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**

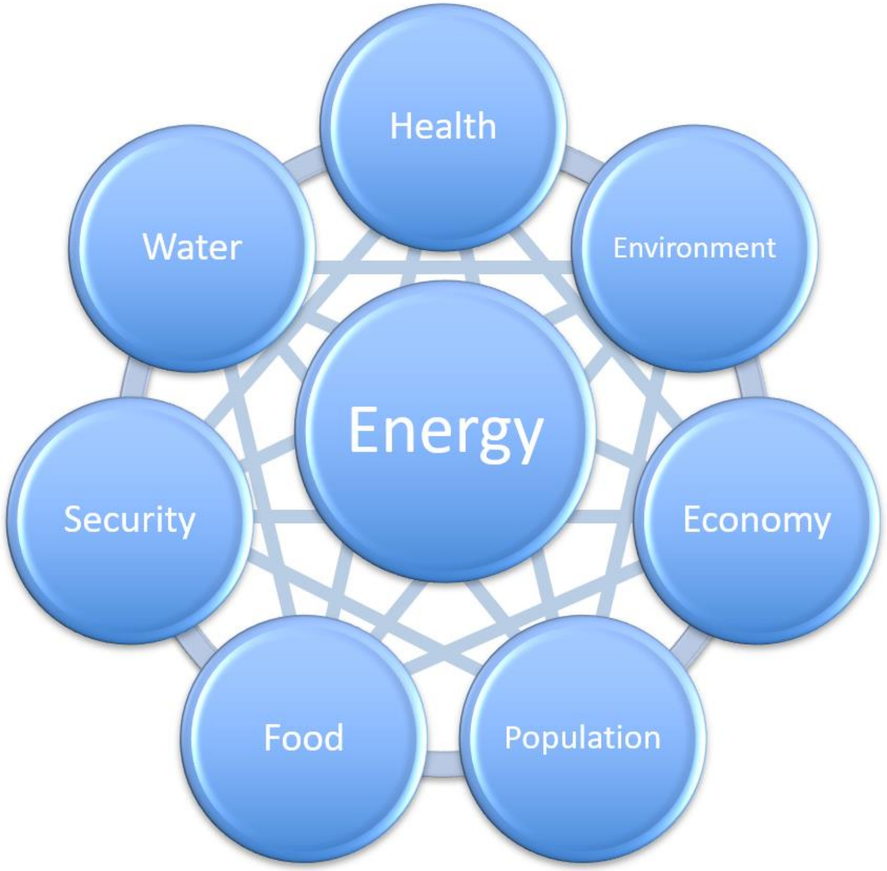
  sempre più spinta dei consumi energetici
- Sempre più utilizzatori sono elettrici:

  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



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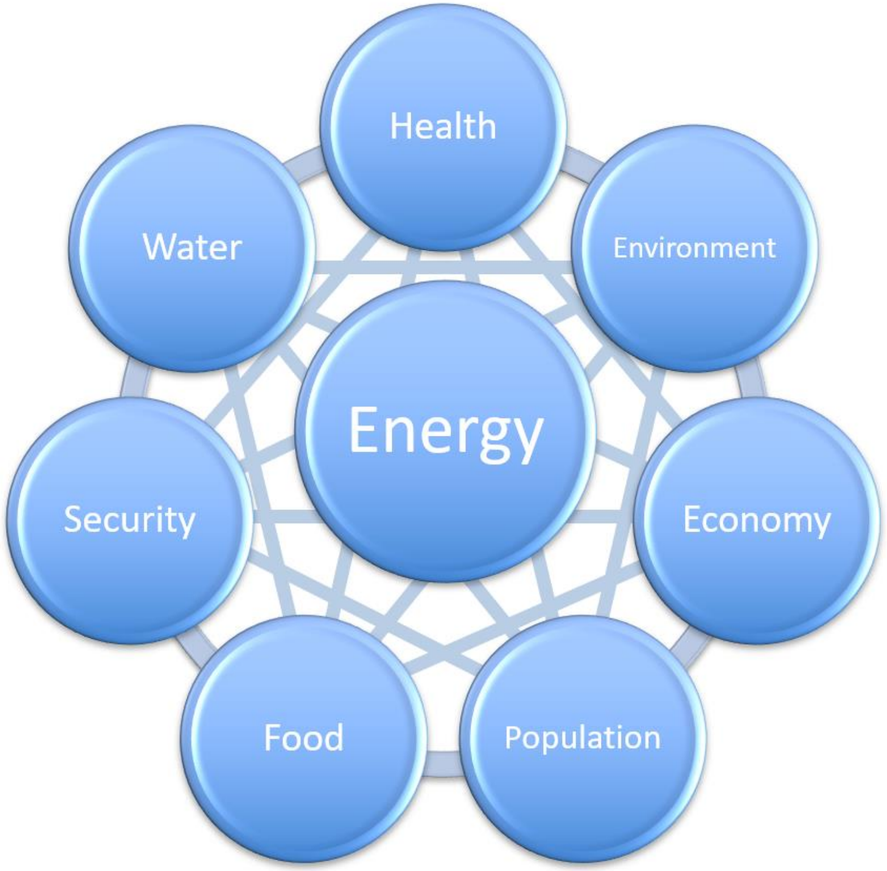

