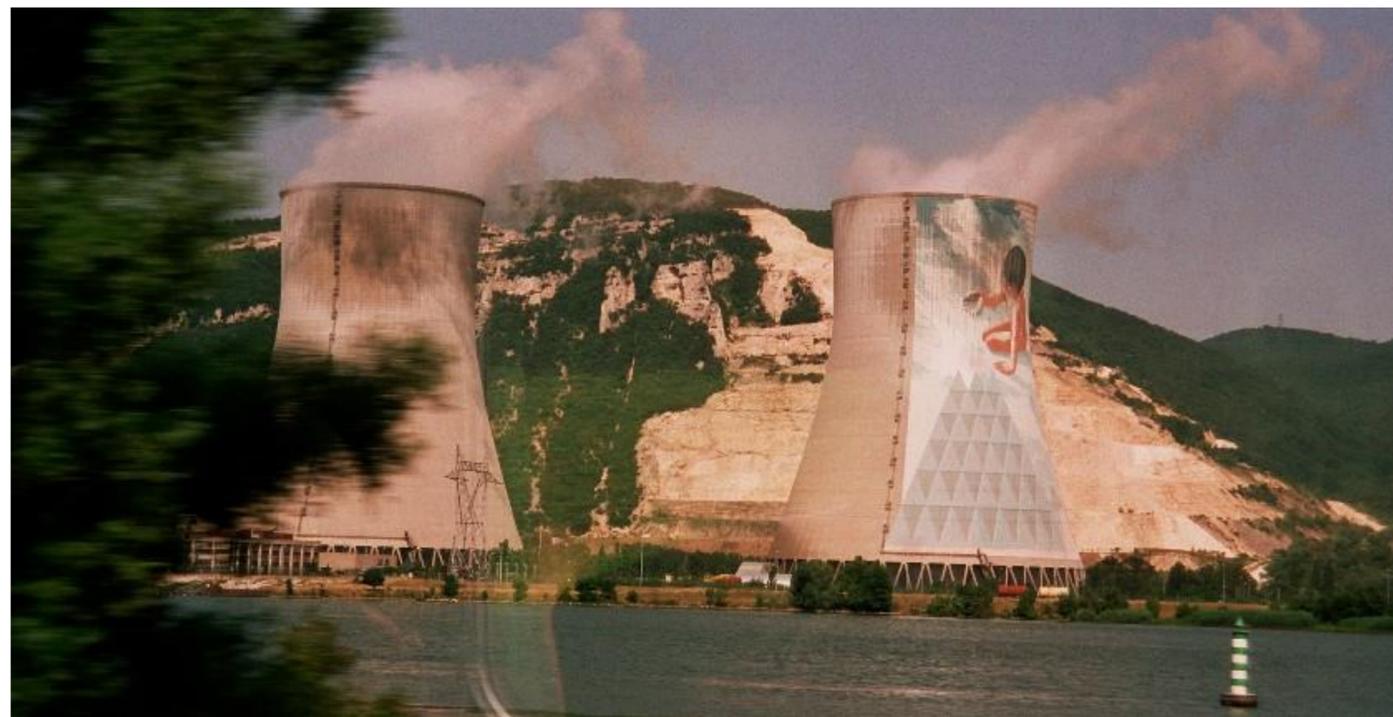
La crisi del sistema energetico

Monthly average Henry Hub natural gas prices (Jan 1997–Jun 2024)
dollars per million British thermal units (\$/MMBtu)



La crisi del sistema energetico

Climate change, water scarcity jeopardizing French nuclear fleet



PRODUZIONE IDROELETTRICA ITALIA

ANNO	ENERGIA [TWh]
2015	46
2018	49
2021	45
2022	28
2023	41

China's Hydro Power Crisis Is Just the Start

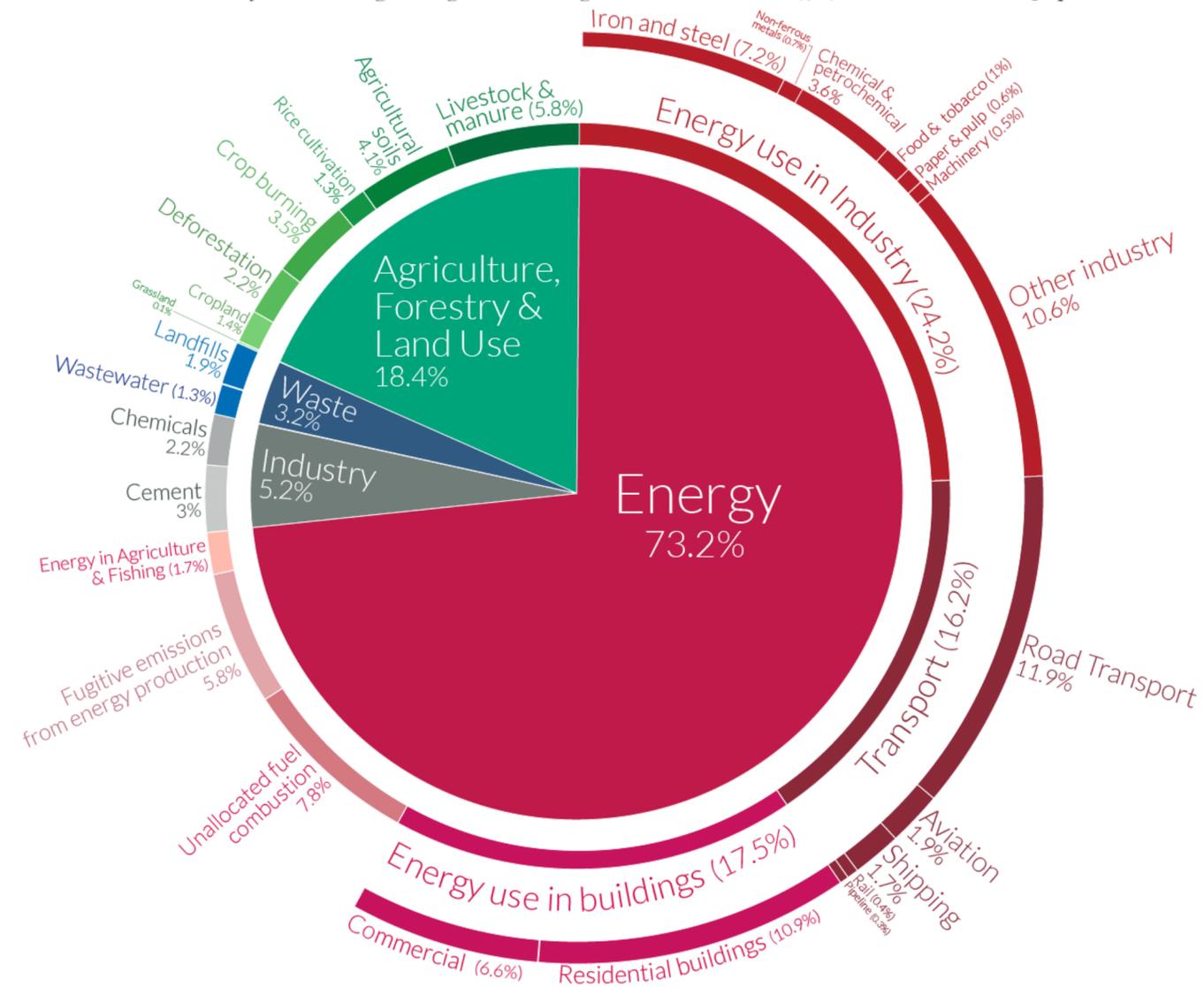
Climate-fueled droughts could make climate change even worse. Plus, more of the week's top opinions.

Il grande emettitore di gas serra

Global greenhouse gas emissions by sector

This is shown for the year 2016 – global greenhouse gas emissions were 49.4 billion tonnes CO₂eq.

Our World
in Data



OurWorldinData.org – Research and data to make progress against the world's largest problems.

Source: Climate Watch, the World Resources Institute (2020).

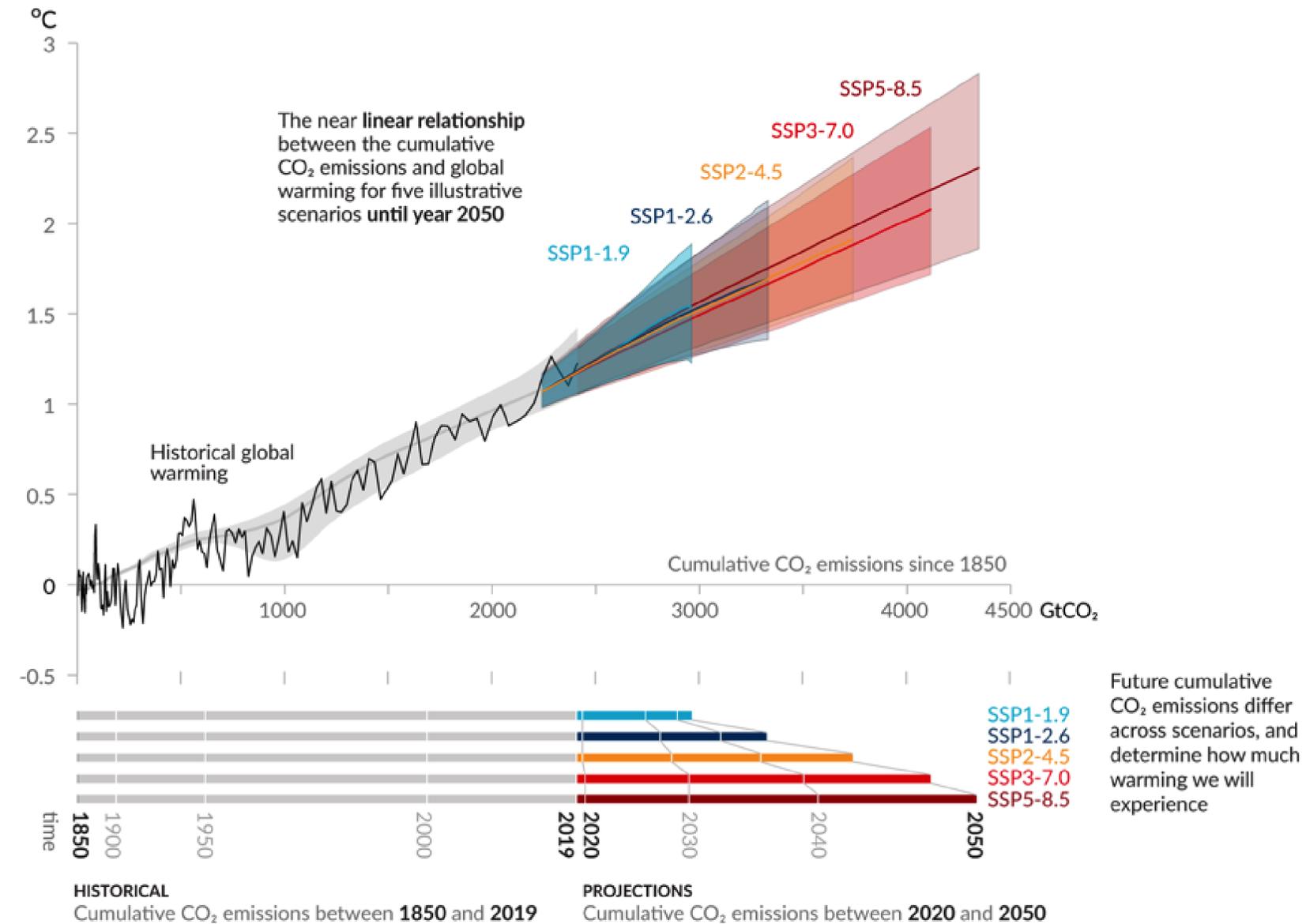
Licensed under CC-BY by the author Hannah Ritchie (2020).

Il sistema energetico basato sull'uso dei combustibili fossili è il principale emettitore di gas serra e responsabile del riscaldamento globale di origine antropica e dei conseguenti cambiamenti climatici

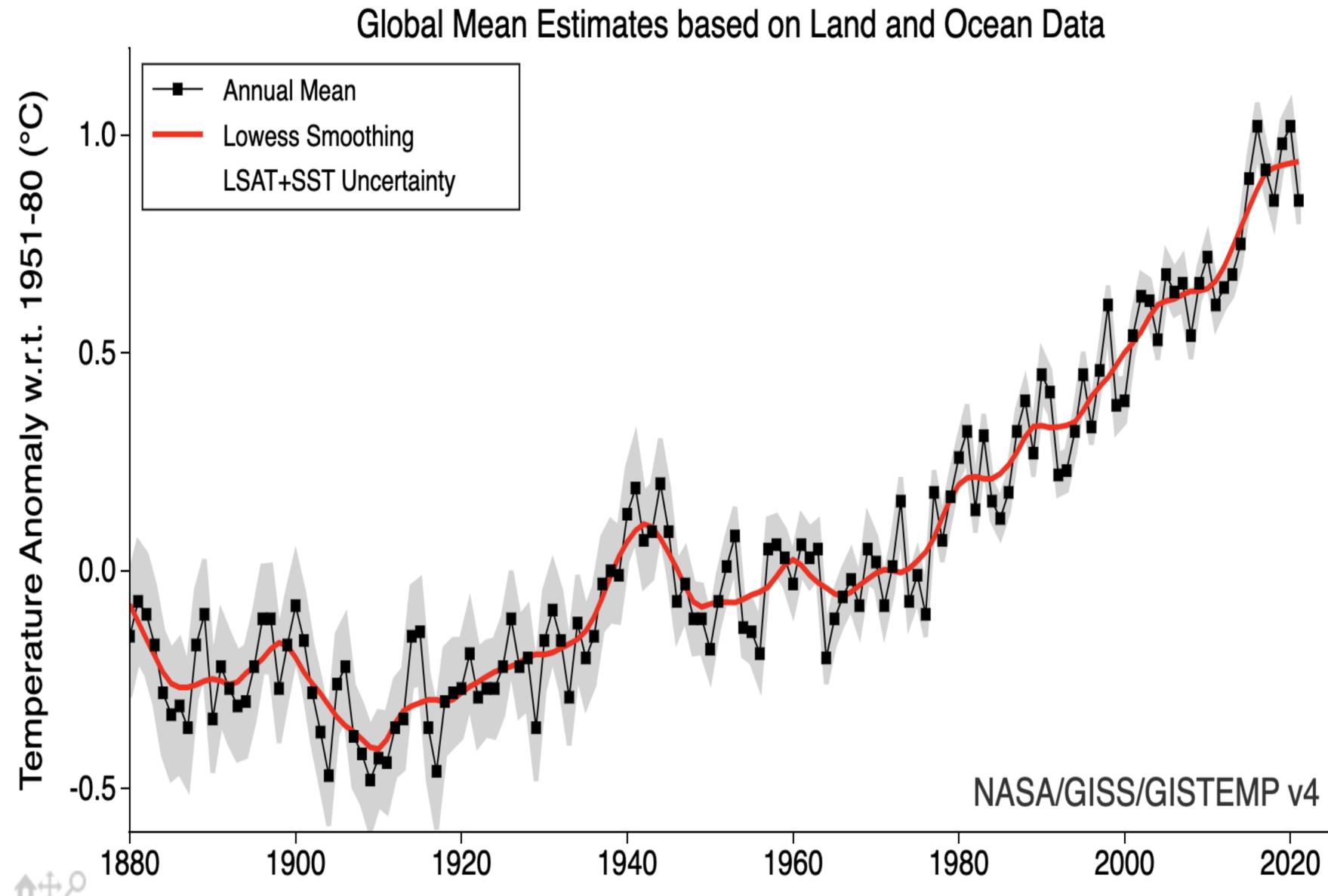
Riscaldamento globale

Every tonne of CO₂ emissions adds to global warming

Global surface temperature increase since 1850-1900 (°C) as a function of cumulative CO₂ emissions (GtCO₂)

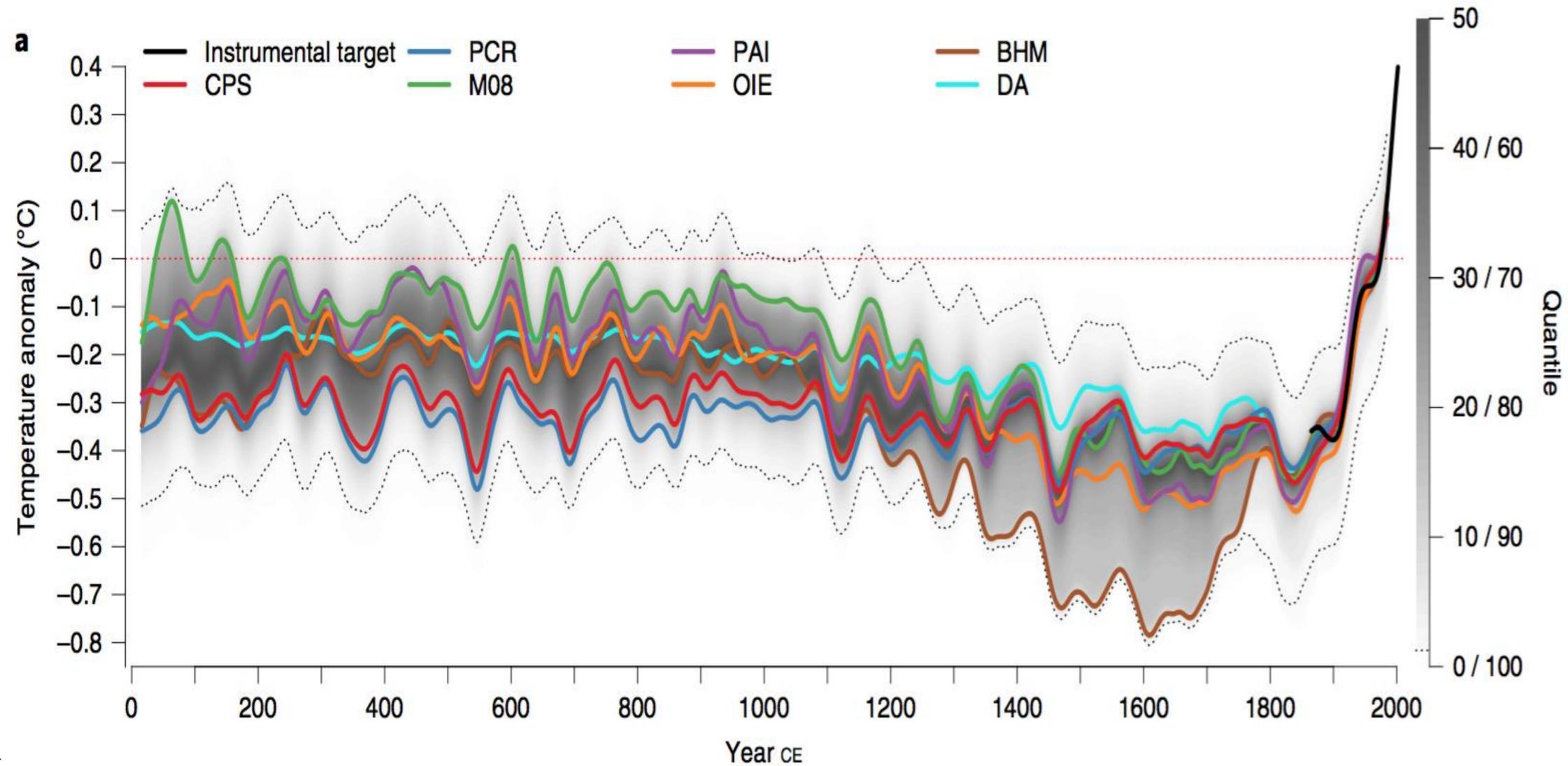


Riscaldamento globale



- + 1.1 ° C in 120 anni
- L'ultimo decennio è stato il più caldo mai registrato
- Il 2024 l'anno più caldo