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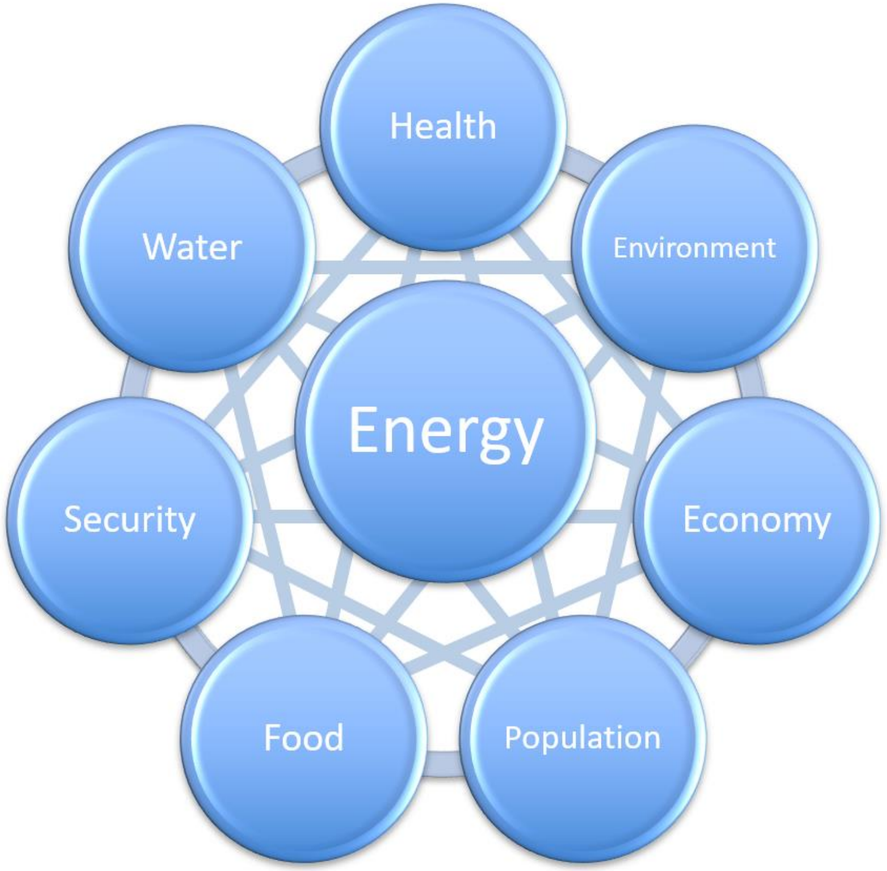