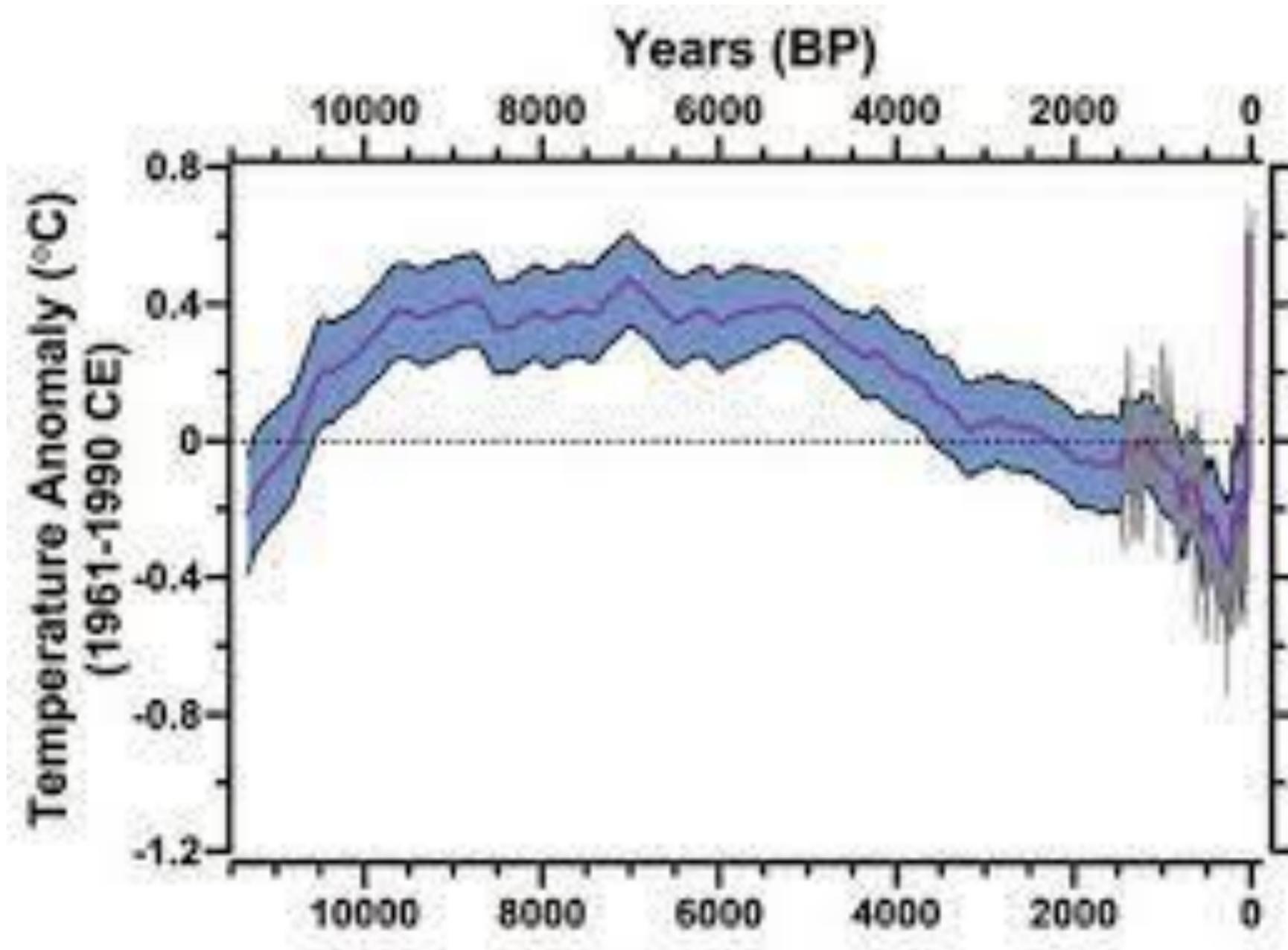
Riscaldamento globale



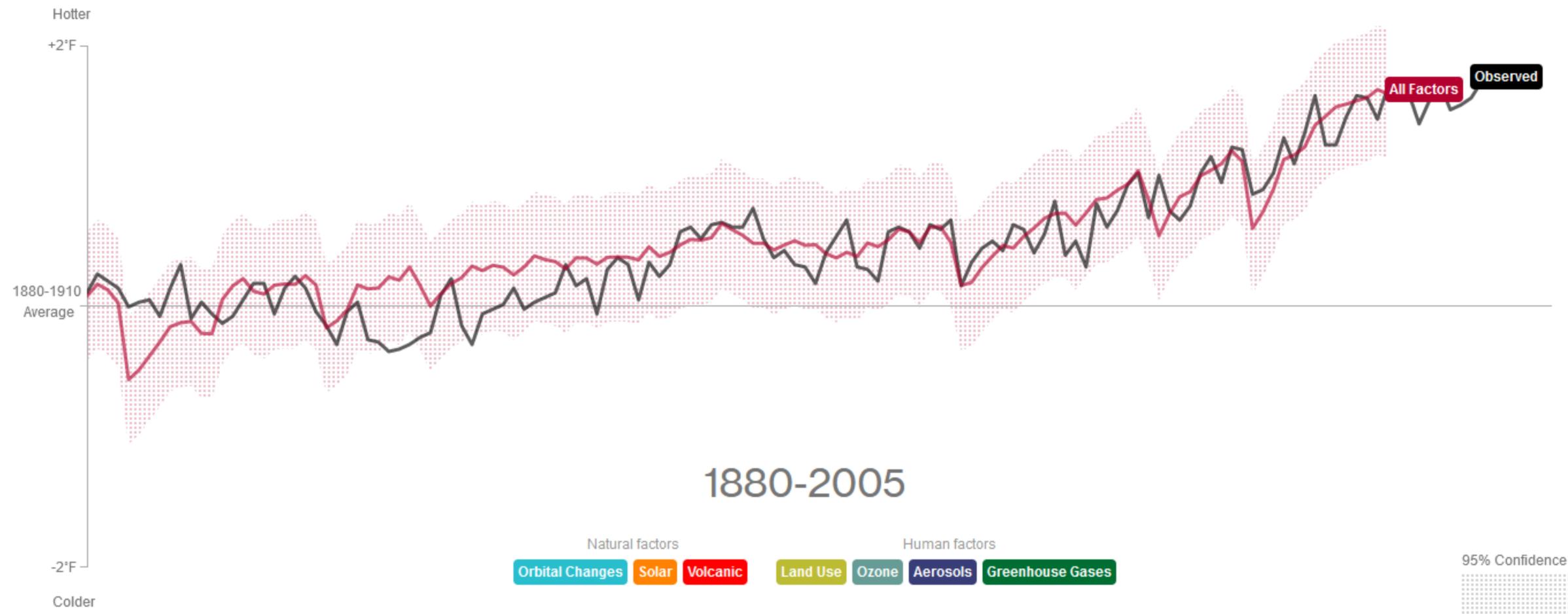
Pages2k

Nature Geoscience 2019

Riscaldamento globale

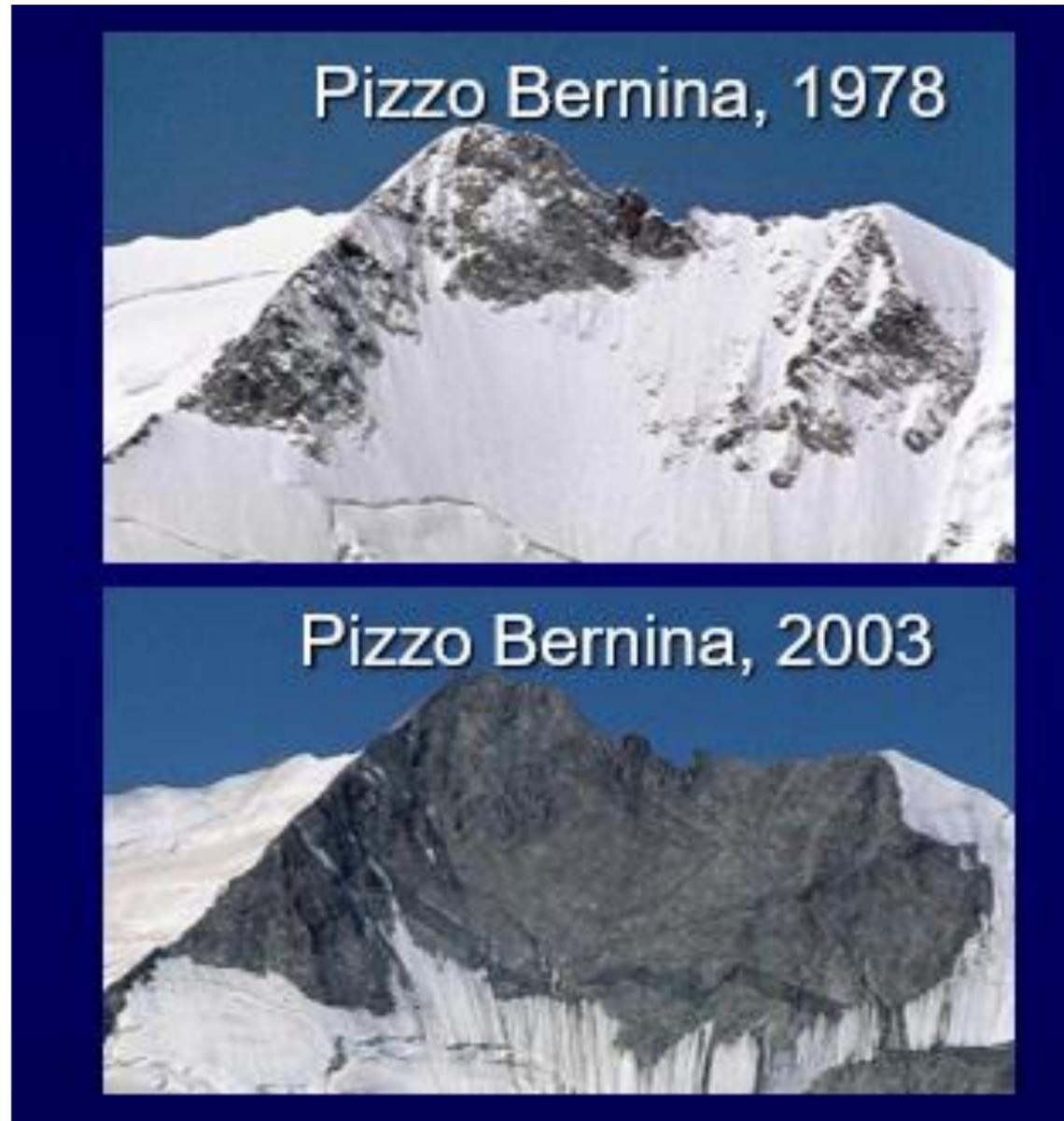


Ma cosa sta realmente scaldando il pianeta?

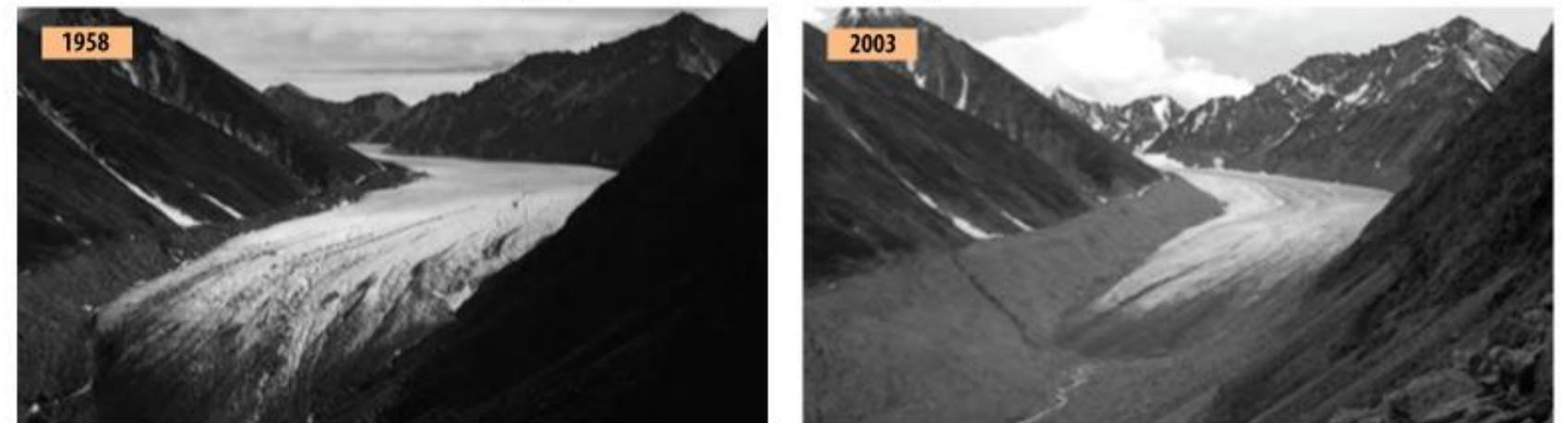


<https://www.bloomberg.com/graphics/2015-whats-warming-the-world/>

Conseguenze: scioglimento dei ghiacciai



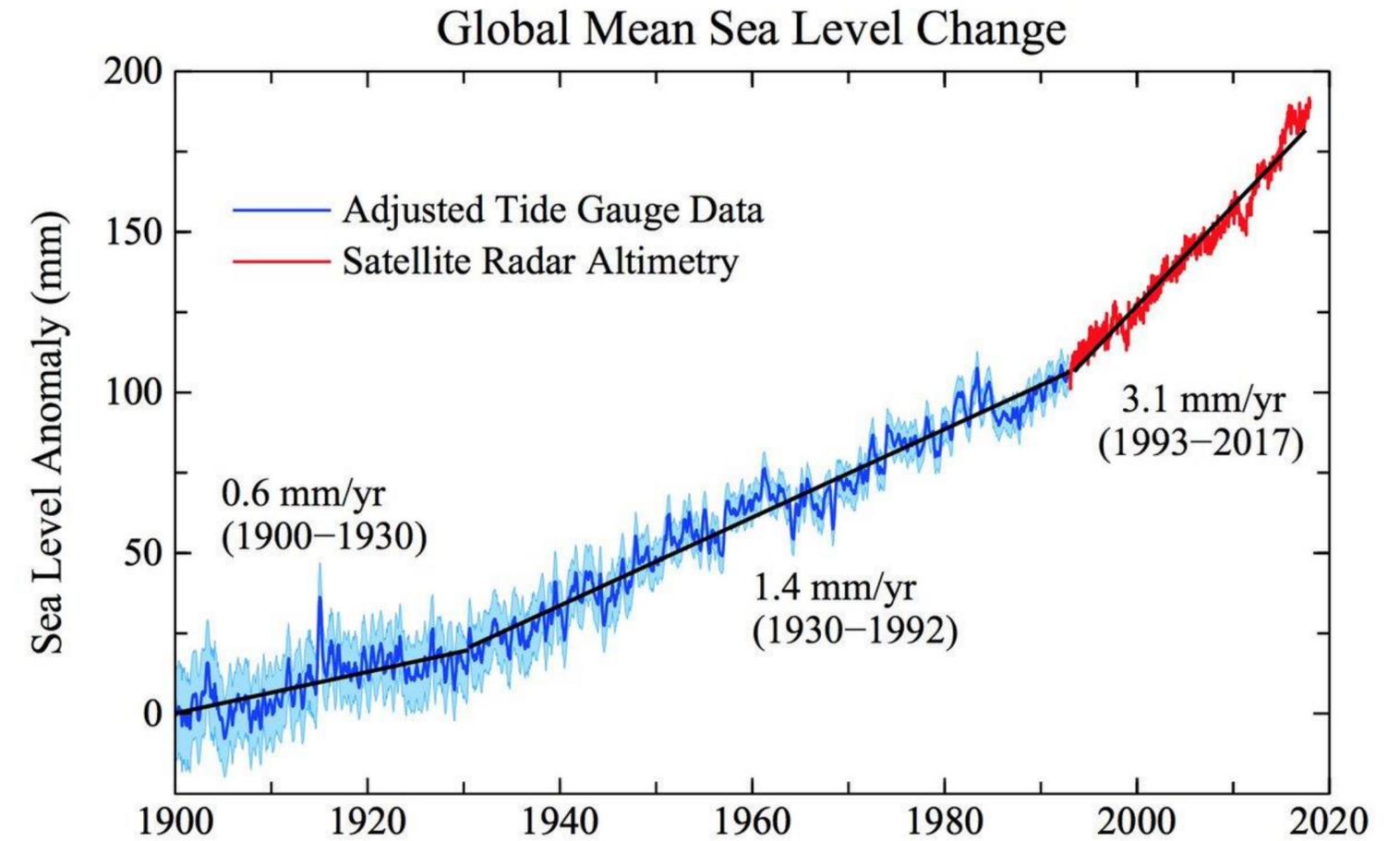
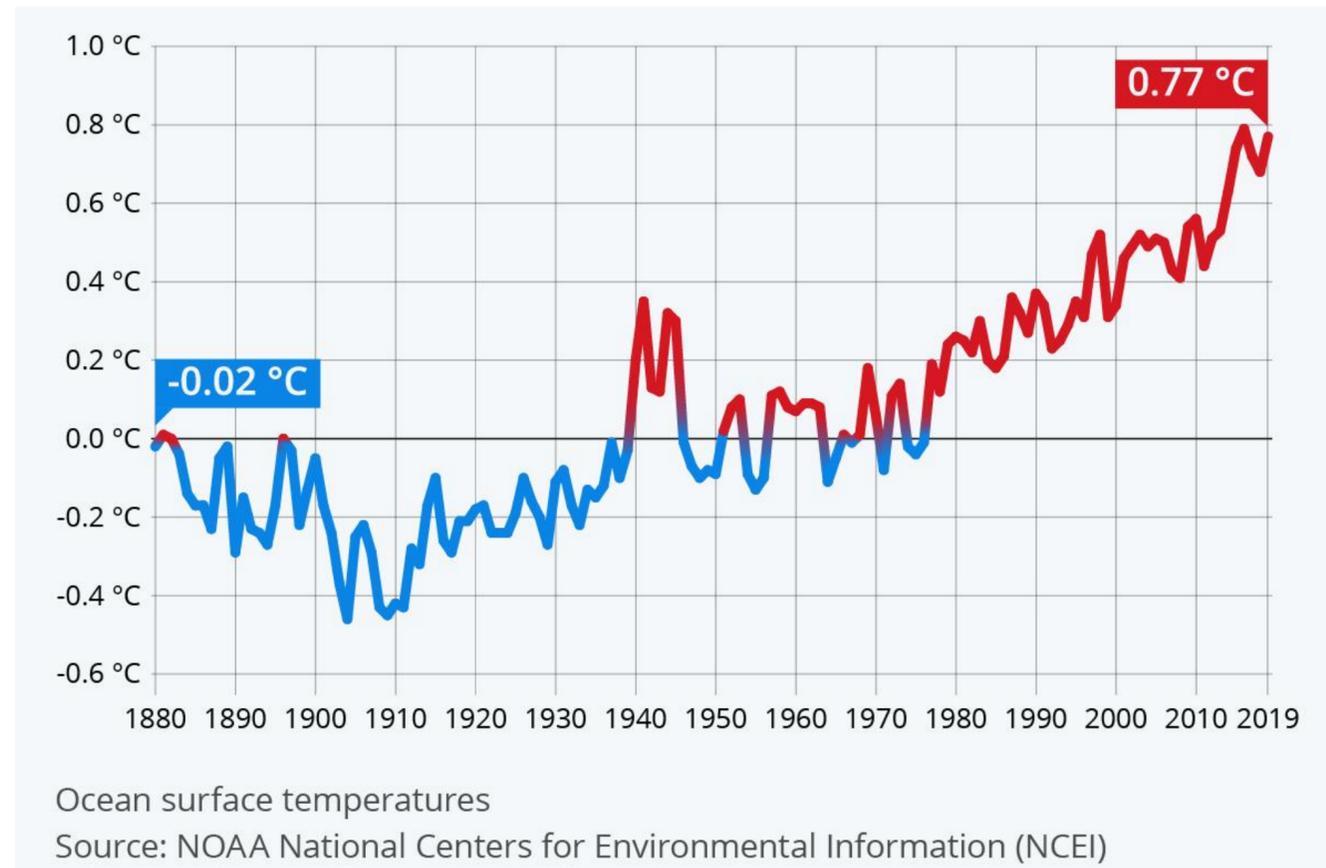
Photographs of McCall Glacier, Alaska (1958 and 2003)



Conseguenze: scioglimento ghiaccio artico e permafrost



Conseguenze: innalzamento del livello del mare

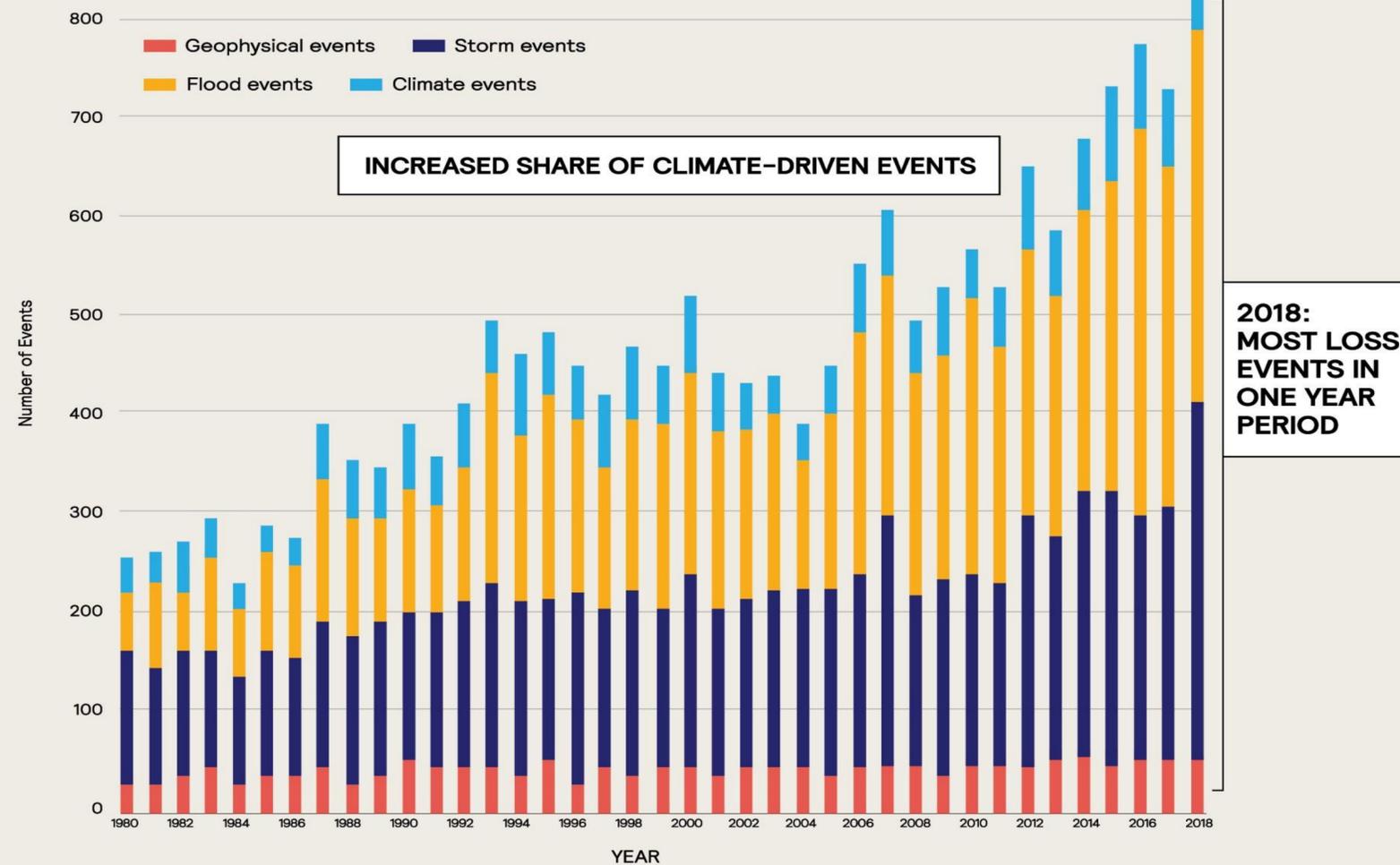


Conseguenze: inondazioni e siccità



Eventi estremi in aumento

Figure 5: Number of Natural Catastrophe Events Worldwide – 1980 to 2018 (Source: Munich Re)

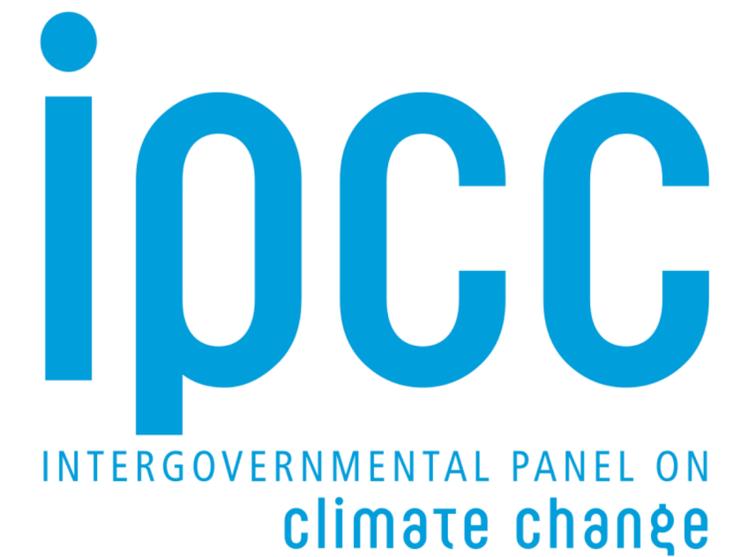


Accounted events have caused at least one fatality and/or produced normalised losses \geq US\$ 100k, 300k, 1m, or 3m (depending on the assigned World Bank income group of the affected country).

E ancora ...

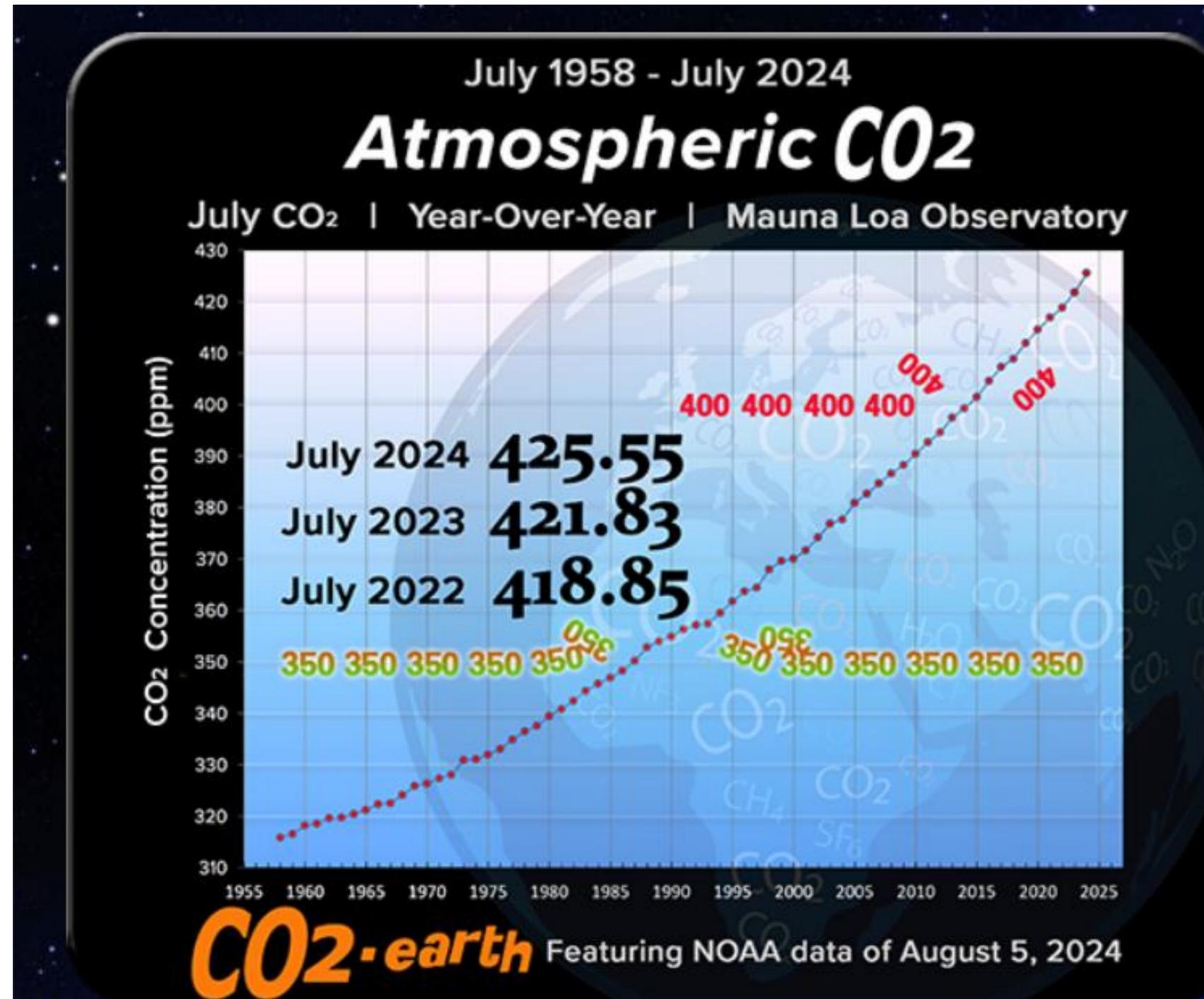
- Modifica della produttività delle piante con raccolti e rese inferiori
- Meno acqua a disposizione
- Sconvolgimento della distribuzione specie vegetali e animali
(estinzioni e migrazioni)
- Maggior diffusione di malattie
- Migrazioni e guerre
- Collasso dell'economia mondiale

E quindi!?



- Adattamento
- Contenimento del riscaldamento
- Diminuzione delle emissioni del 45% rispetto al 2010 entro il 2030 e annullamento entro il 2050 >> 1.5° C
- Diminuzione delle emissioni del 25% rispetto al 2010 entro il 2030 e annullamento entro il 2075 >> 2.0° C

Però ...