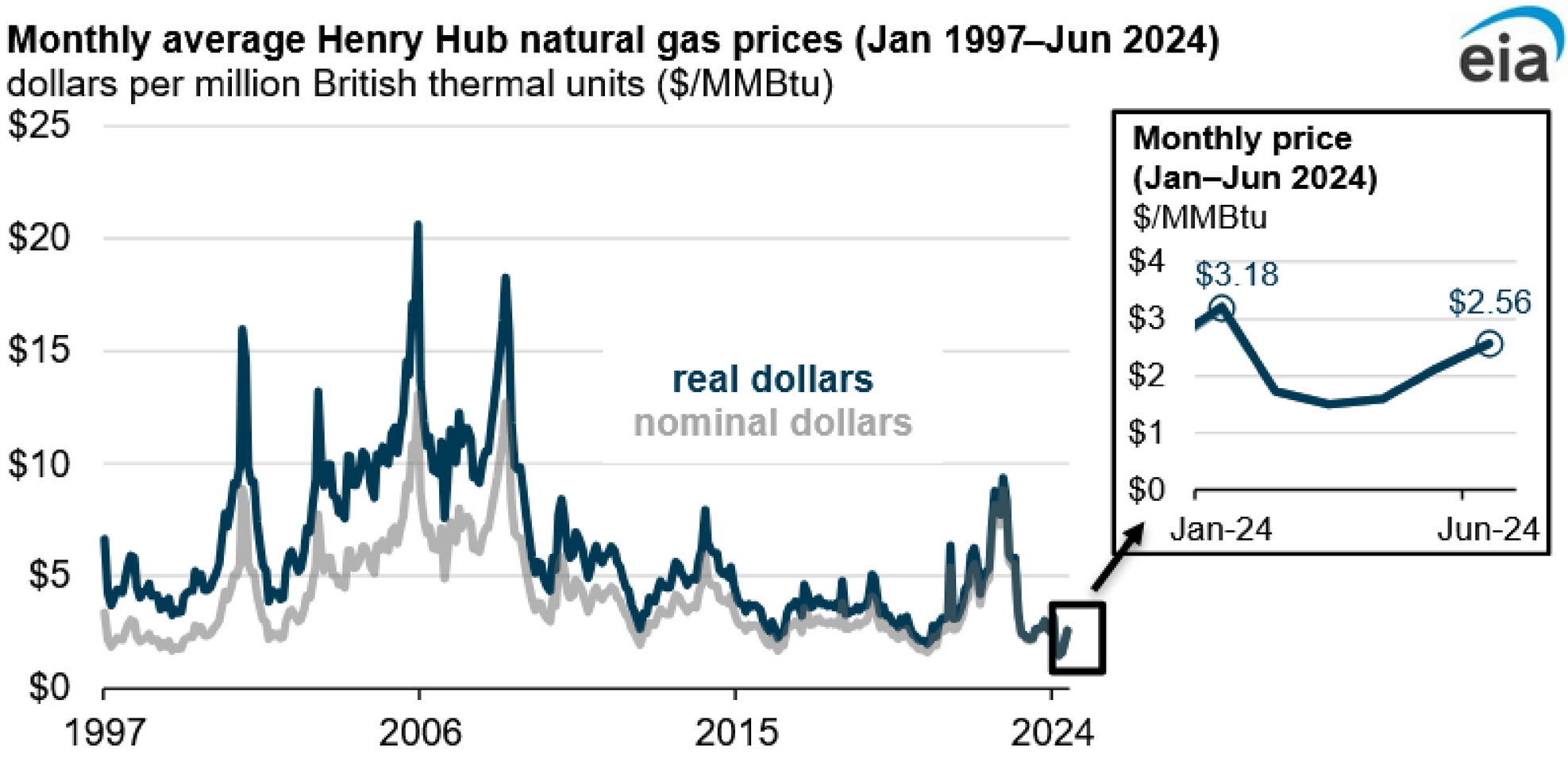
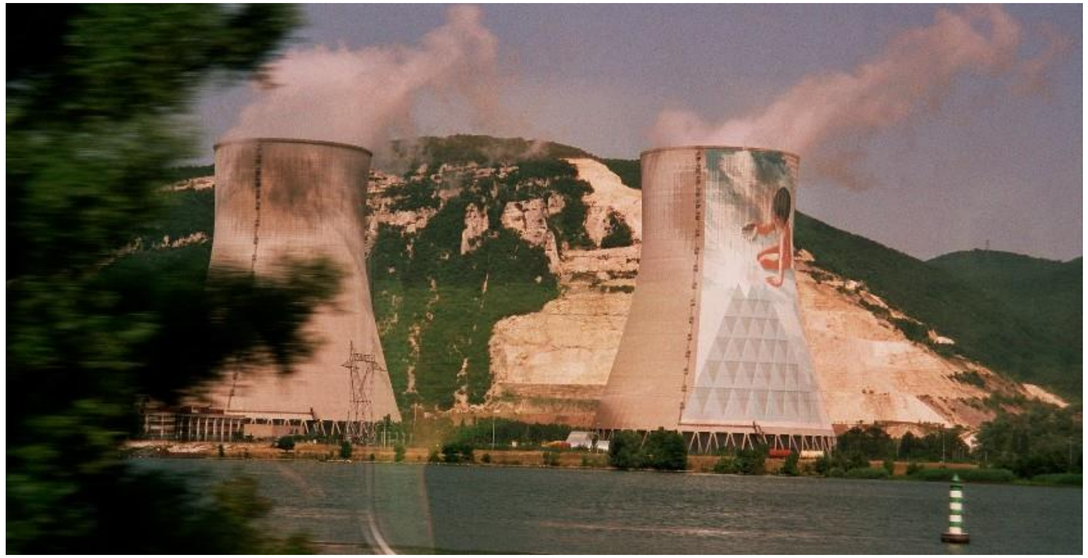