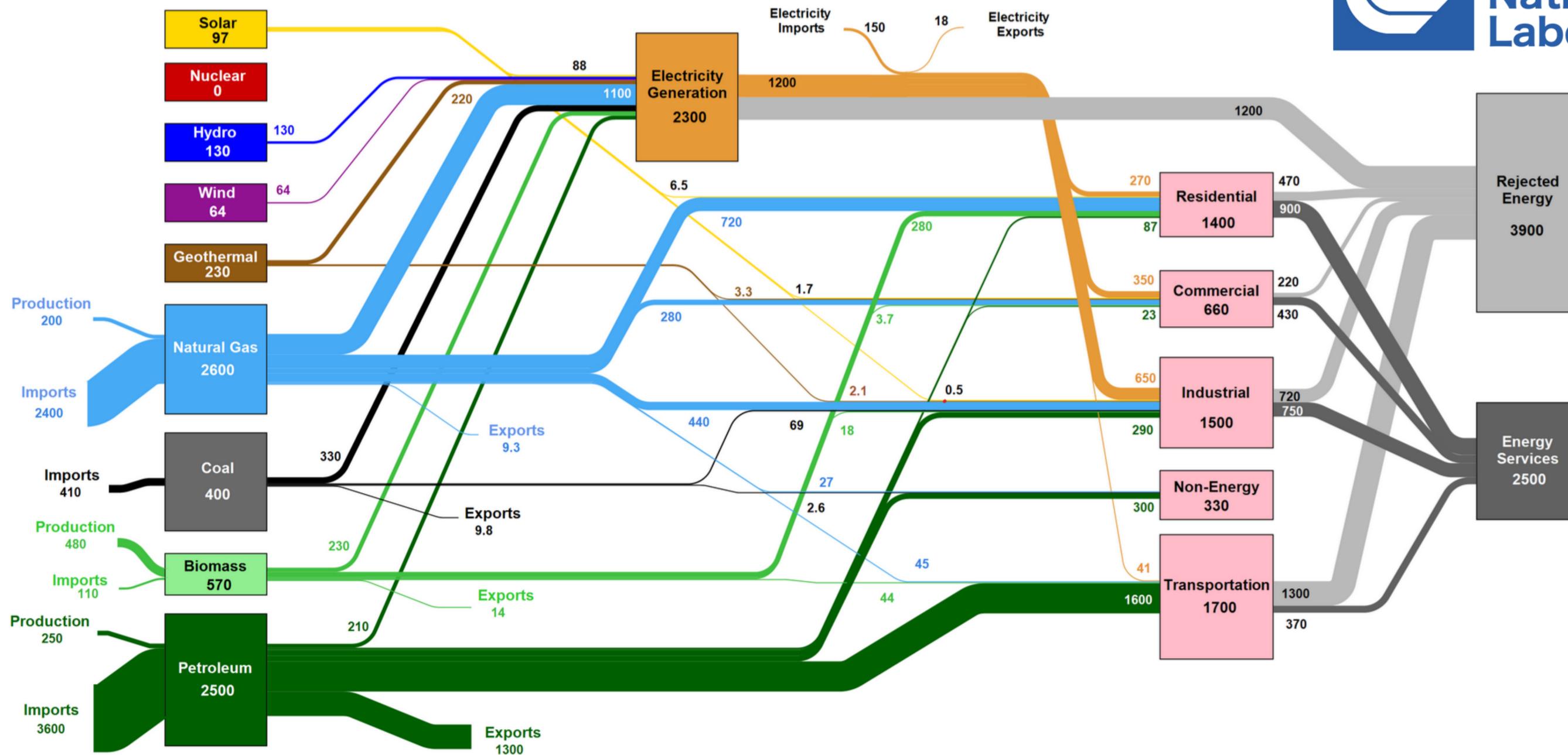




Observed Warming and its Causes

Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850–1900 in 2011–2020. Global greenhouse gas emissions have continued to increase, with unequal historical and ongoing contributions arising from unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions,

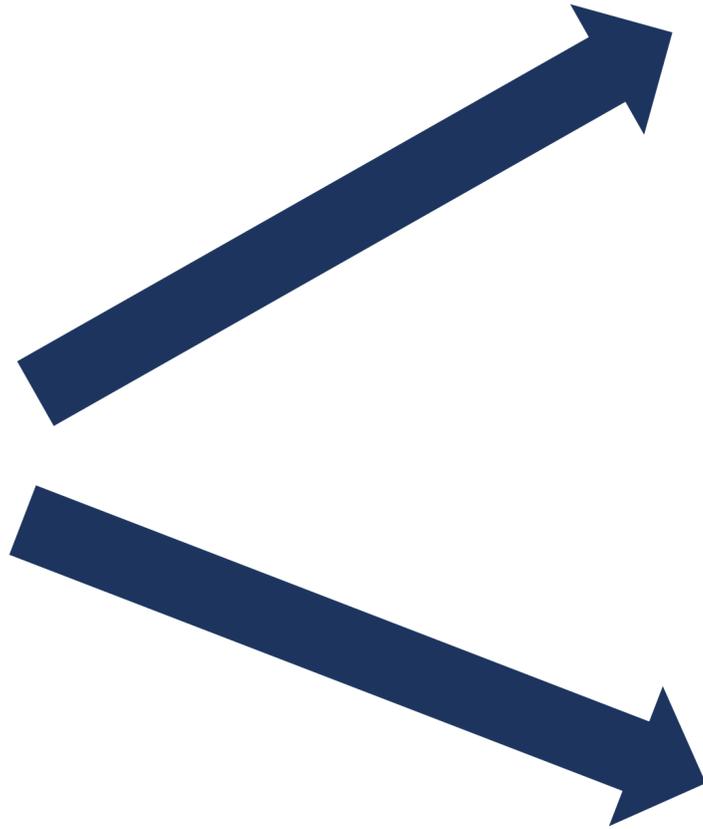
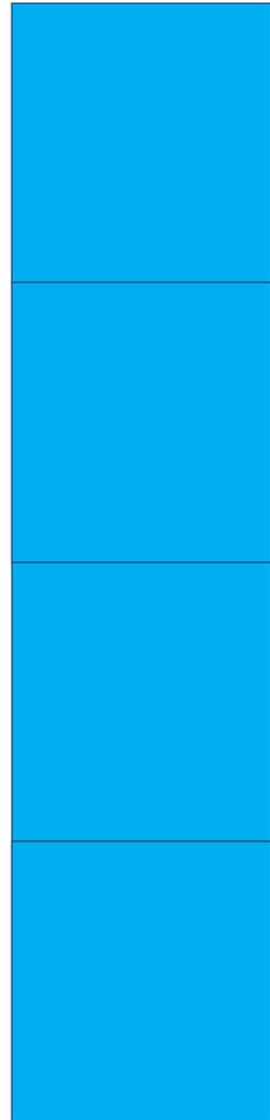
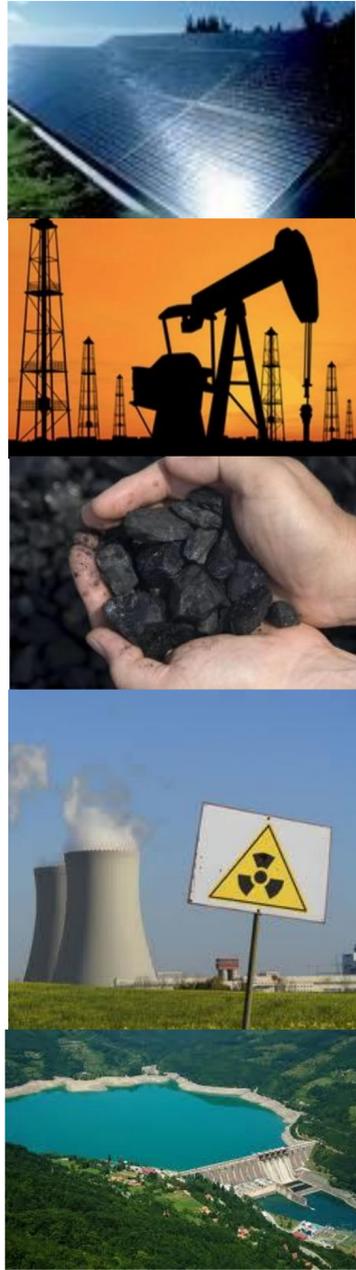
Filiera energetica Italia



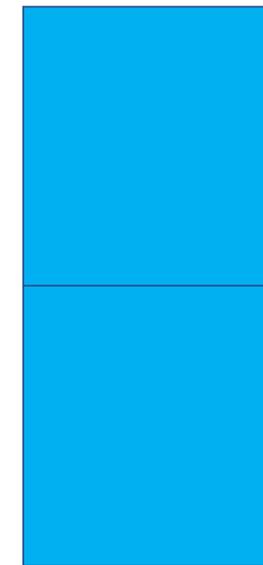
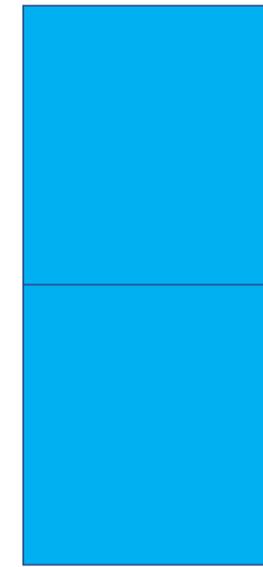
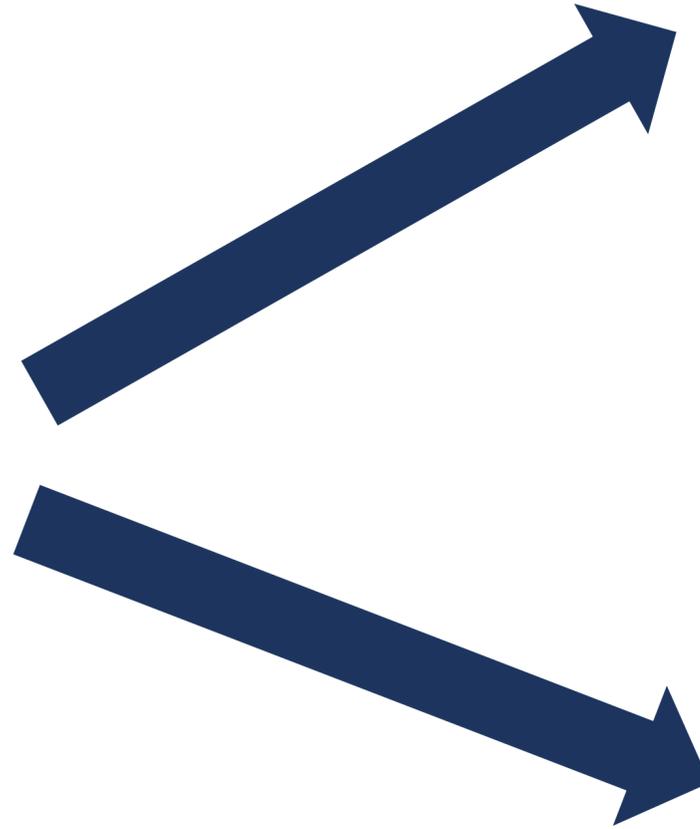
Un sistema inefficiente

- Energia totale: 6.300 PJ
- Energia non utilizzata («rejected energy»): 3.900 PJ
- Energia utilizzata («energy services»): 2.400 PJ
- **Gettiamo il 62% dell'energia (3.900/6.300)**
- Bruciare combustibili fossili per produrre energia elettrica determina perdite pari al 50%
- Bruciarne per muovere automobili determina perdite pari al 75%

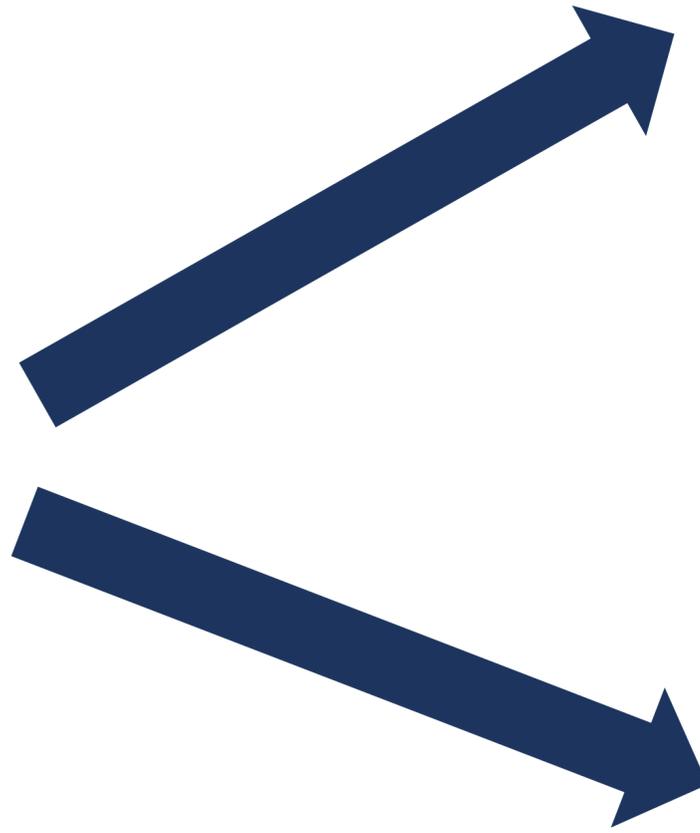
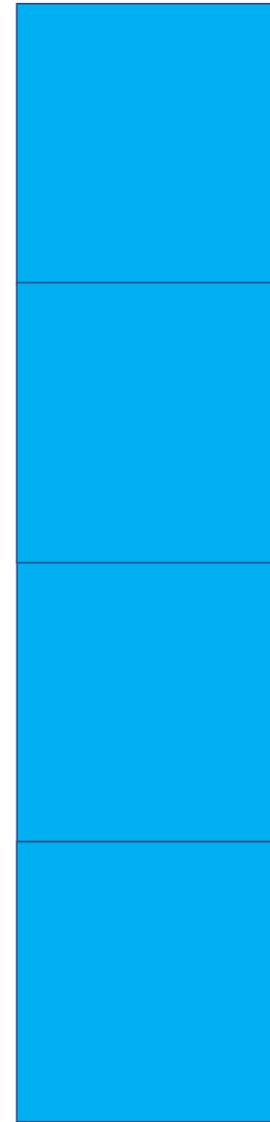
Perdite del sistema energetico



Efficientare la catena energetica



Risparmiare energia



Il costo dei combustibili fossili

Joule

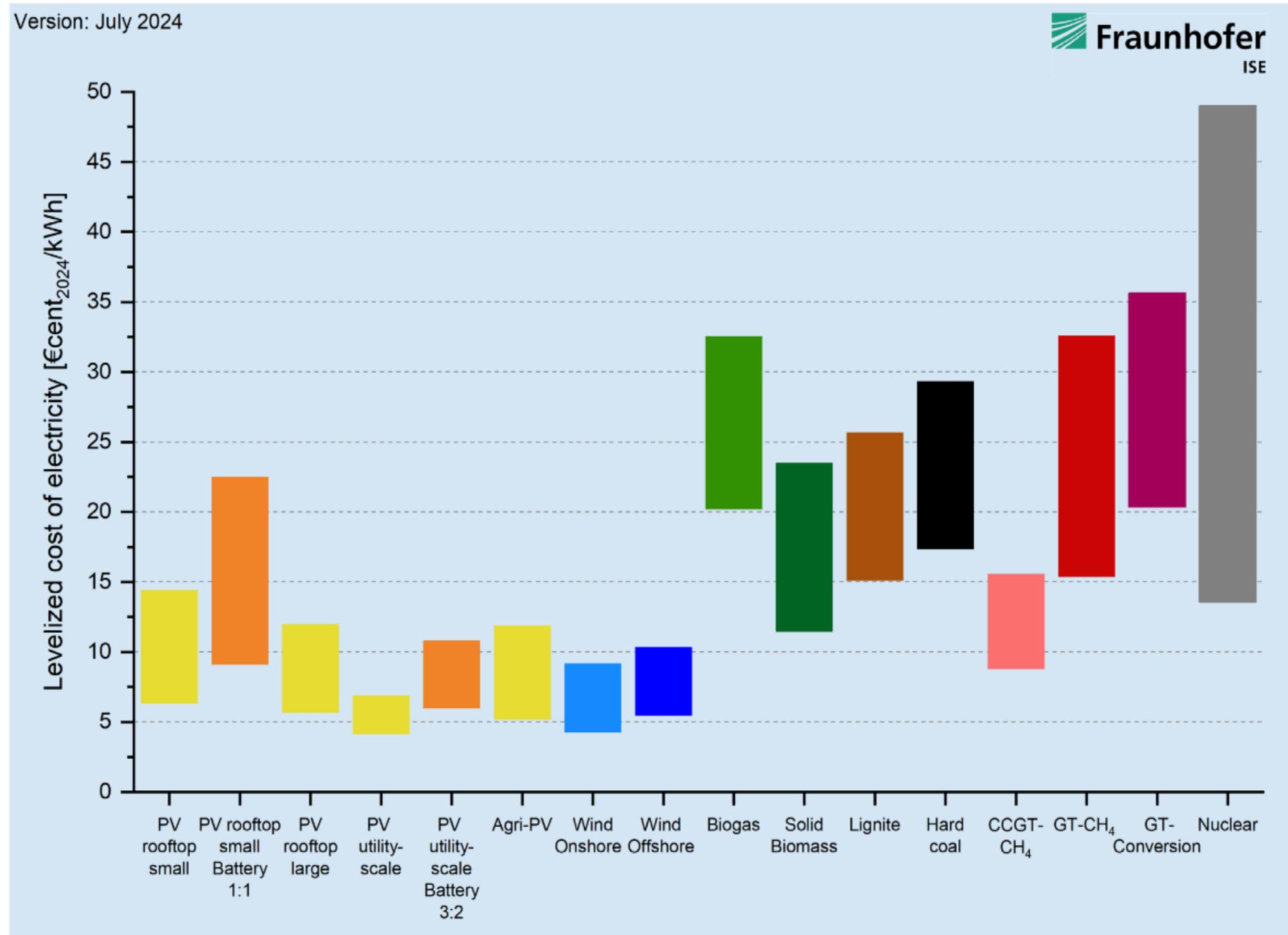
Way et al.
Joule 2022

TRE DIVERSI SCENARI ENERGETICI



La transizione verso le rinnovabili comporterà un risparmio pari a diverse migliaia di miliardi di euro al 2050

Costi di produzione dell'energia elettrica



I fossili continuano a essere incentivati

Support for fossil fuels almost doubled in 2021, slowing progress toward international climate goals, according to new analysis from OECD and IEA

29 August 2022



I supporti globali alle fonti fossili sono passati da 362 G\$ nel 2020 a 697 G\$ nel 2021!!!

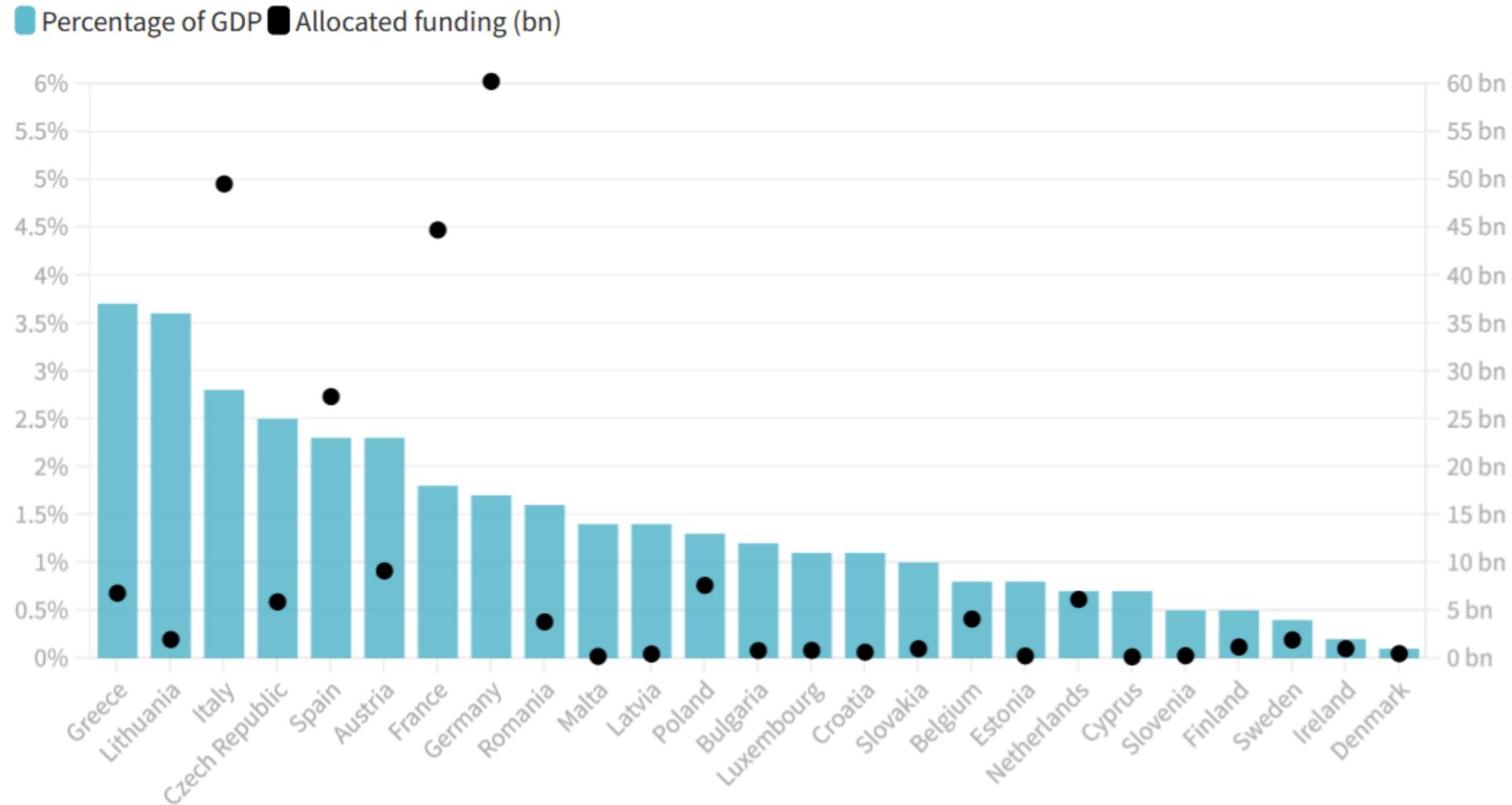
I supporti globali alle fonti rinnovabili nel 2021 non hanno superato i 500 G\$...