La crisi del sistema energetico



La crisi del sistema energetico

Climate change, water scarcity jeopardizing French nuclear fleet

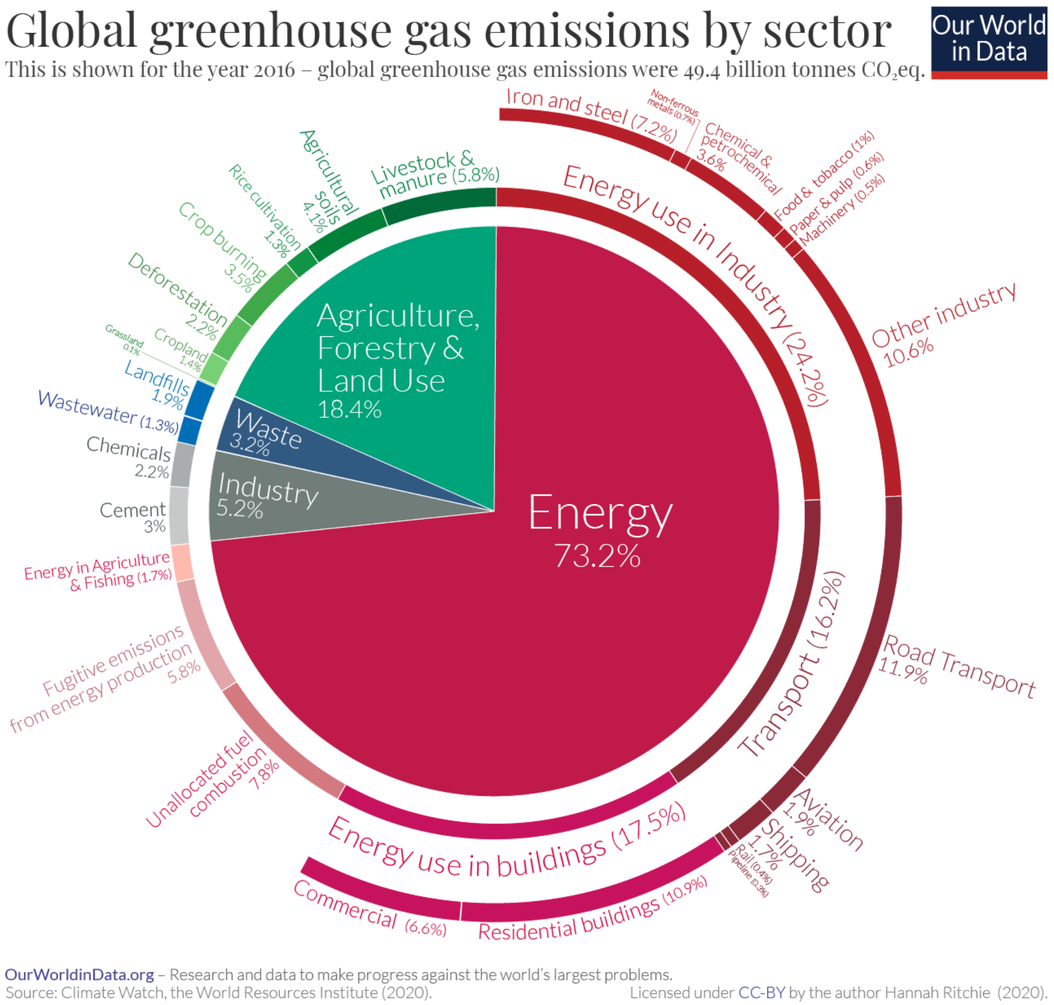


PRODUZIONE IDROELETTRICA ITALIA	
ANNO	ENERGIA [TWh]
2015	46
2018	49
2021	45
2022	28
2023	41

China's Hydro Power Crisis Is Just the Start

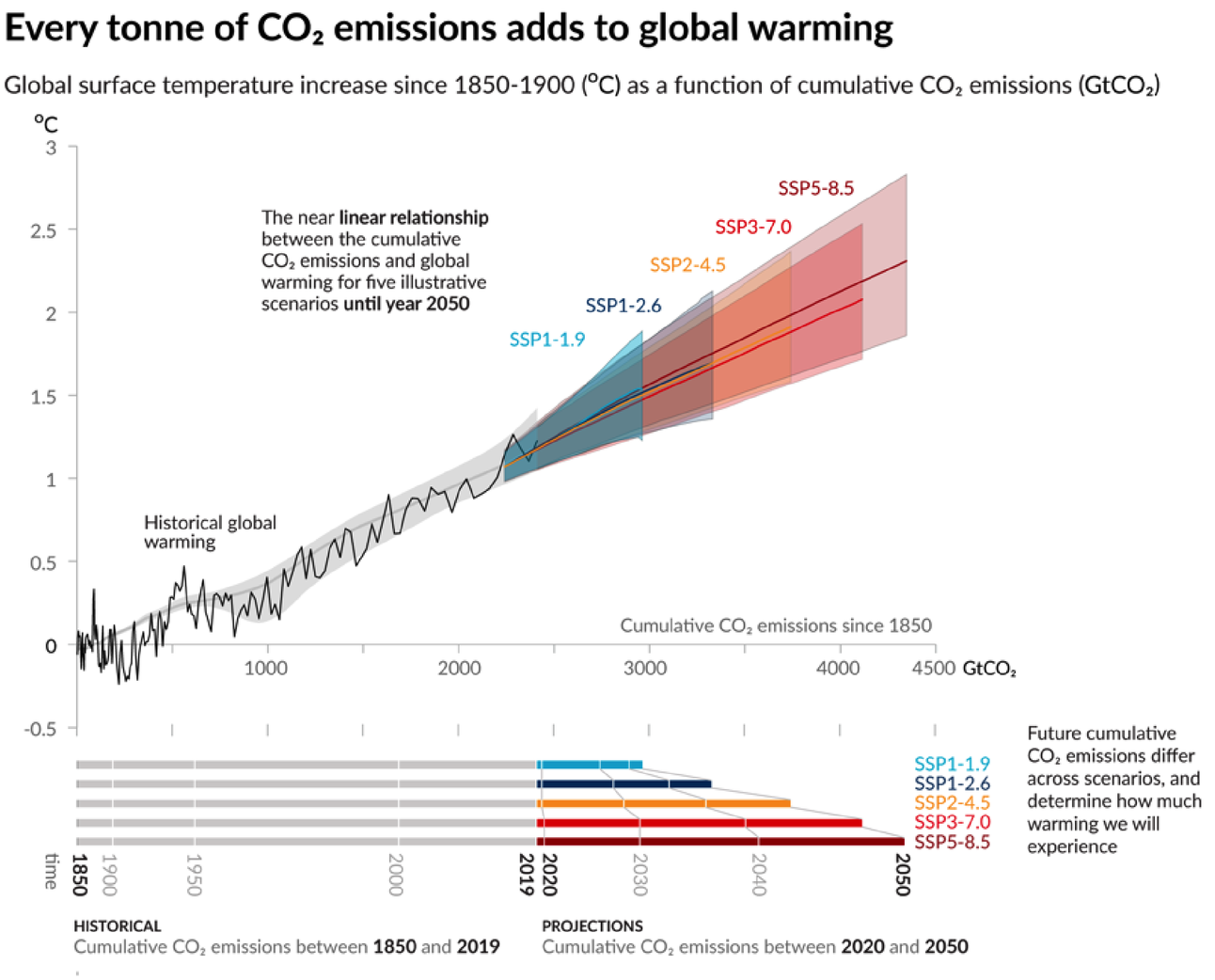
Climate-fueled droughts could make climate change even worse. Plus, more of the week's top opinions.