Aiuti a pagare le bollette



Governments allocated funding (Sep 2021 - Jul 2022) to shield households and businesses from the energy crisis
Last update: 10.08.2022

National policies to shield consumers from rising energy prices



50 miliardi di euro di aiuti corrispondono a 60 GW di fotovoltaico (6Gm3/anno di gas)

Il settore energetico è inadeguato e non sostenibile

- Molto complesso
- Il primo emettitore di gas serra
- Inefficiente
- Costoso
- In crisi

Transizione verso le fonti rinnovabili

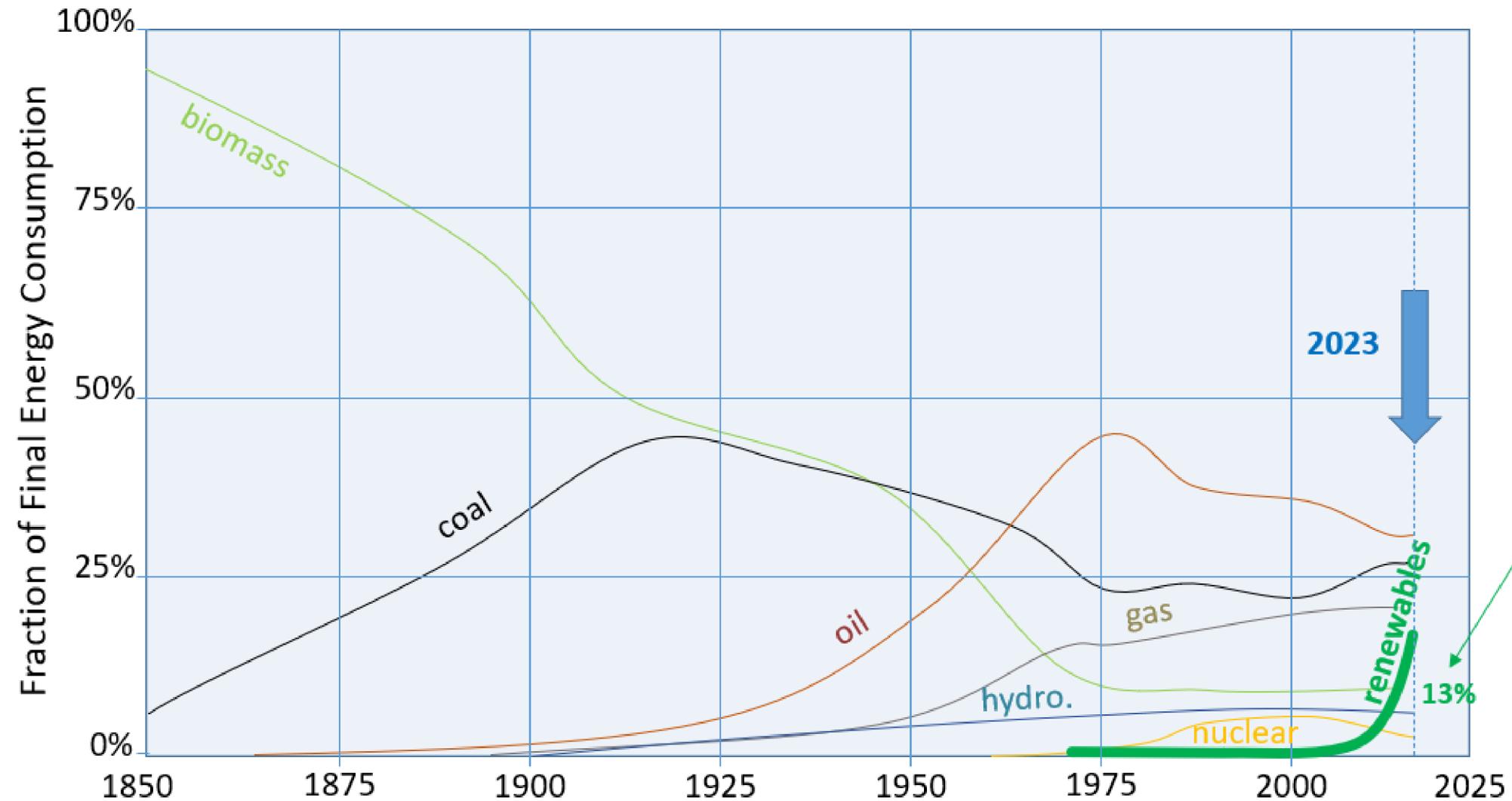
PERSPECTIVE

How to avoid the perfect storm:

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(Received 30 May 2020; accepted 31 August 2020)



Modern renewables account for **13.0%** of total final energy consumption (2022)

Ren21, 2024 Report



Adapted from Lughì, Massi Pavan, «La forza del sole», Sapere (June 2017)

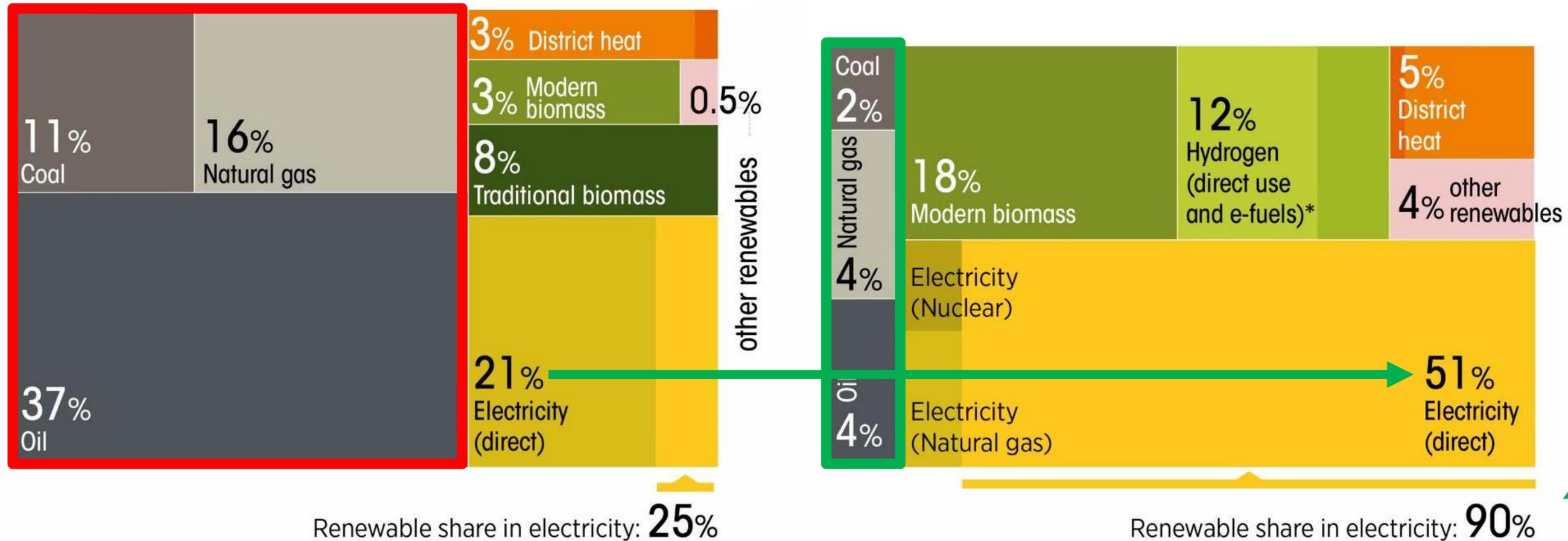
Transizione verso l'energia elettrica

2018

2050 - Where we need to be (1.5-S)

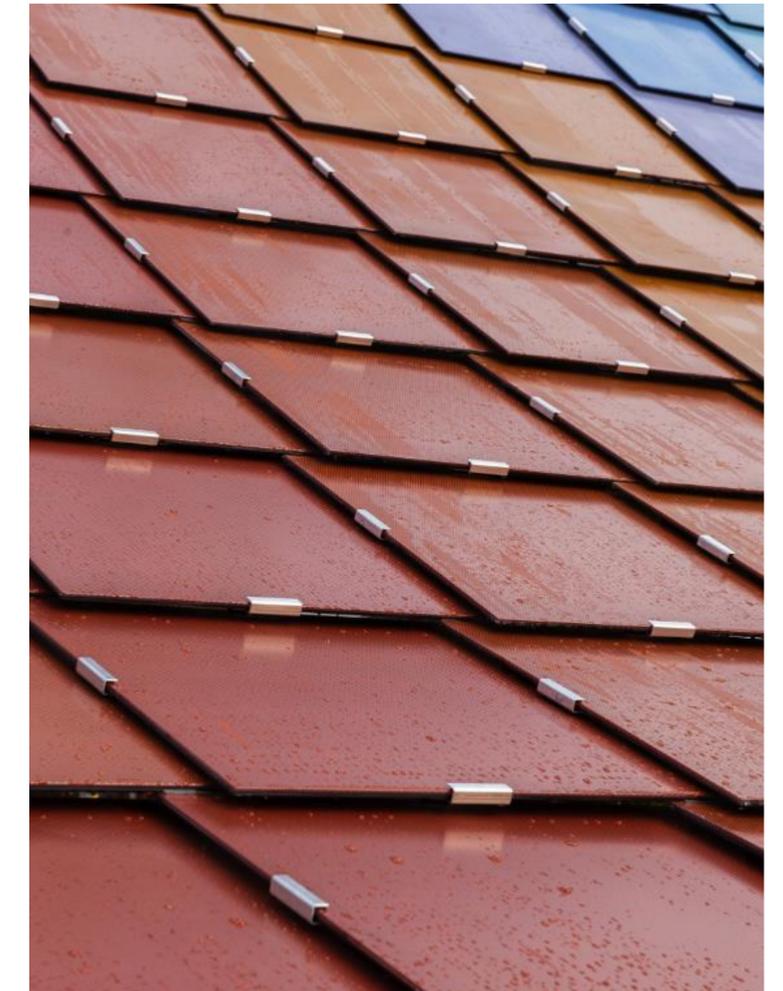
64%

10%



Perché energia elettrica?

- Vettore più efficiente
- Privo di massa
- Pratico da usare
- Impatto nullo
- Facile da trasportare
- Generazione distribuita



Perché energia elettrica?

- Nuovi usi «stazionari»: fornelli a induzione e pompe di calore

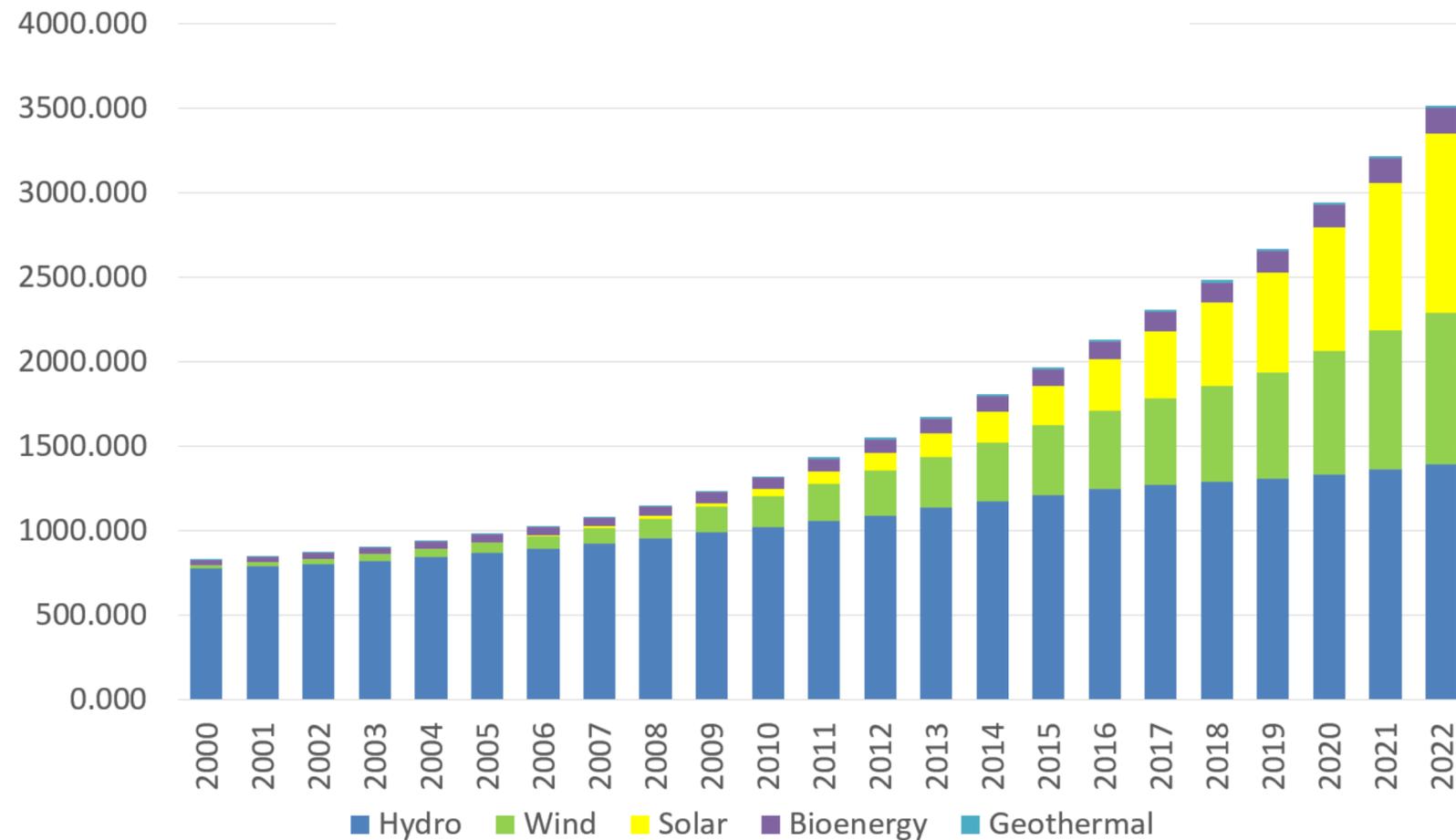


Perché energia elettrica?

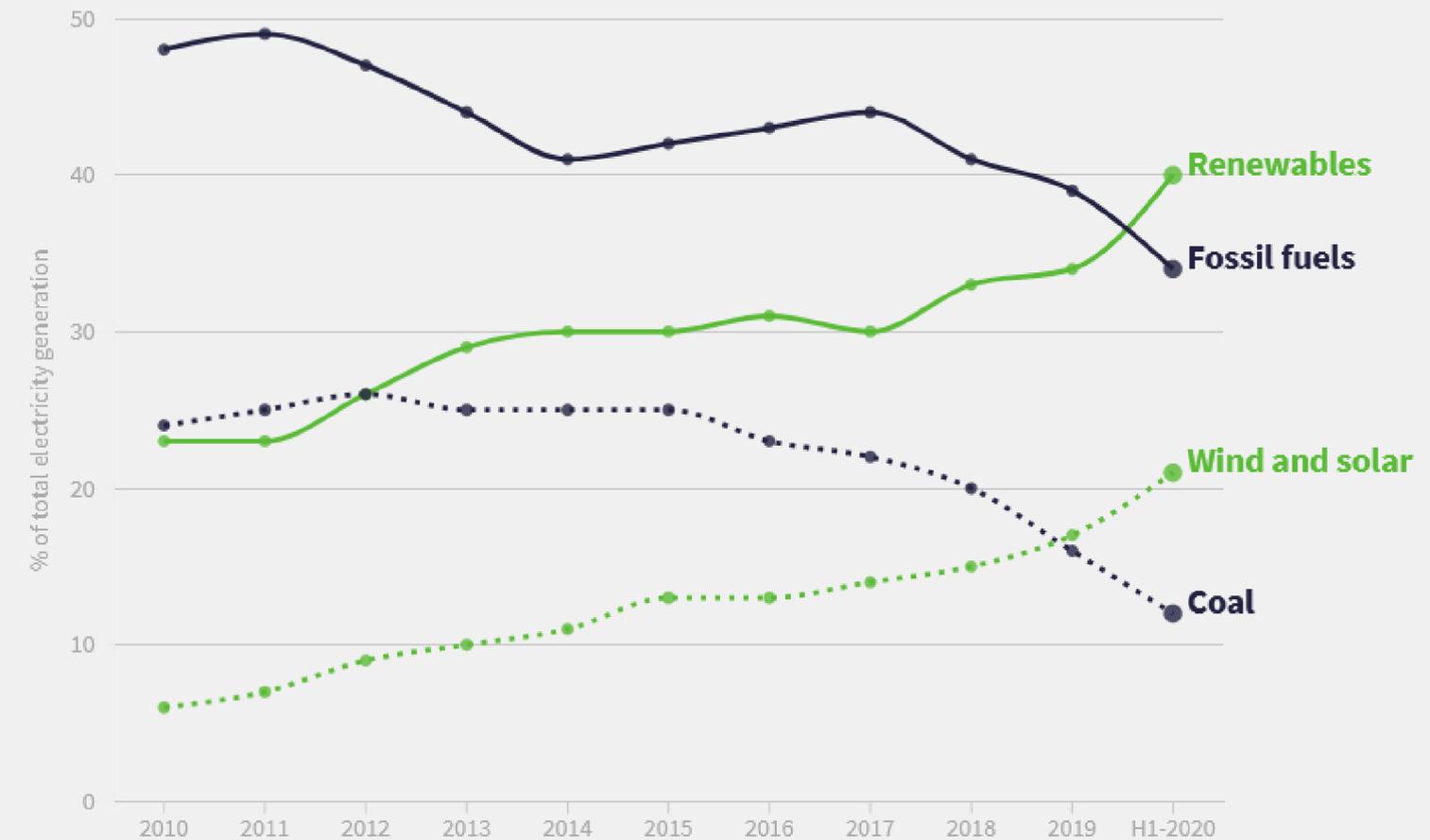
- Nuovi usi: trasporti «leggeri»



Crescita esponenziale delle rinnovabili

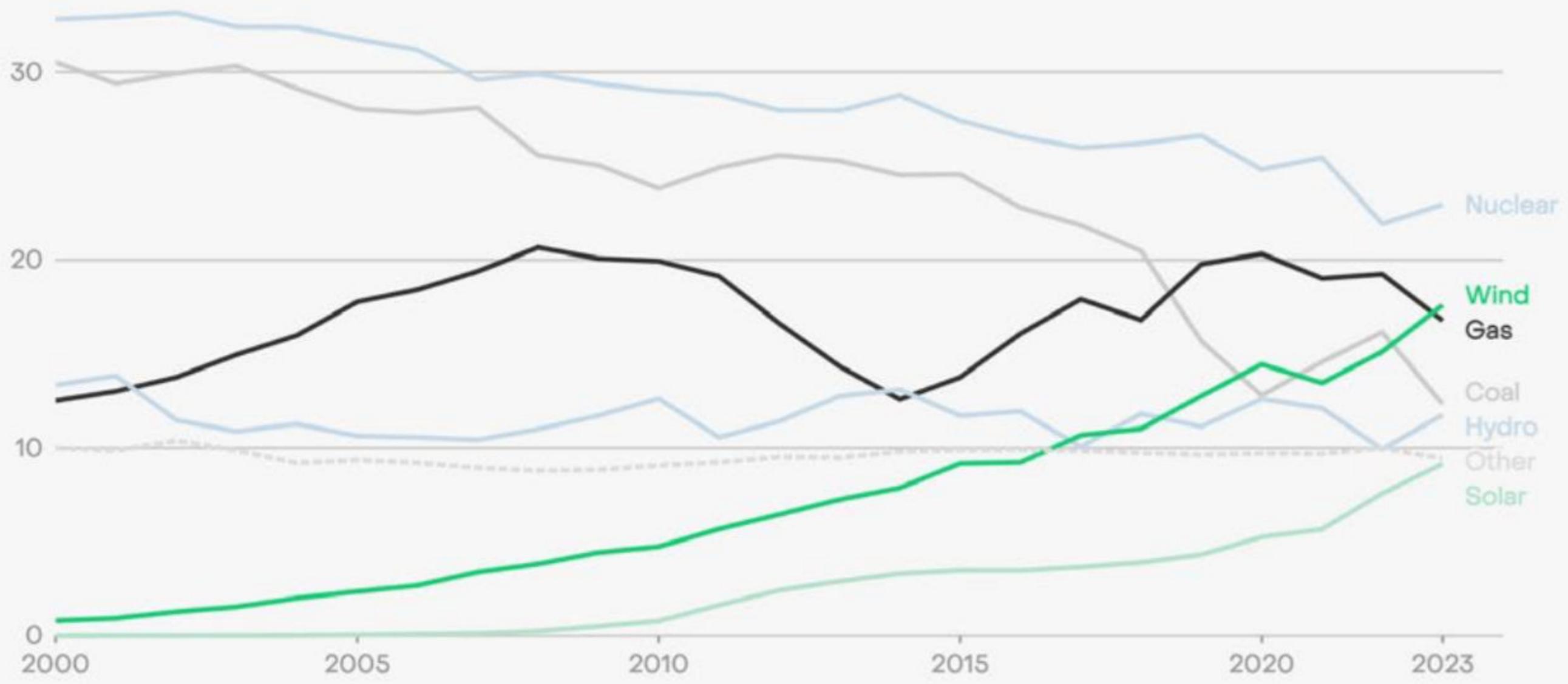


Renewables beat fossil fuels
EU-27 electricity generation



Wind produced more electricity than gas for the first time in 2023

Share of EU electricity generation, by source (%)



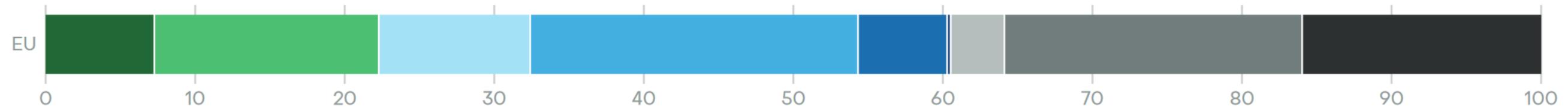
Source: Annual electricity data, Ember
'Other' includes bioenergy, other fossil and other renewables



EU electricity mix

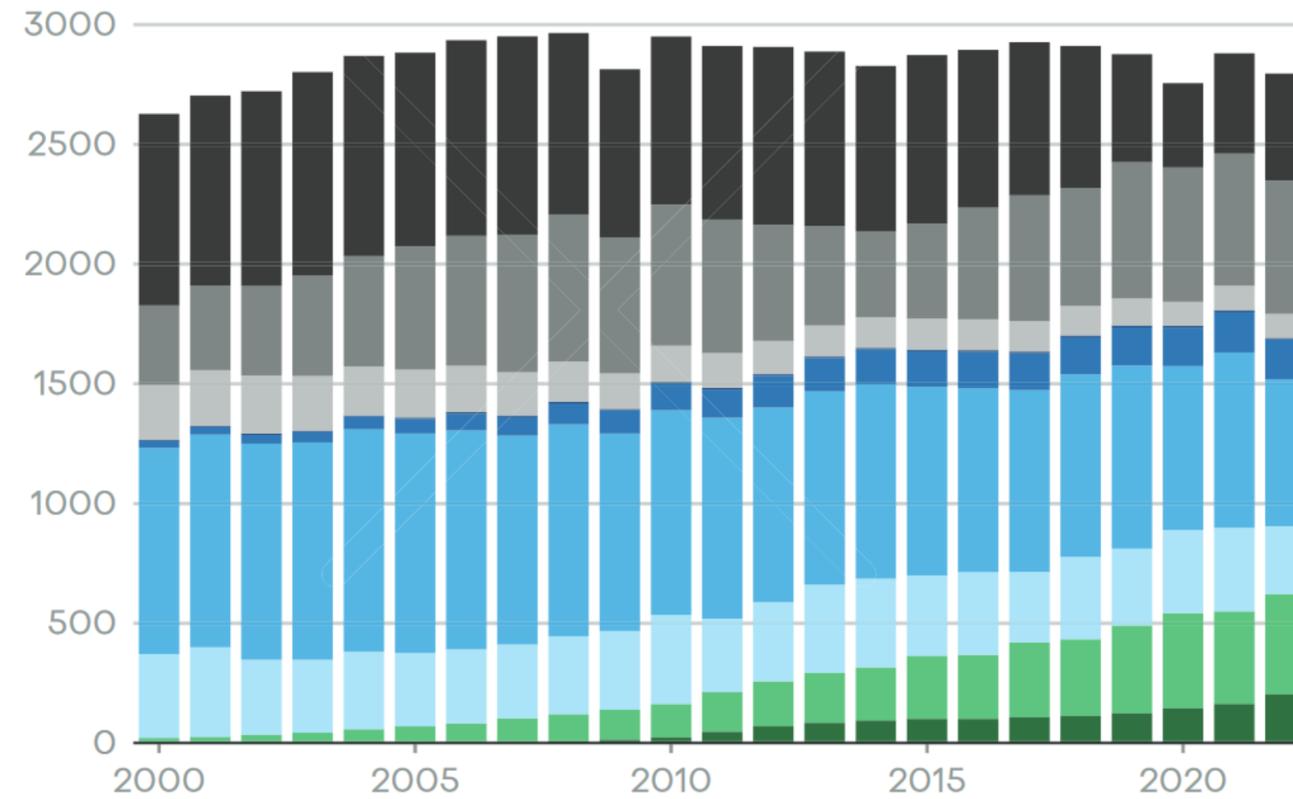
Share of electricity (%)

Solar Wind Hydro Nuclear Bioenergy Other res Other fossil Gas Coal



Generation (TWh)

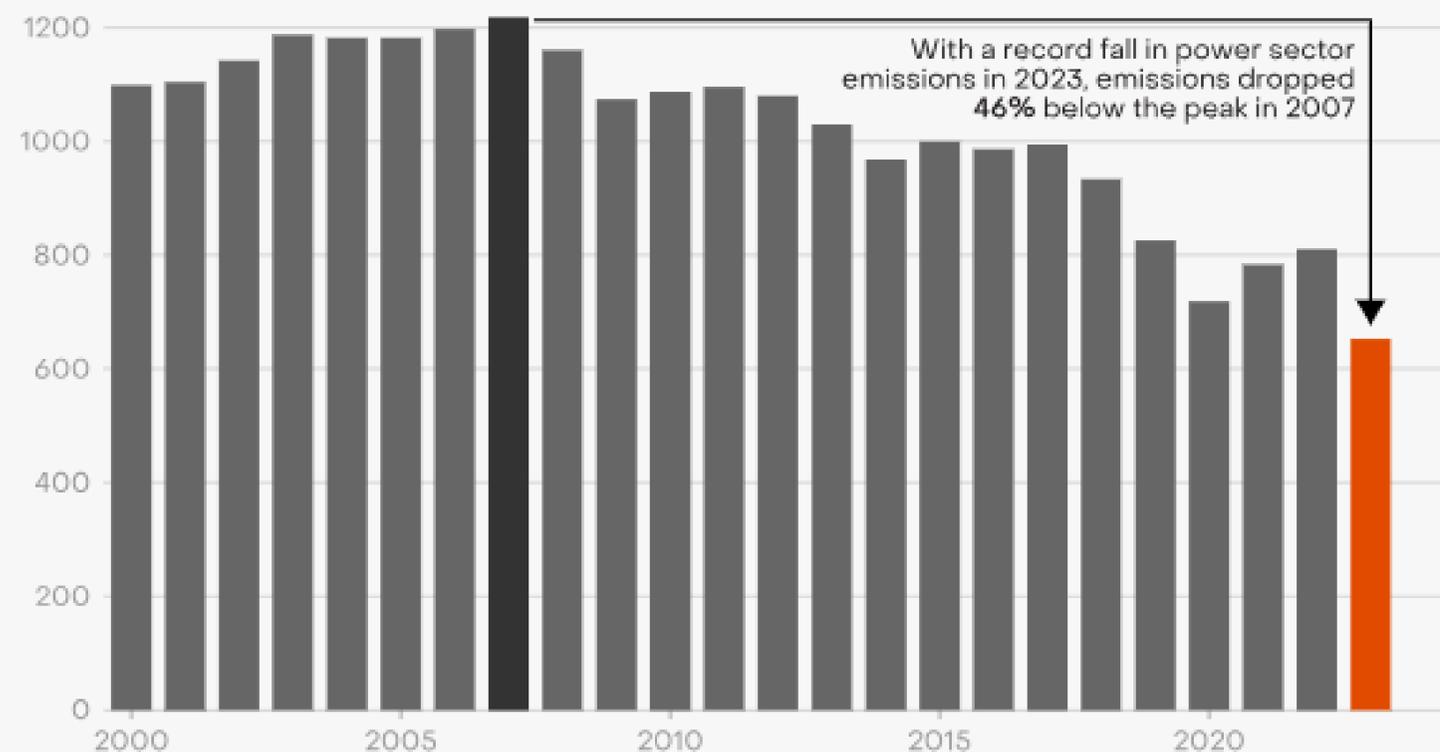
Solar Wind Hydro Nuclear Bioenergy Other res Other fossil Gas Coal