Il grande emettitore di gas serra

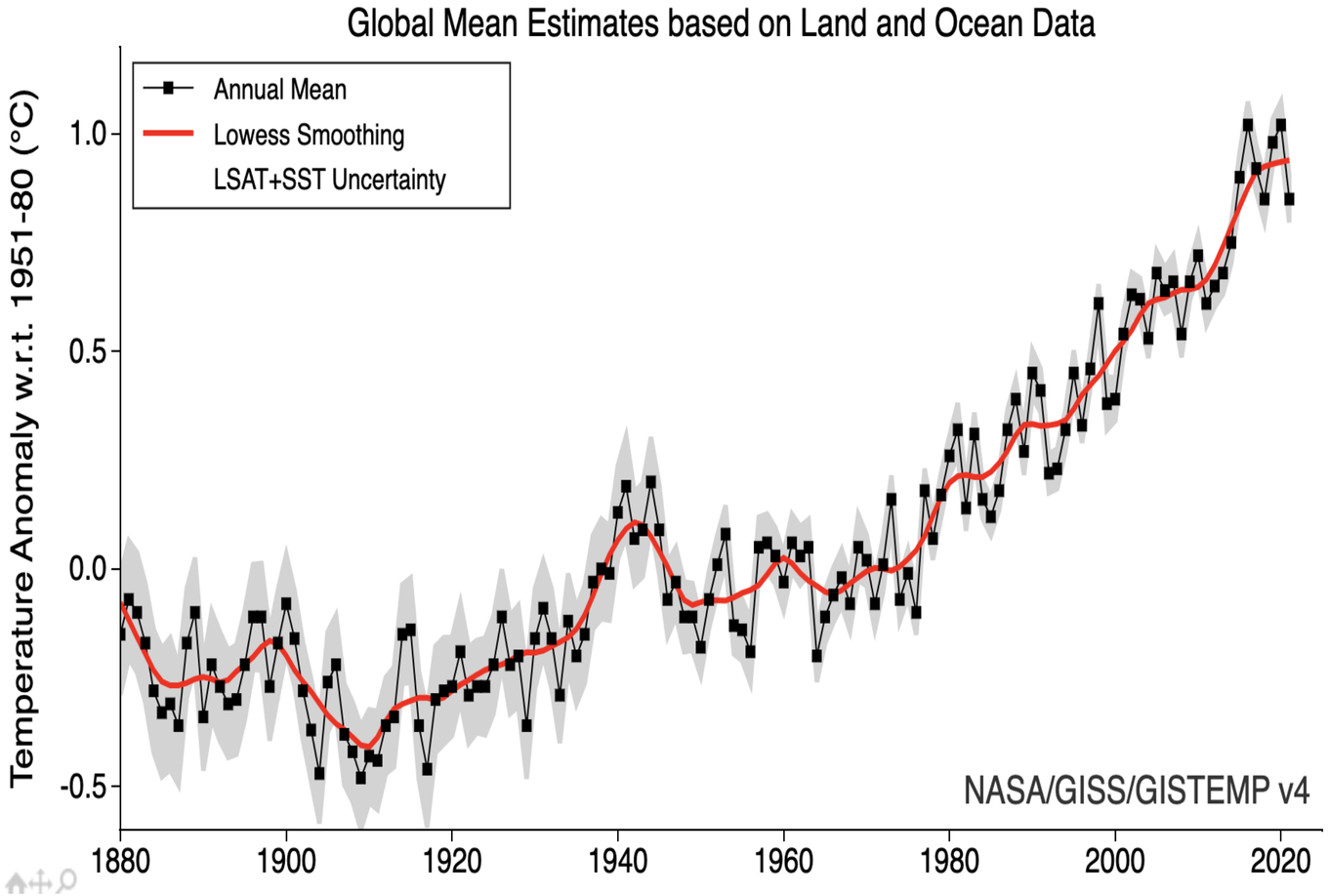


Il sistema energetico basato sull'uso dei combustibili fossili è il principale **emettitore di gas serra** e responsabile del **riscaldamento globale di origine antropica** e dei conseguenti **cambiamenti climatici**