Carbon intensity

EU power sector emissions have nearly halved since their peak in 2007

Total power sector emissions (MtCO₂)



Source: Annual electricity data, Ember

EMBER

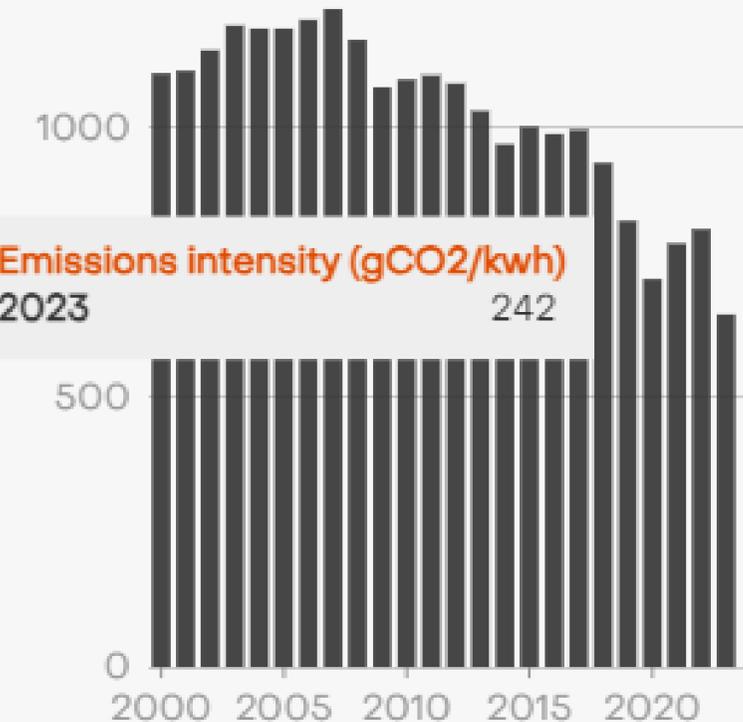
Long-term trend in EU power sector emissions

Emissions intensity (gCO₂/kwh)



Source: Annual electricity data, Ember

Total emissions (MtCO₂)



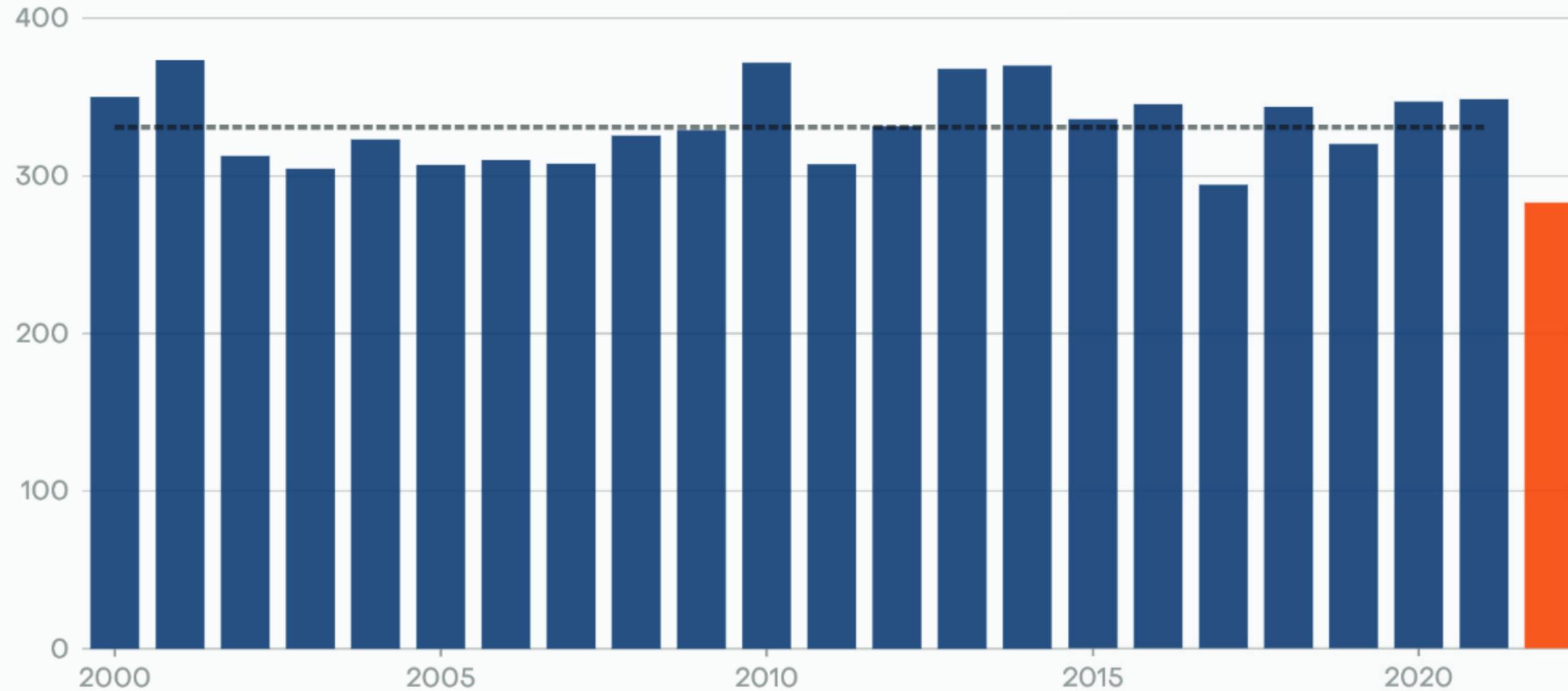
Emissions intensity (gCO₂/kwh)
2023
242

EMBER

A particularly bad year for hydro power in Europe

Electricity generation (TWh)

Dotted line = 2000-2021 average



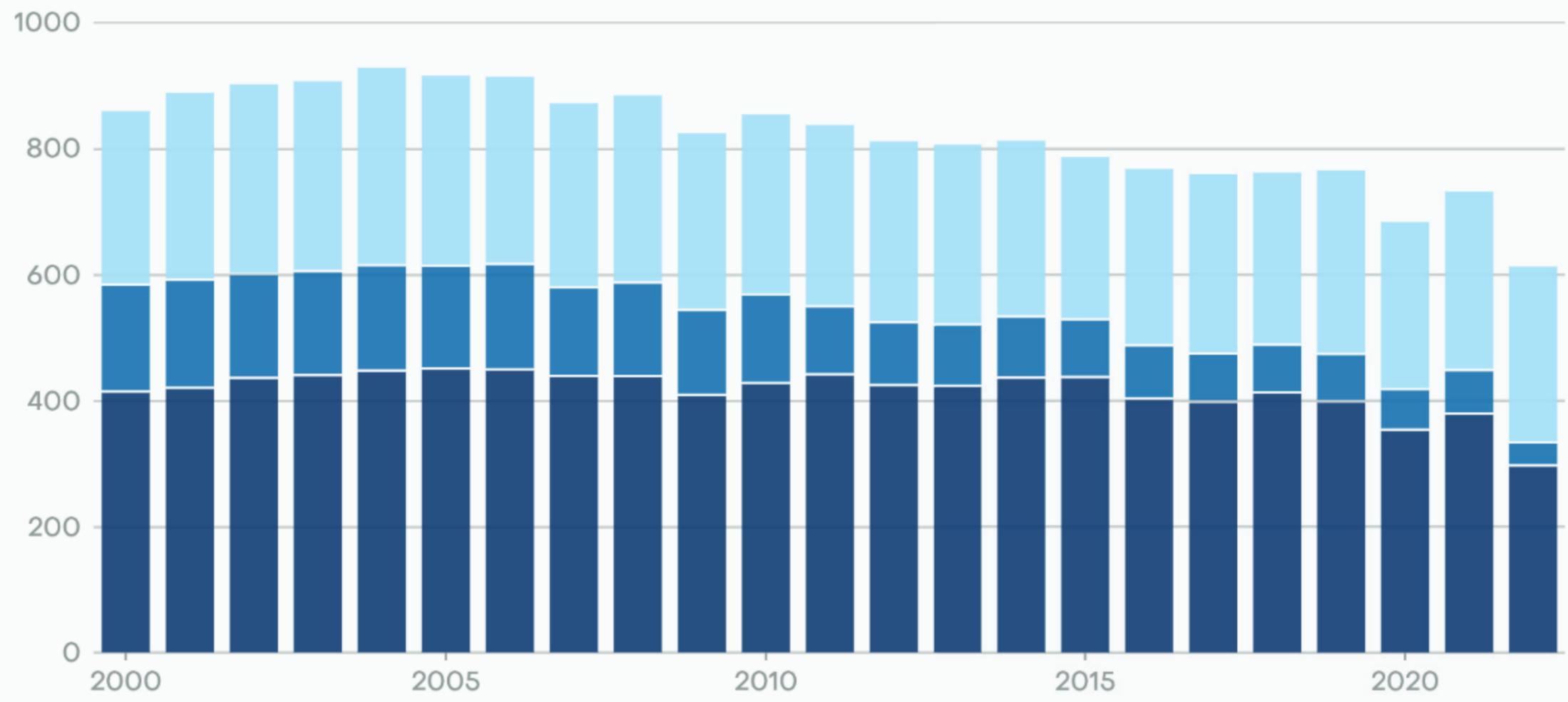
Source: Annual electricity data, Ember

EMBER

EU nuclear power generation dropped significantly in 2022

TWh

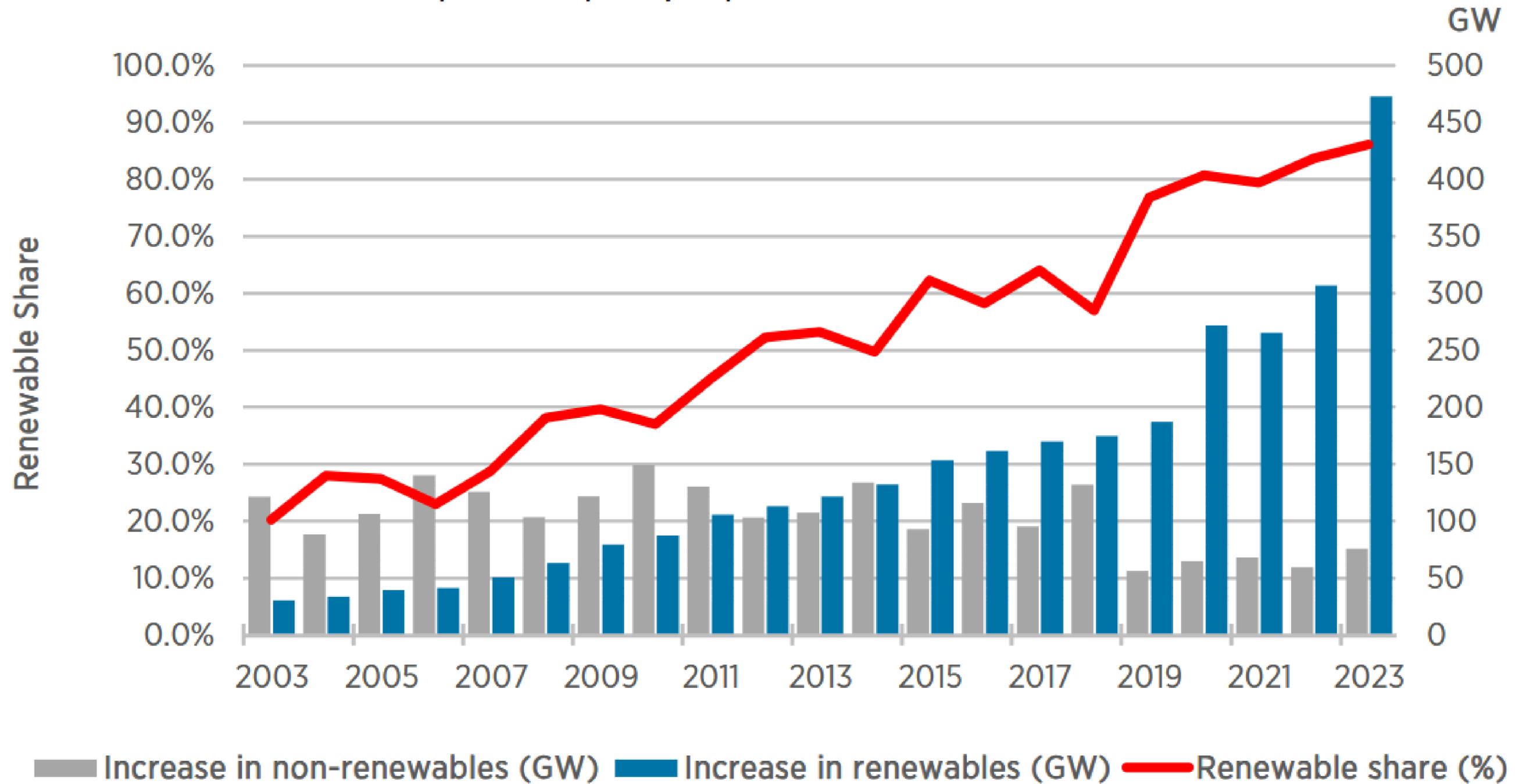
■ France ■ Germany ■ Rest of the EU



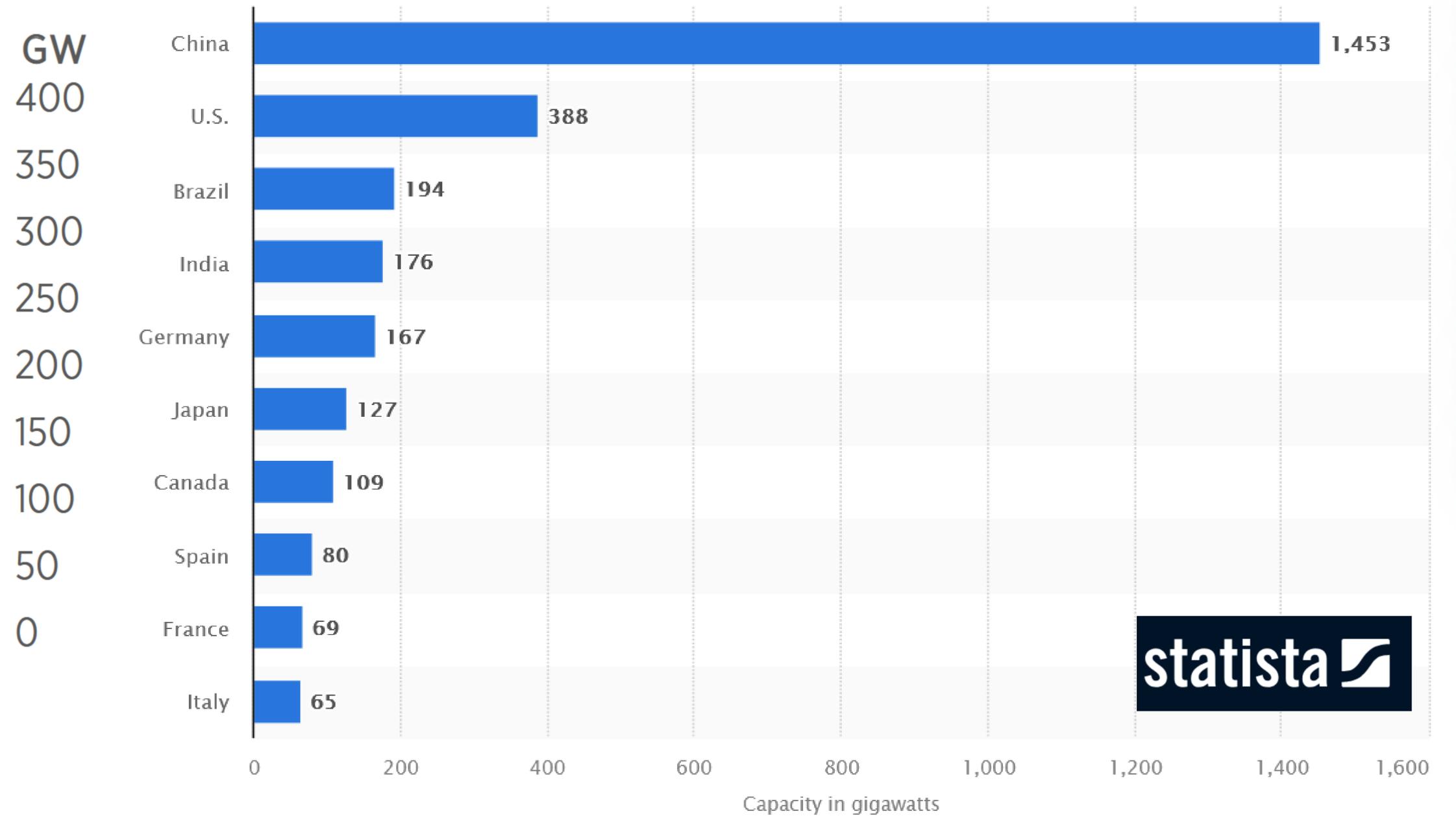
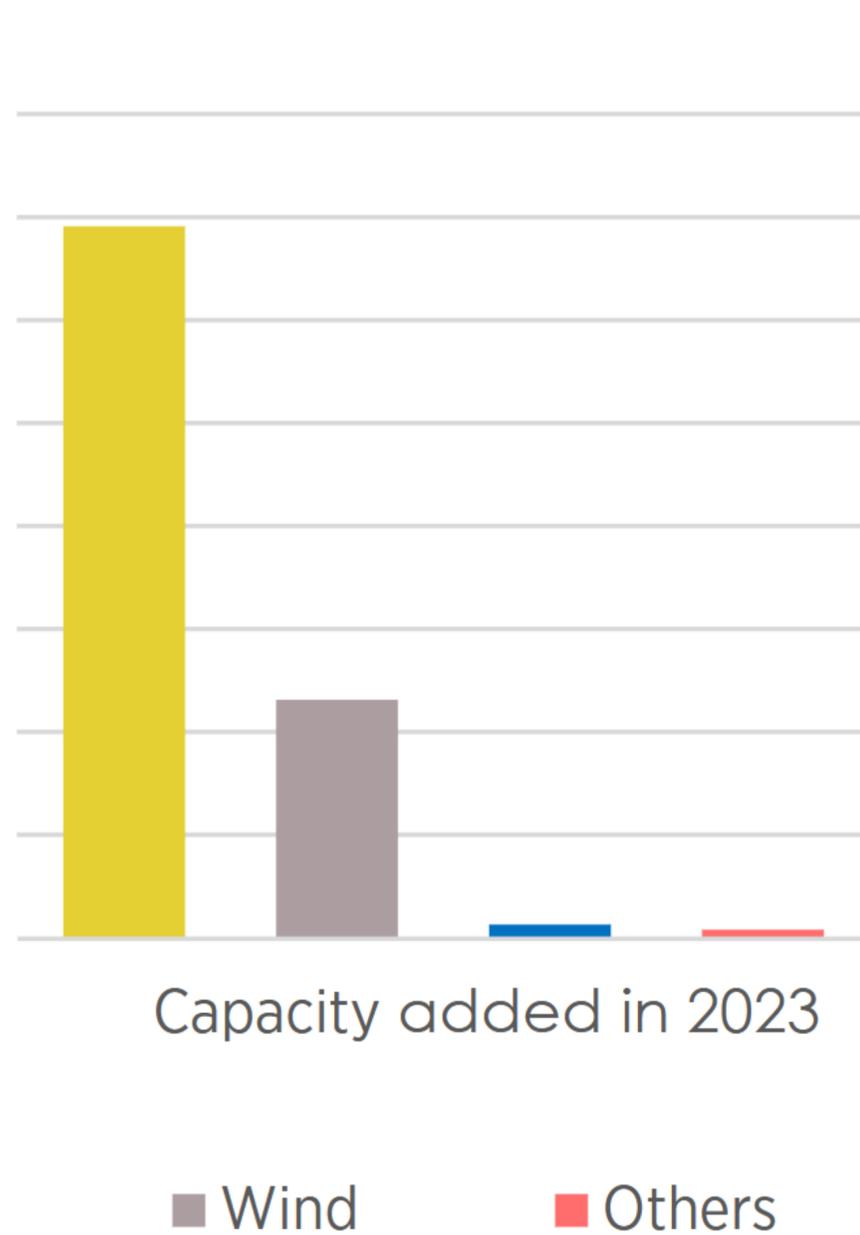
Source: Annual electricity data, Ember



A livello globale «solo» rinnovabili!



Investimenti nel settore elettrico

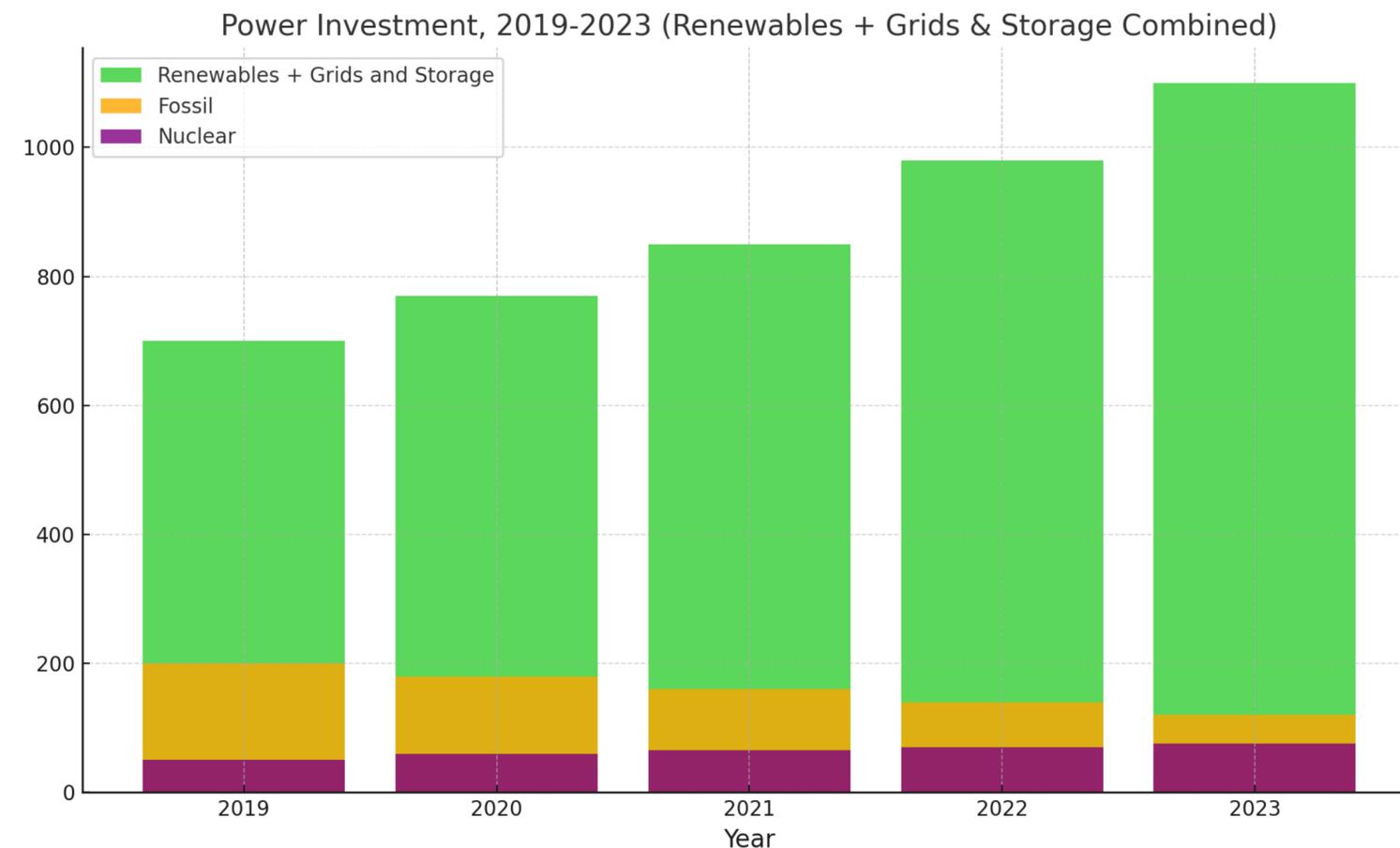
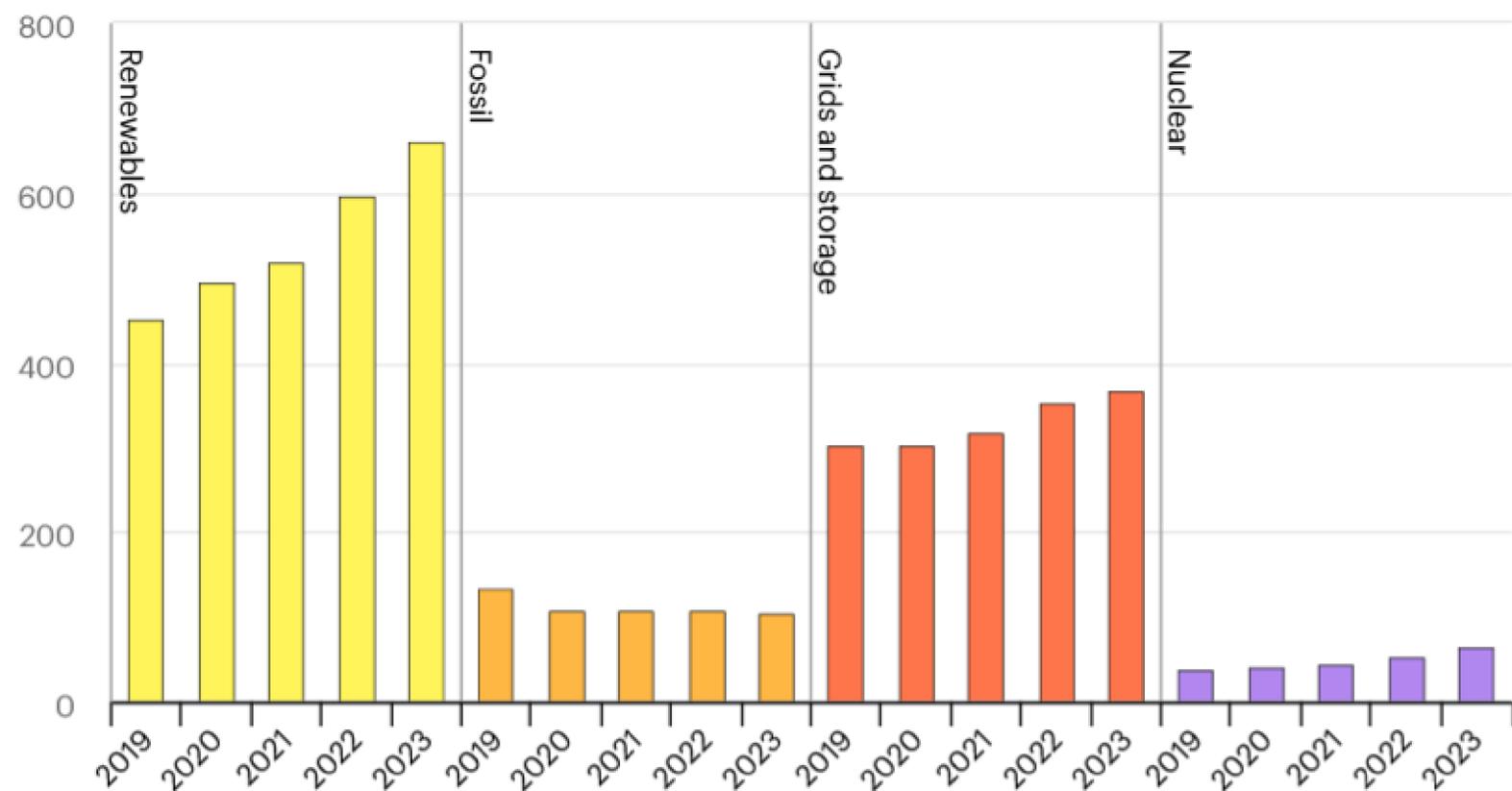


Investimenti nel settore elettrico

Power investment, 2019-2023

Open ↗

billion USD (2022)



IEA. Licence: CC BY 4.0

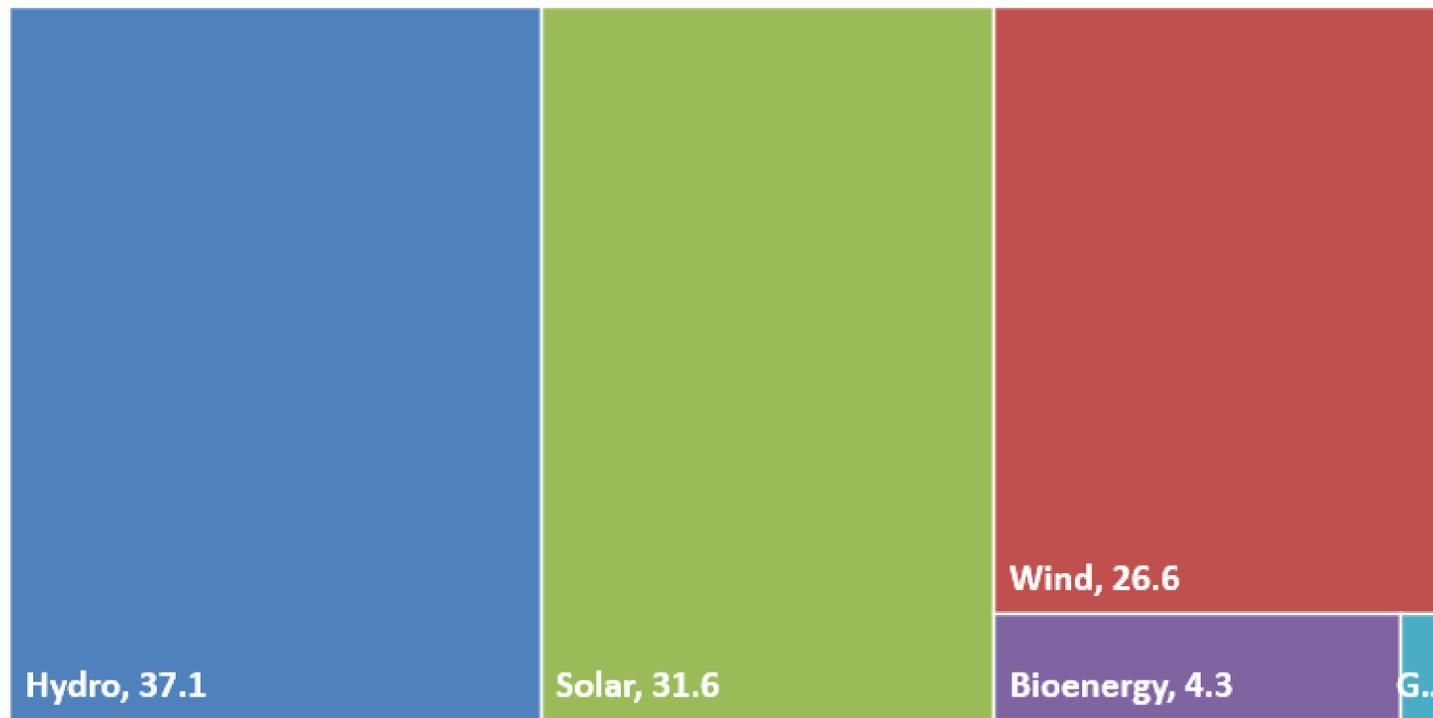
● Renewables ● Fossil ● Grids and storage ● Nuclear

2000

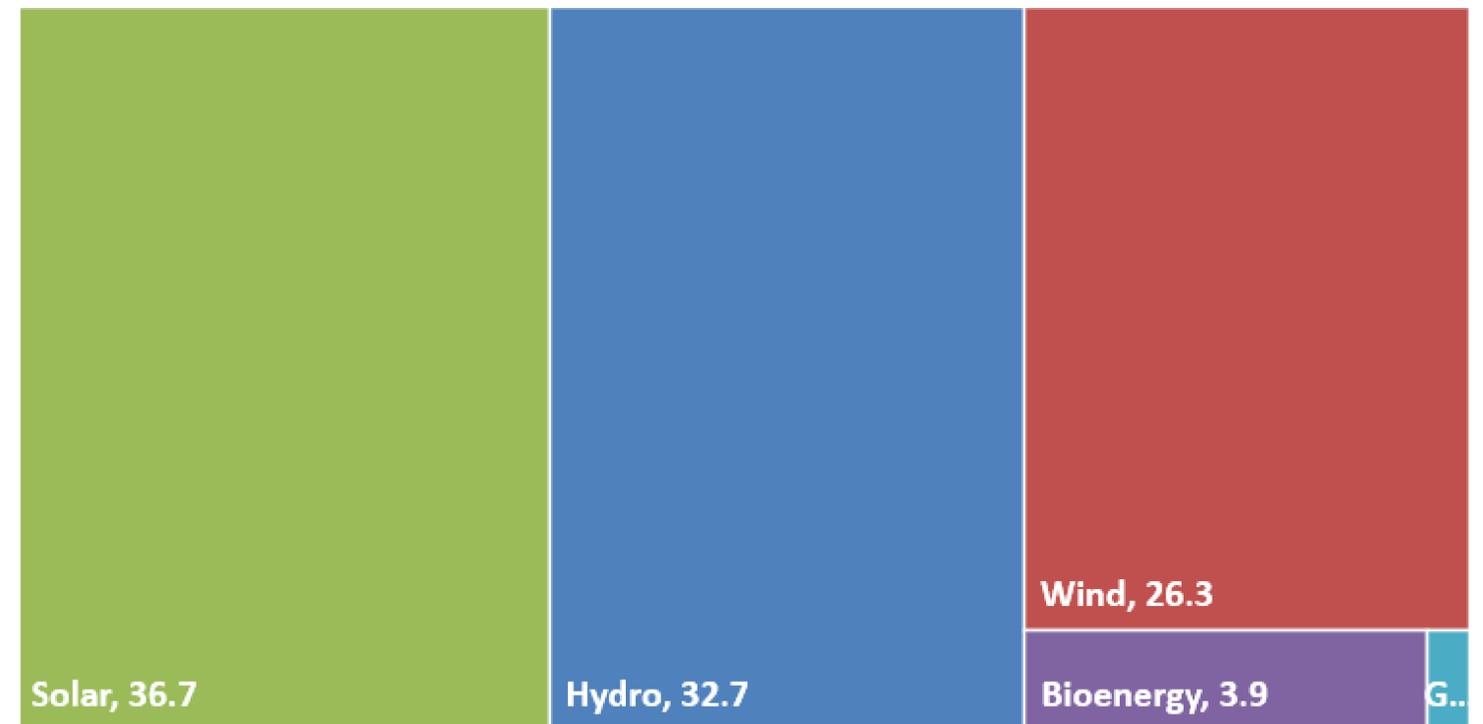


- Hydro
- Wind
- Solar
- Bioenergy
- Geotherma

2022



2023

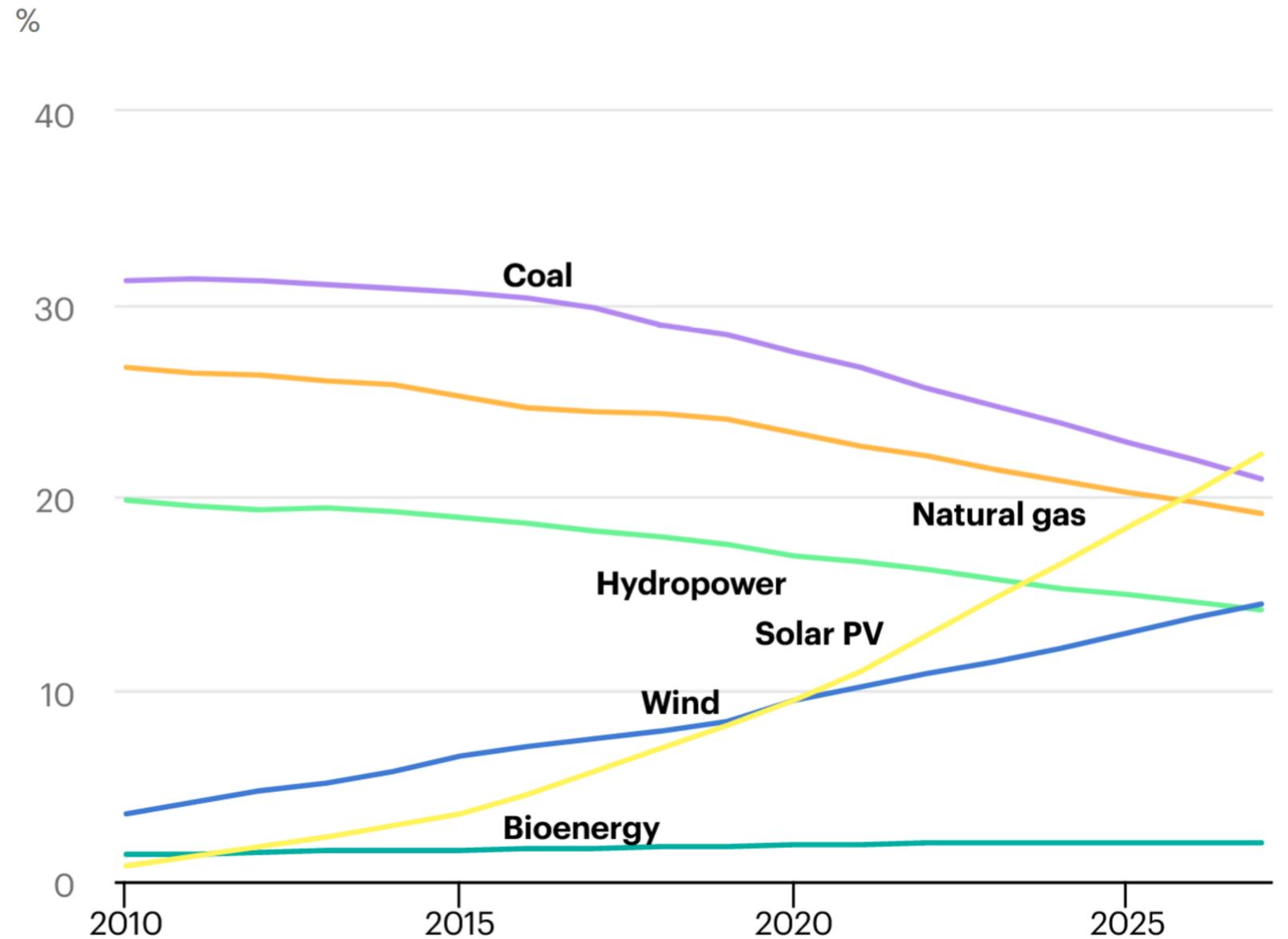
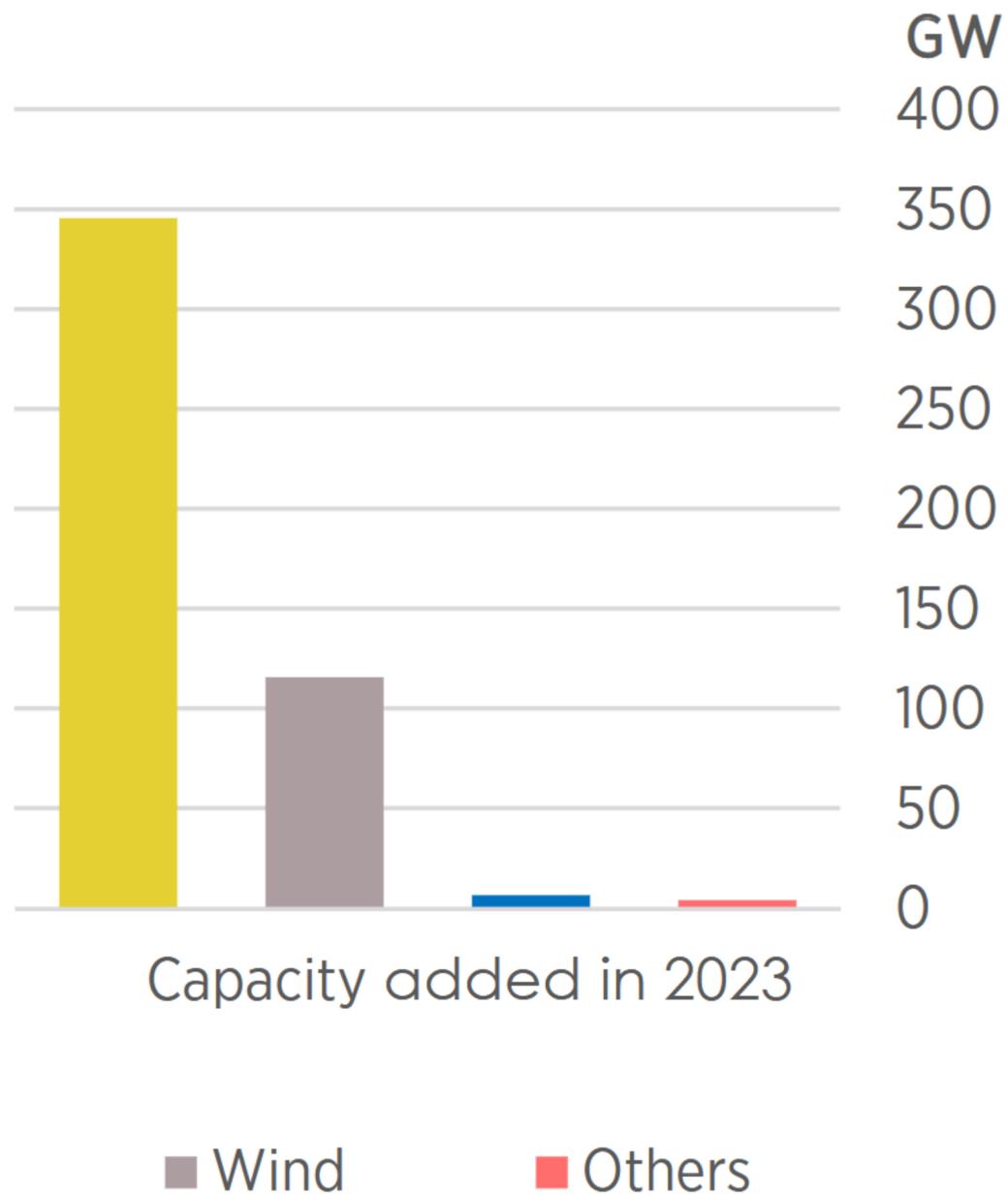


Nuove installazioni

TECHNOLOGY	2022 [GW]	2021 [GW]	VARIATION [%]
PHOTOVOLTAICS	1055	866	21.8
WIND	899	826	8.8
BIOMASS, SOLID BIOFUELS AND WASTE	277	262	5.7
GAS	1895	1853	2.3
HYDROPOWER	1392	1360	2.4
COAL	2142	2139	0.1
NUCLEAR	371	390	-4.9

- China 2023: 217GW of PV, 90GW of wind, 1GW of nuclear
- Nuclear in China: 34.4GW during the last 10 years, they have a plan to install other 30GW by 2030 (5 per year)

Il fotovoltaico guida la transizione



Power generation in Italy

TECHNOLOGY	2005	2020	2022	2023
THERMAL POWER	81%	60%	67%	58%
HYDROPOWER	15%	17%	9%	16%
PHOTOVOLTAICS	0%	9%	9%	12%
WIND POWER	1%	6%	7%	9%
BIOMASS	2%	6%	6%	3%
GEO THERMAL	2%	2%	2%	2%

Renewables doubled from 20 to 40% in 15 years!

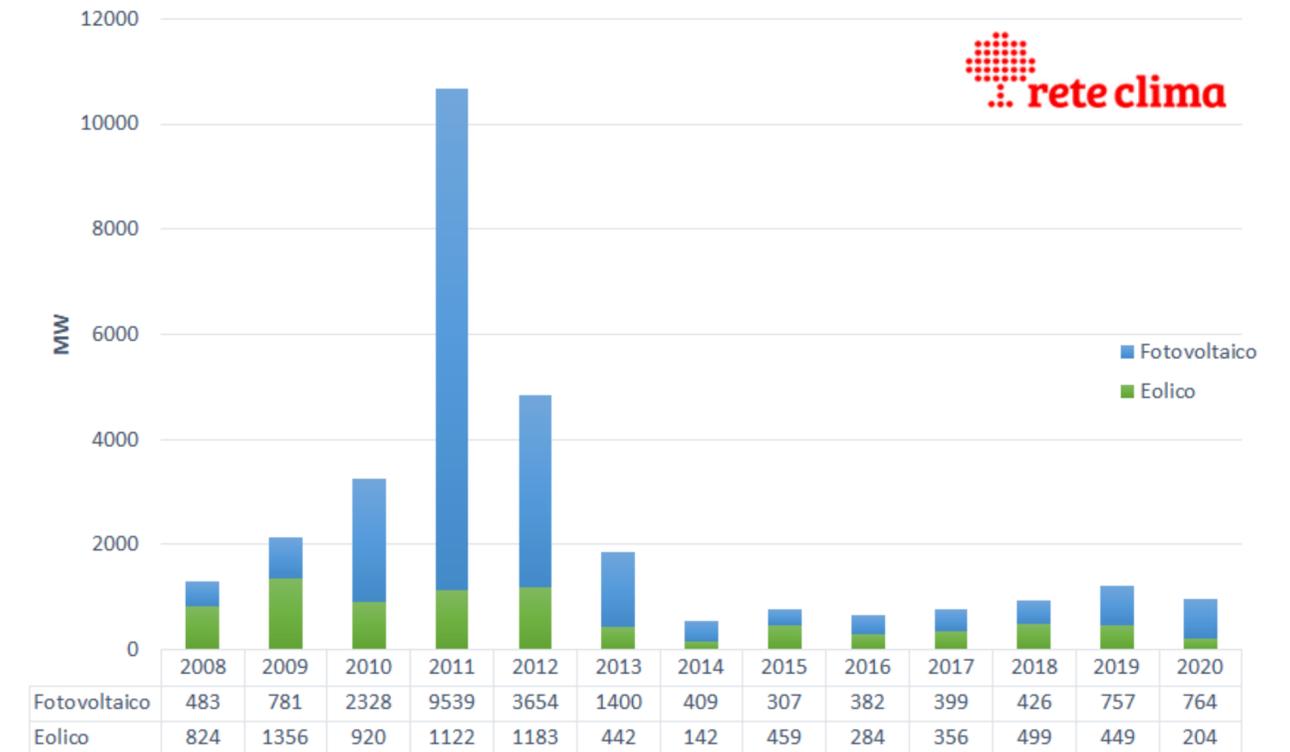
Il futuro del settore elettrico in Italia

Tabella 10 - Obiettivi di crescita della potenza da fonte rinnovabile al 2030 (MW) [Fonte: RSE, GSE]

	2020	2021	2025	2030
Idrica*	19.106	19.172	19.172	19.172
Geotermica	817	817	954	1.000
Eolica	10.907	11.290	17.314	28.140
- di cui off shore	0	0	300	2.100
Bioenergie	4.106	4.106	3.777	3.052
Solare	21.650	22.594	44.848	79.921
- di cui a concentrazione	0	0	300	873
Totale	56.586	57.979	86.065	131.285

In 2023: 27 GW of PV and 12.5 GW of wind
53 GW of PV in 7 years >> 7.6 GW/year
12.5 GW of wind power >> 2.2 GW/year

Evoluzione installato al 31 dicembre 2020 (MW)

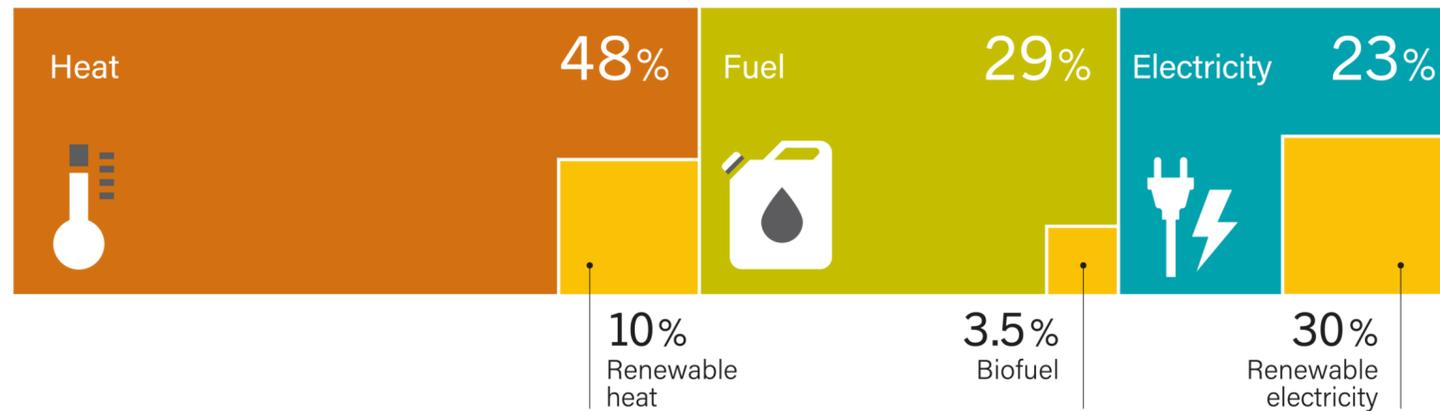


PHOTOVOLTAICS

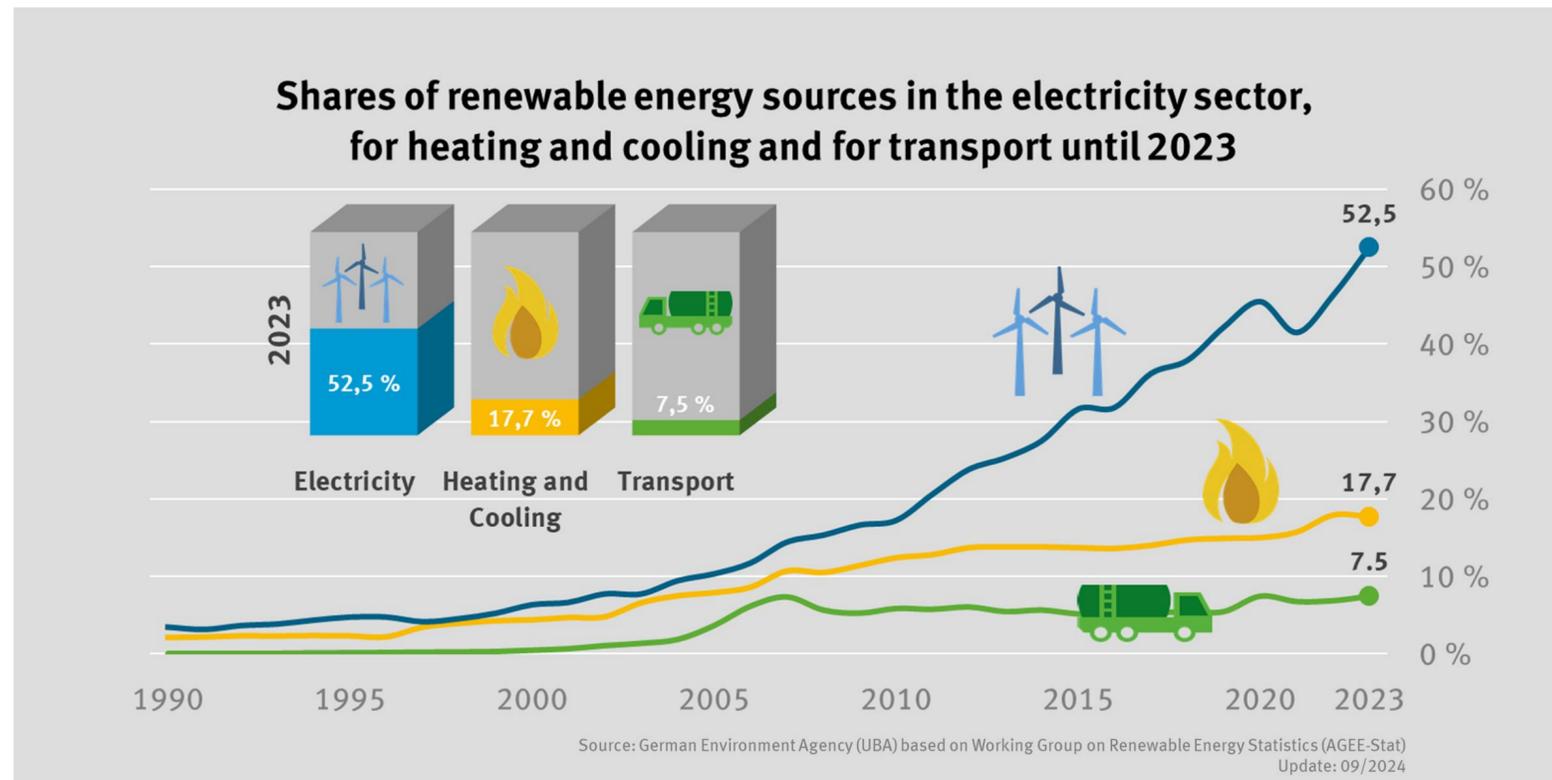
2,5 GW in 2022, 5,2 GW in 2023, 6.8 in 2024
In Germany (7 in 2022, 15 in 2023, 16.2 in 2024!!!!)

Non solo energia elettrica

Total Final Energy Consumption and Share of Modern Renewables, by Energy Carrier, 2021



REN21 RENEWABLES 2024 GLOBAL STATUS REPORT - ENERGY SUPPLY



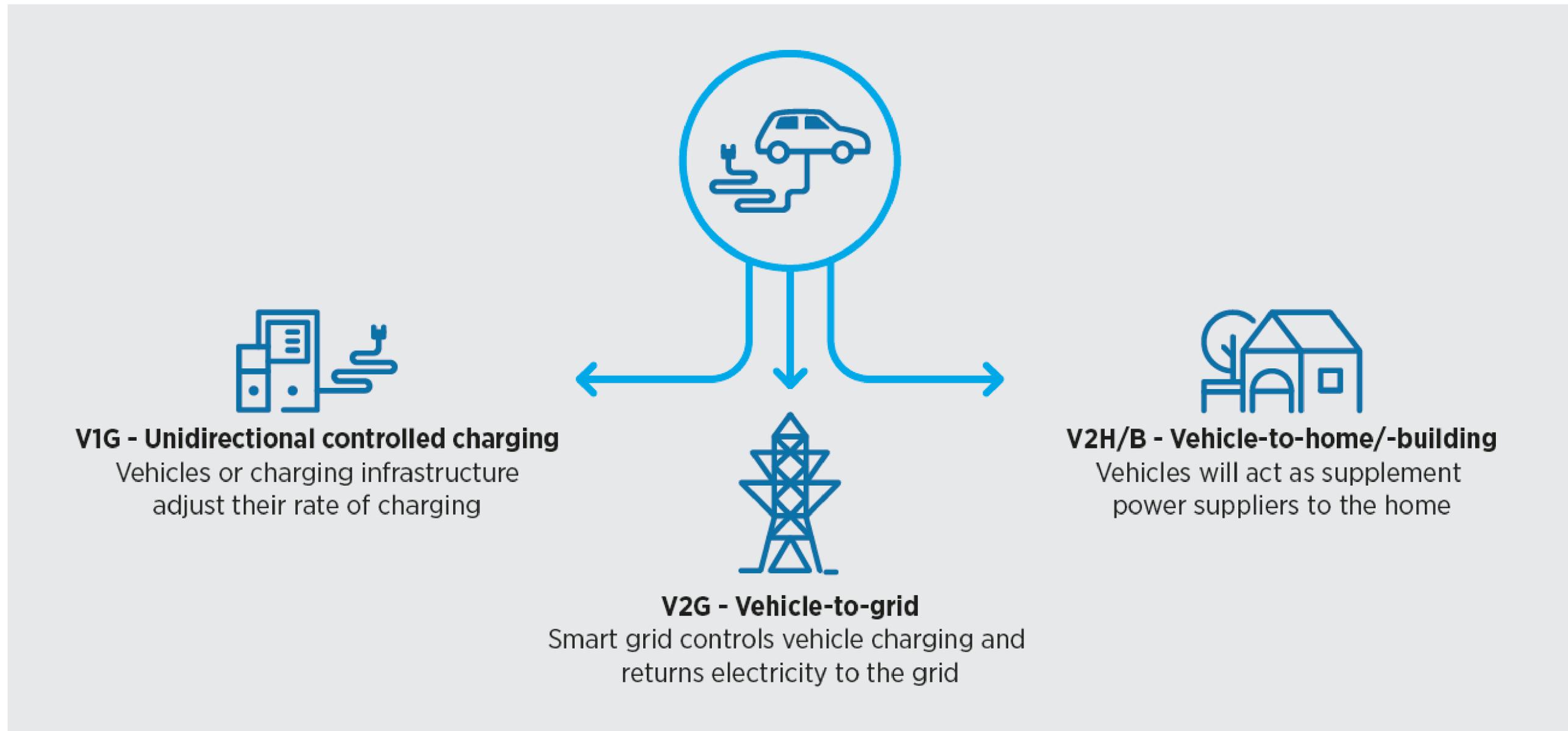
ITALIA

	2022	2030
FONTI PRIMARIE	22%	30%
ENERGIA ELETTRICA	39%	55%
CALORE	25%	34%
TRASPORTI	12%	22%

Smart grid & Mobility Lab @ UNITS



Figure 5 Forms of smart charging of electric vehicles

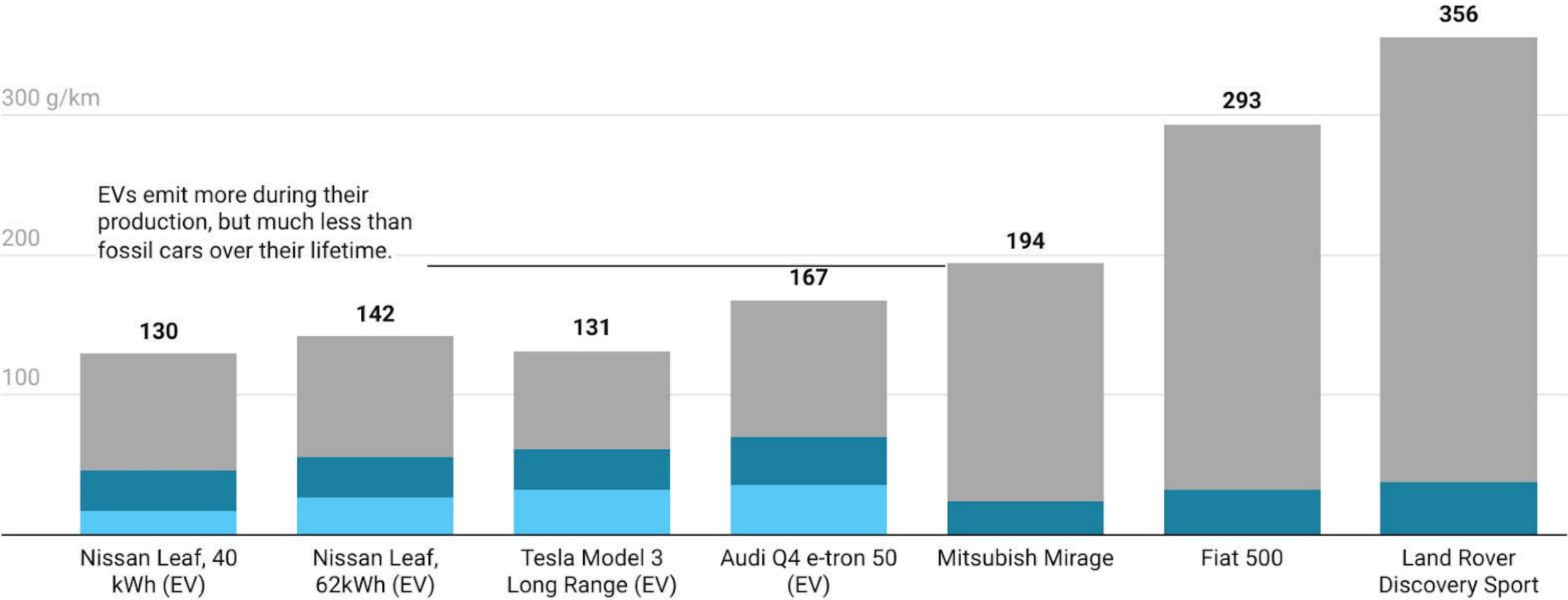


Source: IRENA (2019d)

Emissions of electric vehicles vs. fossil fuel cars, US average energy mix

Life-cycle emissions of electric vehicles (EVs) versus fossil fuel cars. This is based on production and fuelling of the car in the US. Emissions are measured in grams CO₂ per kilometer.

■ Battery production ■ Car production ■ Fuel and electricity



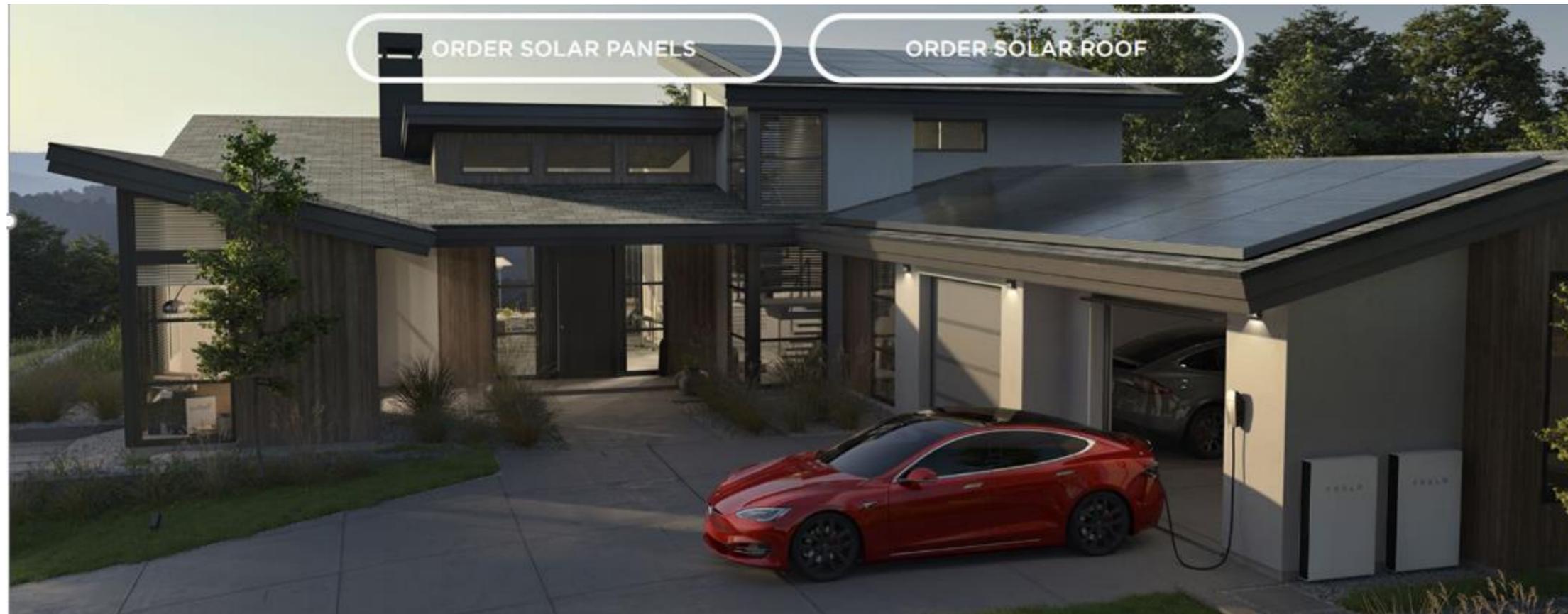
Assumes a mileage of 14,000 miles per year, which is the average in the US, and a car lifetime of 10 years.

Chart: Hannah Ritchie • Source: Based on data from CarbonCounter.com • Created with Datawrapper

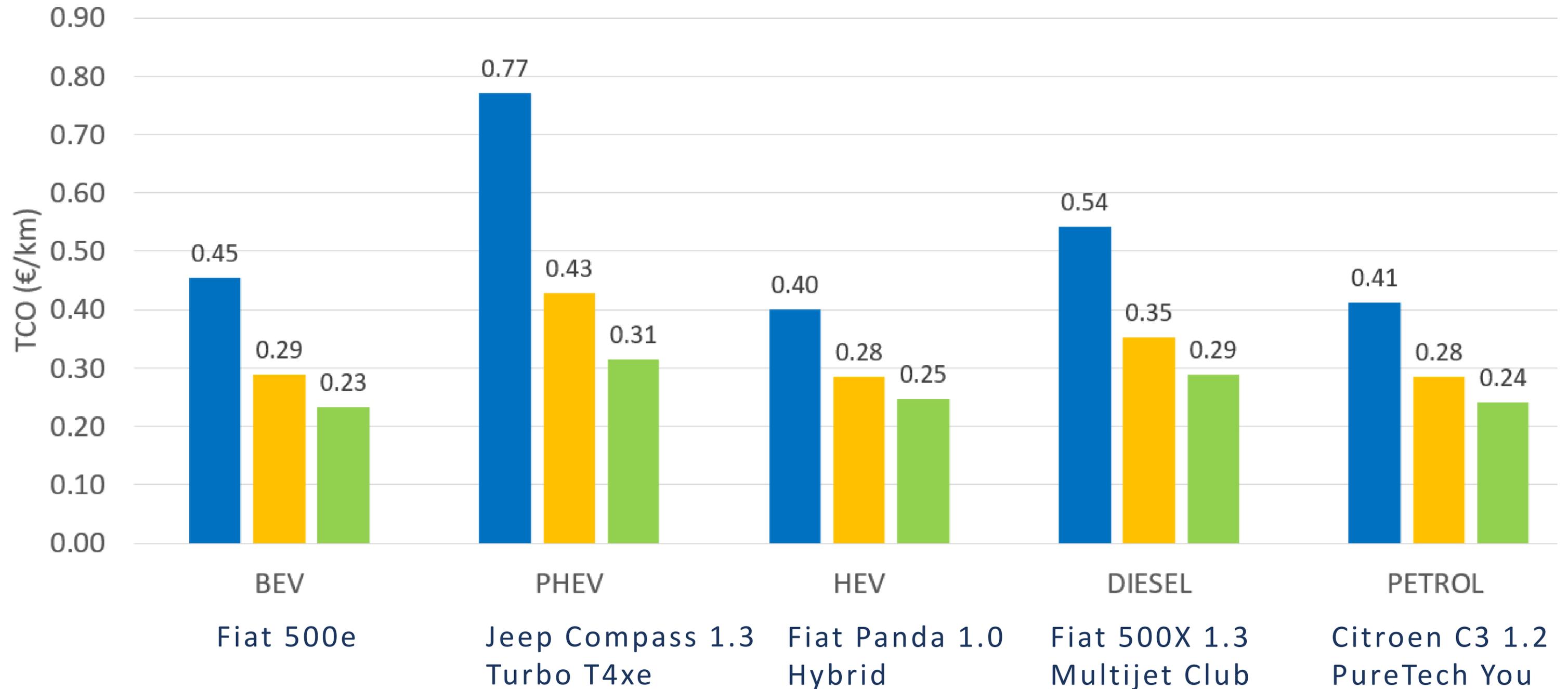
Un milione di case europee sono alimentate a batterie solari

SolarPower Europe pubblica gli ultimi dati sui sistemi a batteria connessi al fotovoltaico domestico. La capacità in Europa è quasi raddoppiata in un solo anno

8 Dicembre 2022

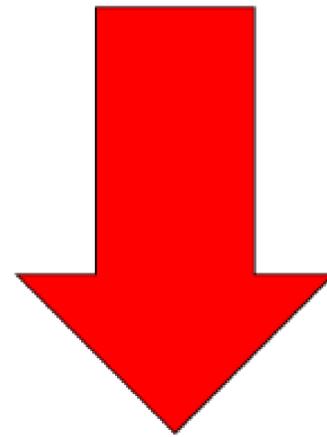


Total Cost of Ownership (TCO)

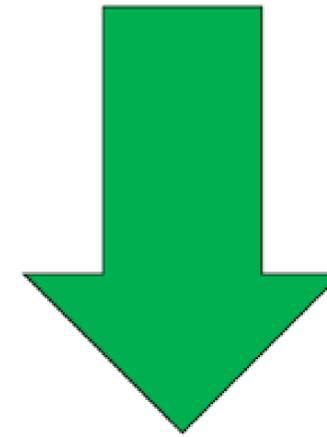


ELECTRIC MOBILITY SAVES (A LOT OF) ENERGY

35% of battery e (BEV) e plug-in hybrid (PHEV) in Italy



+ 30 TWh
electricity

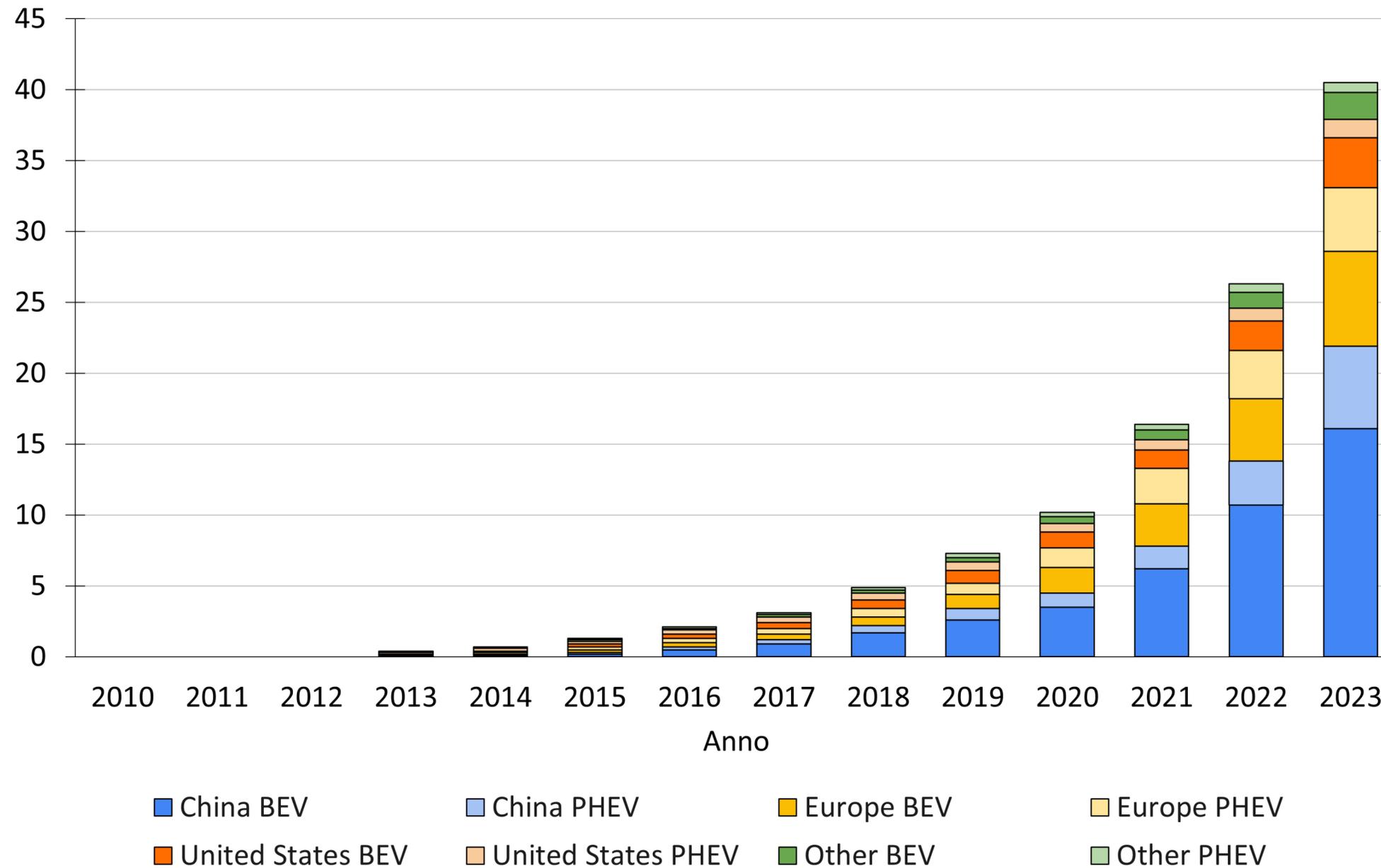


- 140 TWh
oil



Nicola Armaroli, CNR, Bologna – Summer School on Energy Giacomo Ciamician, Sesto, June 17th 2022

Mercato globale delle automobili elettriche

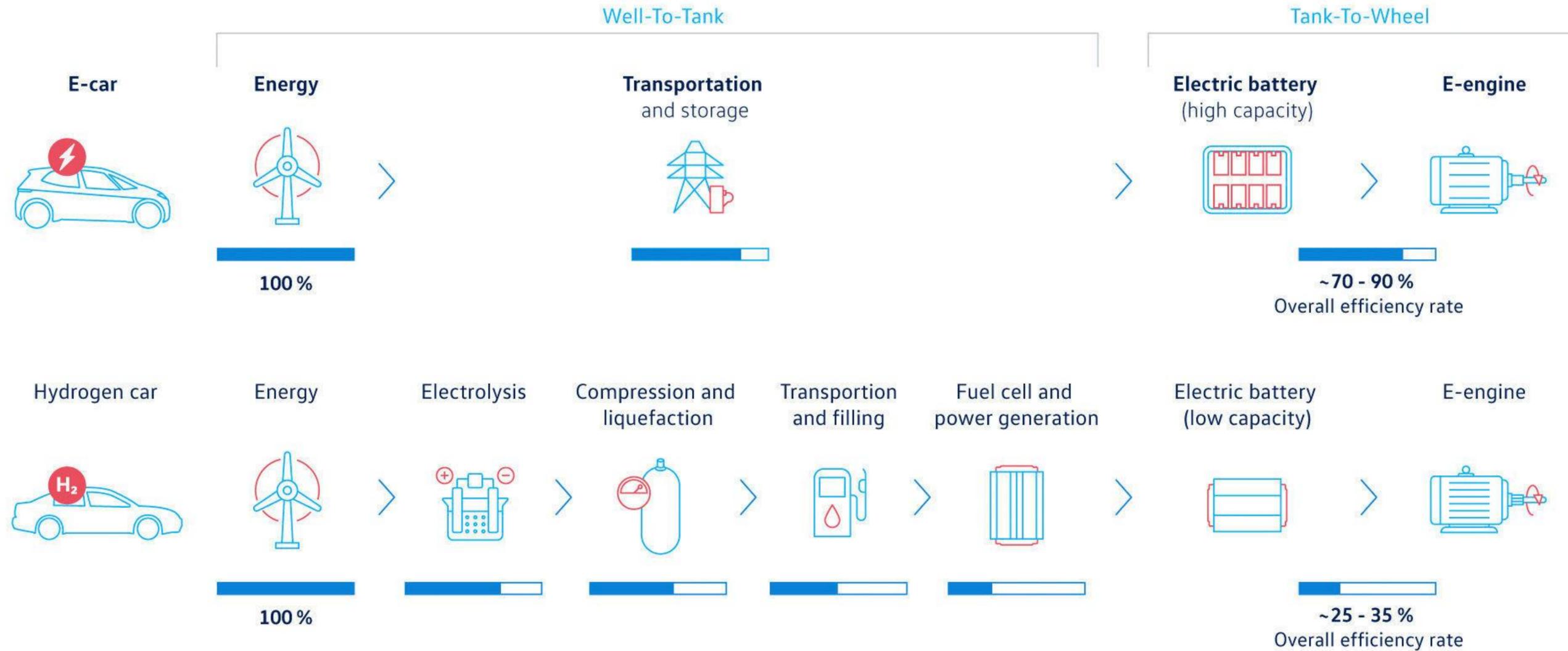


Top selling countries 2023

Country Region	Cumulative 2023	Annual sales 2023	Market Share 2023	Market Share 2022	Cars in use 2023	Cars in use 2022
China	21,800,000	8,095,078	38.0%	29.0%	7.6%	5.1%
Europe	11,200,000	3,016,880	21.0%	20.0%	3.8%	2.7%
US	4,800,000	1,390,000	9.5%	7.4%	2.1%	1.3%
Germany	2,500,000	699,943	24.0%	31.0%	5.4%	3.9%
France	1,570,000	470,000	25.0%	20.0%	4.1%	2.8%
UK	1,580,000	450,000	24.0%	23.0%	5.0%	2.9%
Norway	900,000	110,000	93.0%	89.0%	29.0%	26%
Netherlands	700,000	210,000	44.0%	35.0%	8.3%	6.0%
Sweden	560,000	171,000	60.0%	54%	11.0%	8.7%
Italy	302,000	136,000	9.2%	8.6%	1.3%	0.9%
Global	40,000,000	13,800,000	18.0%	14%	3.2%	2.1%

Hydrogen and electric drive

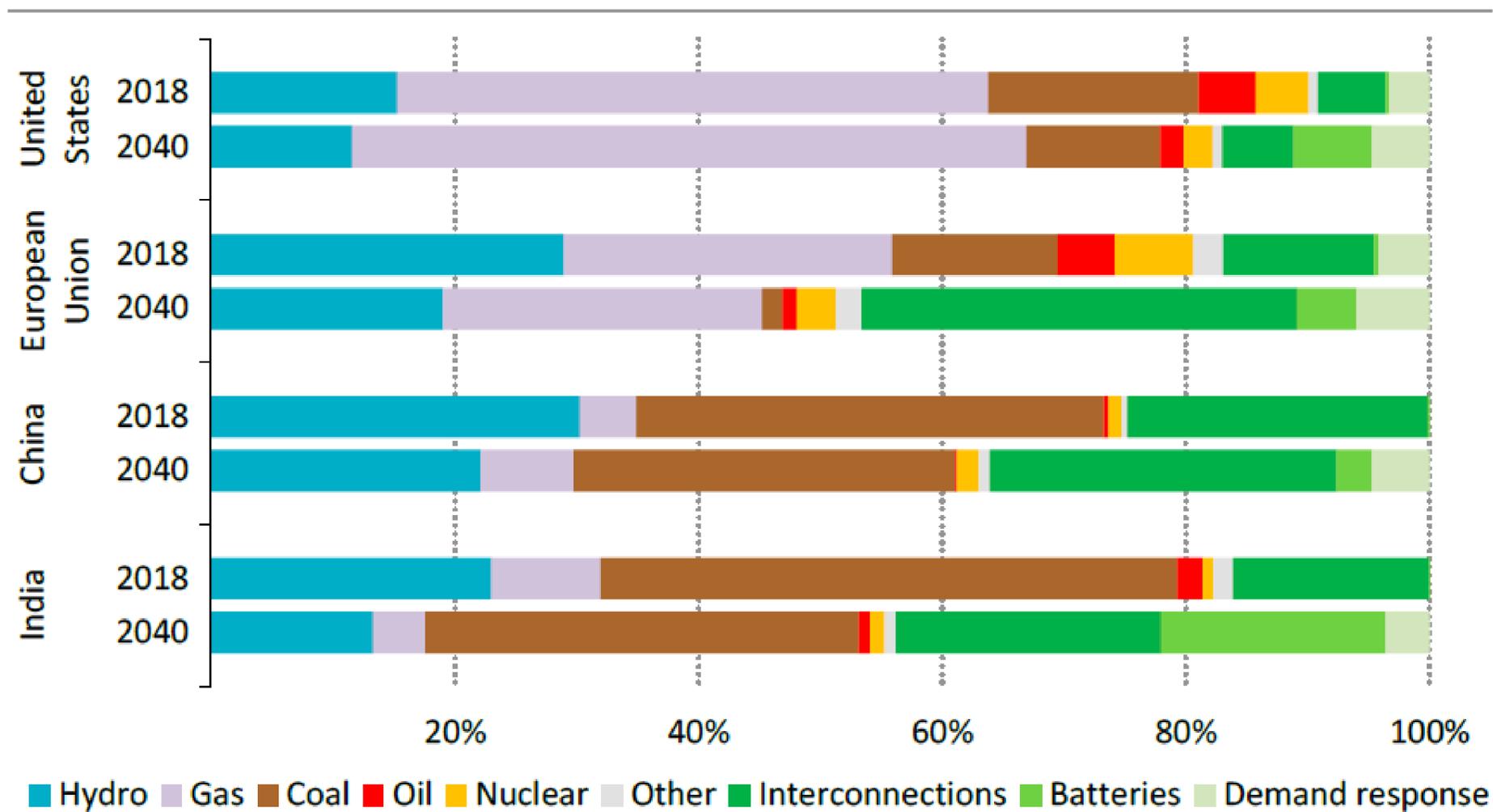
Efficiency rates in comparison using eco-friendly energy



Source Volkswagen

Ma le fonti rinnovabili non sono intermittenti!?!

Figure 6.22 ▸ Sources of flexibility by region in the Stated Policies Scenario



Thermal power plants continue to provide the bulk of flexibility needs, along with interconnections, but batteries and demand-side response are rising fast

Certo, ma il sistema elettrico è flessibile!!!



Tecnologie abilitanti la transizione 100% rinnovabile

- Fotovoltaico ed eolico sovradimensionati
- Interconnessioni
- Demand response
- Sistemi di stoccaggio (batterie, idroelettrico, termico, ...)
- Elettrolizzatori e celle a combustibile (idrogeno)
- Vehicle-to-grid (V2G) and Vehicle-to-home (V2H)
- Corrente continua e generazione distribuita
- Smart Grid (previsione della produzione e dei consumi)
- Trasformazione digitale (IoT, Big data, Block Chain, 5G, ...)
- Nano e microreti
- Comunità energetiche
- W la ricerca!!

Ritorno alla corrente continua



gheginonline.it



Ritorno alla corrente continua



Baker Electric Vehicles

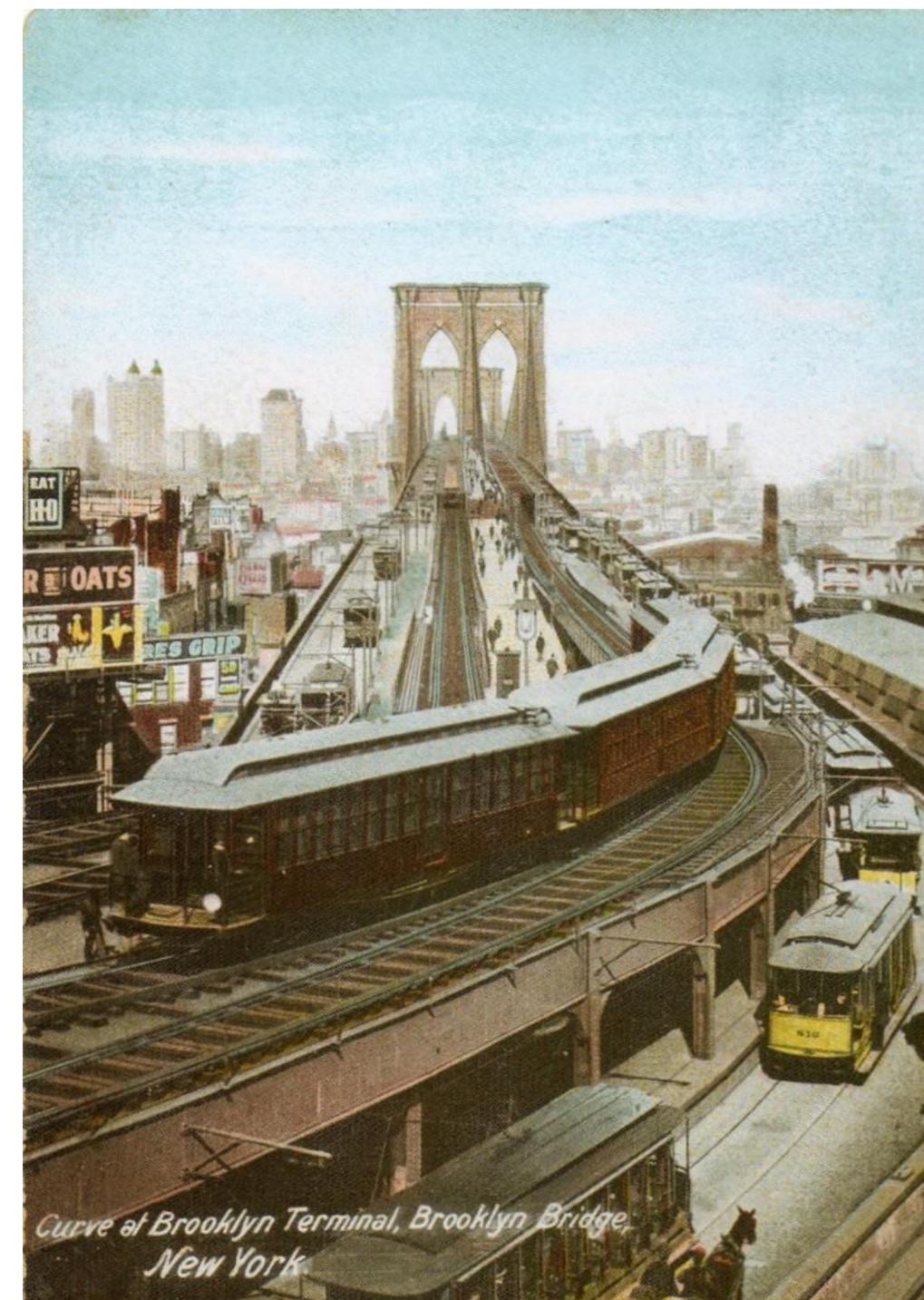
The Aristocrats of Motordom

gettyimages
Stock Montage

The Electric Sensation of 1909
The Baker Electric Runabout has unusual speed and a mileage capacity of one hundred miles. It is swift, noiseless, and easy of control in congested streets.

The Ideal Car for Professional and Business Men
Our catalogue describing our latest models of Baker Electric Runabouts, Victorias, Coupés, Roadsters, Broughams, Landaulets, etc., mailed on request.

THE BAKER MOTOR VEHICLE COMPANY, 33 W. 80TH ST., CLEVELAND, OHIO.
Agencies in the principal cities.



La guerra delle correnti

THE CURRENT WAR

THE TALE OF AN EARLY TECH RIVALRY

DC

DIRECT CURRENT

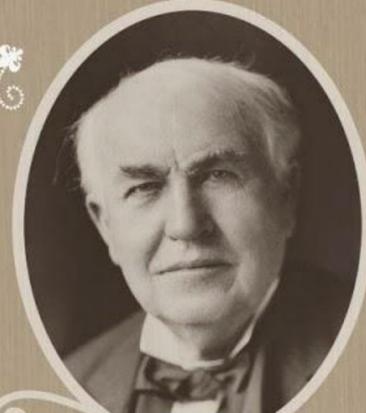
The flow of electricity is in one direction only. The system operates at the same voltage level throughout and is not as efficient for high-voltage, long distance transmission.

Direct current runs through:

 Battery-Powered Devices
  Fuel and Solar Cells
  Light Emitting Diodes

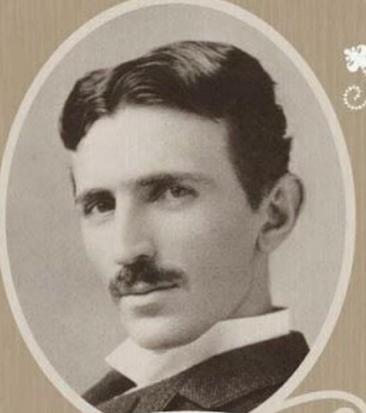
"[TESLA'S] IDEAS ARE SPLENDID, BUT THEY ARE UTTERLY IMPRACTICAL."

- THOMAS EDISON



THOMAS EDISON

VS.



NIKOLA TESLA

You would have never found two geniuses so spiteful of each other beyond turn-of-the-century inventors Nikola Tesla and Thomas Edison. They worked together—and hated each other. Let's compare their life, achievements, and embittered battles.

AC

ALTERNATING CURRENT

Electric charge periodically reverses direction and is transmitted to customers by a transformer that could handle much higher voltages.

Alternating current runs through:

 Car Motors
  Radio Signals
  Appliances

"IF EDISON HAD A NEEDLE TO FIND IN A HAYSTACK, HE WOULD PROCEED AT ONCE... UNTIL HE FOUND THE OBJECT OF HIS SEARCH. I WAS A SORRY WITNESS OF SUCH DOINGS, KNOWING THAT A LITTLE THEORY AND CALCULATION WOULD HAVE SAVED HIM 90 PERCENT OF HIS LABOR."

- NIKOLA TESLA

1847 BORN 1858

Milan, Ohio	BIRTHPLACE	Smiljan, Croatia
Wizard of Menlo Park	NICKNAME	Wizard of the West
Home-schooled and self-taught	EDUCATION	Studied math, physics, and mechanics at The Polytechnic Institute at Graz
Mass communication and business	FORTE	Electromagnetism and electromechanical engineering
Trial and error	METHOD	Getting inspired and seeing the invention in his mind in detail before fully constructing it

DC (Direct Current) WAR OF CURRENTS: ELECTRICAL TRANSMISSION IDEA AC (Alternating Current)

Incandescent light bulb; phonograph; cement making technology; motion picture camera; DC motors and electric power	NOTABLE INVENTIONS	Tesla coil - resonant transformer circuit; radio transmitter; fluorescent light; AC motors and electric power generation system
1,093	NUMBER OF US PATENTS	112
0	NUMBER OF NOBEL PRIZES WON	0
1	NUMBER OF ELEPHANTS ELECTROCUTED	0

1931—Passed away peacefully in his New Jersey home, surrounded by friends and family	DEATH	1943—Died lonely and in debt in Room 3327 at the New Yorker Hotel
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TESLA: MAN OUT OF TIME | WIRTH, ROBERT. "TESLA: MASTER OF LIGHTNING." | THOMASEDISON.COM | PBS.ORG | WEB.MIT.EDU | WIRED.COM

WAR OF CURRENTS OFFICIALLY SETTLED

In 2007, Con Edison ended 125 years of direct current electricity service that began when Thomas Edison opened his power station in 1882. It changed to only provide alternating current.

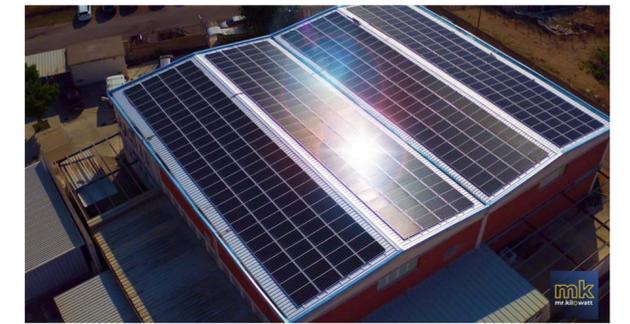
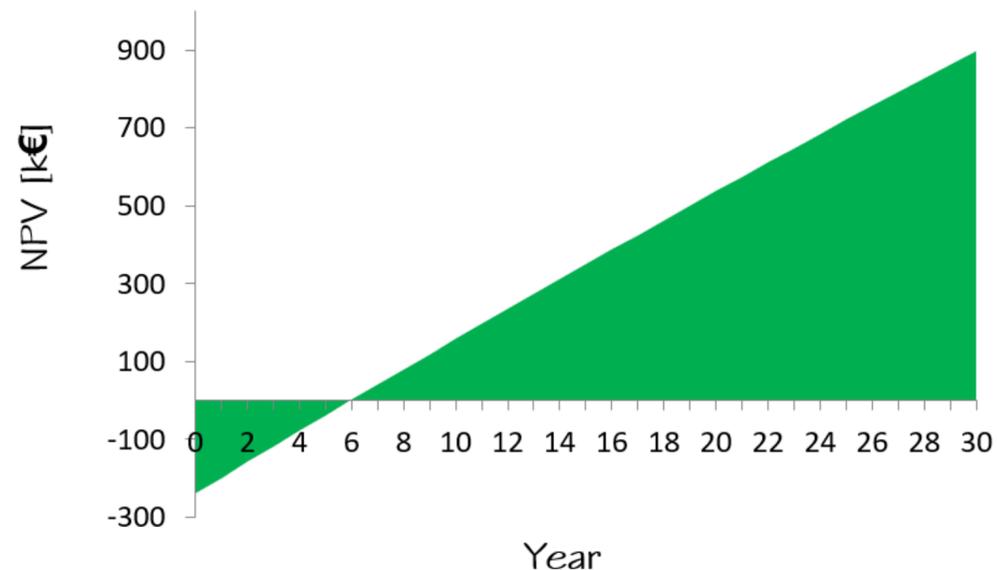
NOBEL PRIZE CONTROVERSY

In 1915, both Edison and Tesla were to receive Nobel Prizes for their strides in physics, but ultimately, neither won. It is rumored to have been caused by their animosity towards each other and refusal to share the coveted award.

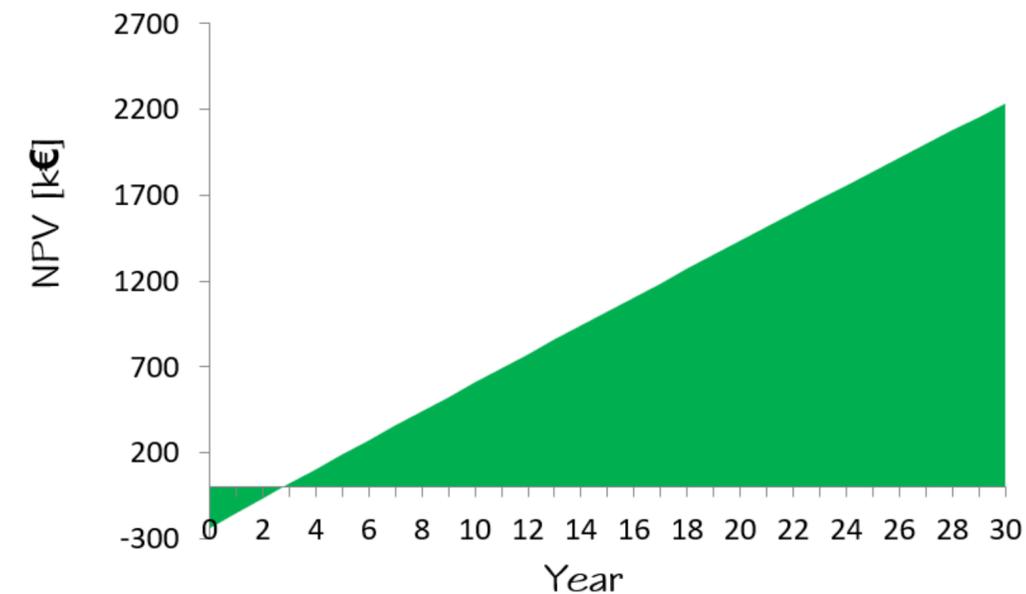


Il ruolo dell'autoconsumo

- Potenza 200 kWp
- Autoconsumo 100%
- Prezzo energia elettrica **0.15 €/kWh**
- Costo energia fotovoltaica 0.04 €/kWh
- Tempo di ritorno 5.5 anni
- Rendimento investimento 16%

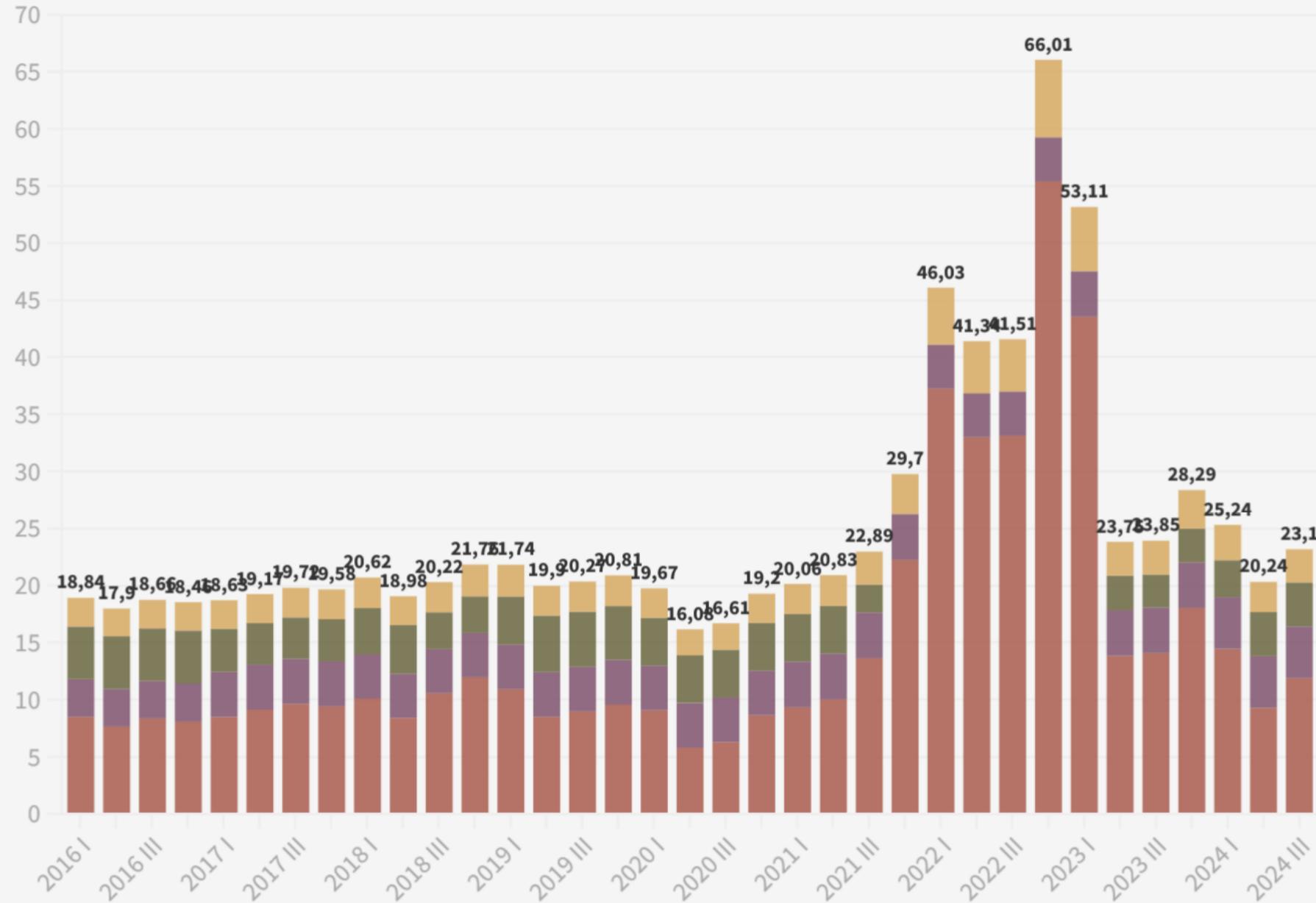


- Potenza 200 kWp
- Autoconsumo 100%
- Prezzo energia elettrica **0.30 €/kWh**
- Costo energia fotovoltaica 0.04 €/kWh
- Tempo di ritorno 2.8 anni
- Rendimento investimento 35%



Il ruolo dell'autoconsumo

Prezzo complessivo dell'energia elettrica
con consumo annuo di 2700 kWh



■ spesa per la materia energia
 ■ spesa per il trasporto e la gestione del contatore
■ spesa per oneri di sistema
 ■ imposte



ARERA
Autorità di Regolazione per Energia Reti e Ambiente



Comunità energetiche rinnovabili



Gruppo associato di consumatori di energia elettrica che producono **localmente** energia da **fonti rinnovabili** «condividendola» per il proprio fabbisogno

Scopo principale è fornire **benefici ambientali, economici e/o sociali** a livello della comunità

L'energia condivisa tra i membri viene incentivata attraverso un **contributo economico**

Gruppi di autoconsumatori



Gruppo associato di consumatori di energia elettrica che producono **localmente** energia da **fonti rinnovabili** «condividendola» per il proprio fabbisogno

Scopo principale è fornire **benefici ambientali, economici e/o sociali** a livello della comunità

L'energia condivisa tra i membri viene incentivata attraverso un **contributo economico**

Zero energy houses



Ecolibera®

- Fotovoltaico
- Pompa di calore (geotermica)
- Batteria
- Wallbox
- Solare termico
- Cappotto
- No gas

Nuclear

- On paper is the perfect solution: no CO2 emissions
- Out of control **costs** increase. In UK, France and Finland quadrupled
- Not a single nuclear plant managed to repay its costs with the sale of electricity
They survive only because of the tax payers and their children (to dismantle)
- They were supposed to be accident proof but then ... human error in Chernobyl and tsunami in Fukushima (200G\$)
- War scenarios: when they saw a tank in Ukraine they searched for the war scenario in the protocol but there was none. The next plants will need to take this into account and the costs will increase further
- **Timing**: in Finland the last nuclear plant was supposed to grid-connect in 2005 but it only happened at the end of 2022
- Very low **social acceptance**