Riscaldamento globale

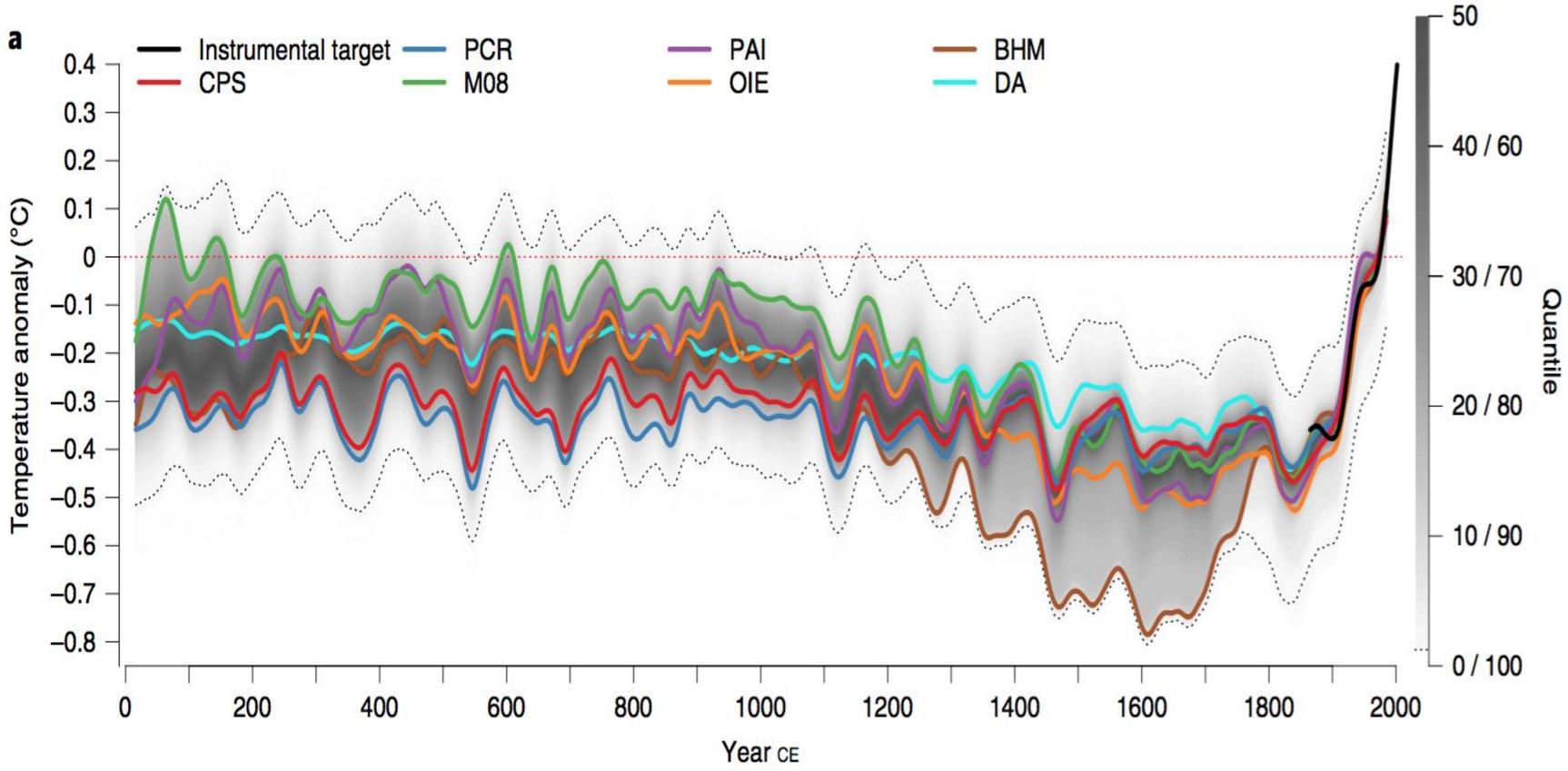


Riscaldamento globale



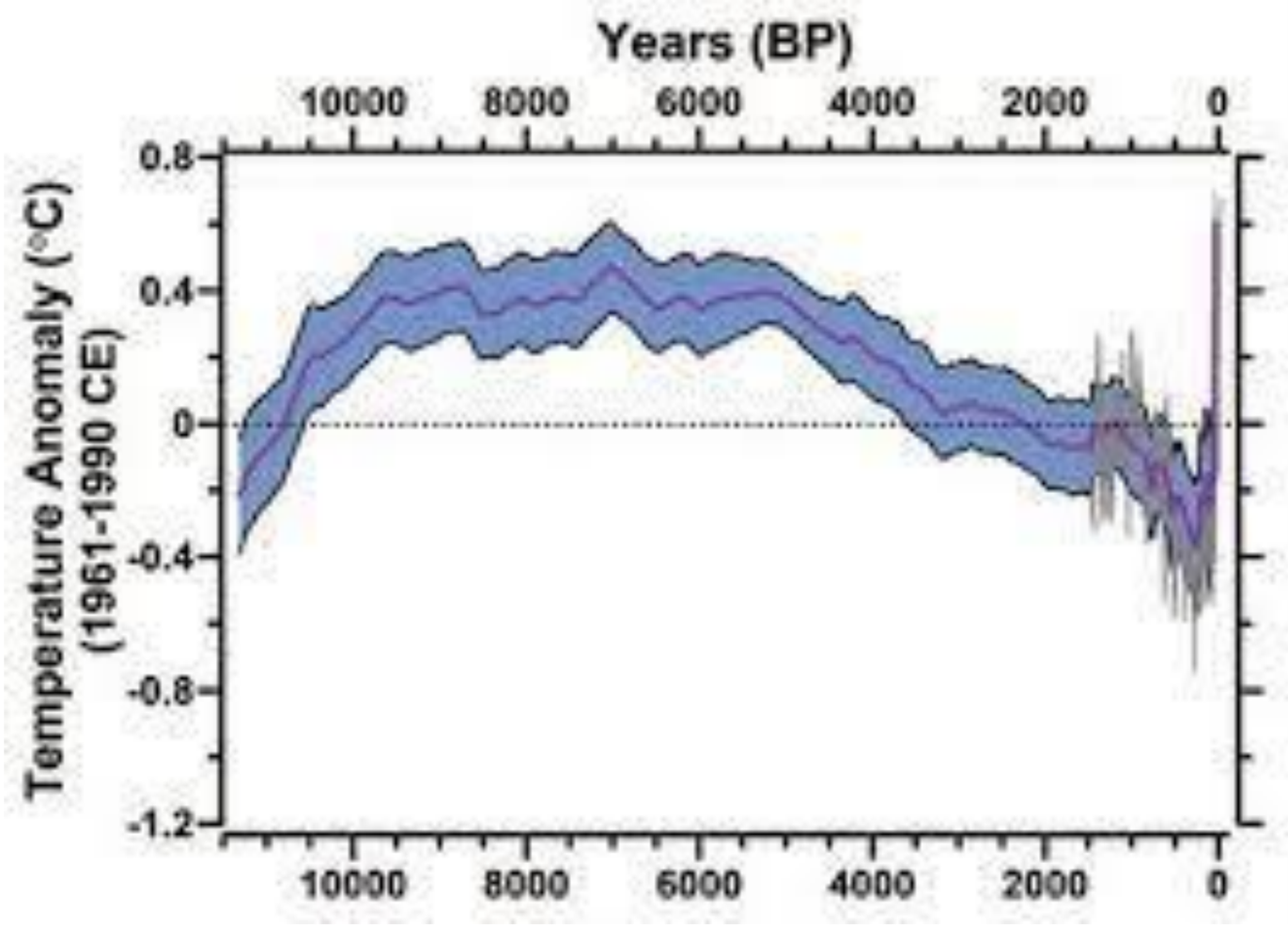
- + 1.1 ° C in 120 anni
- L'ultimo decennio è stato il più caldo mai registrato
- Il 2024 l'anno più caldo

Riscaldamento globale

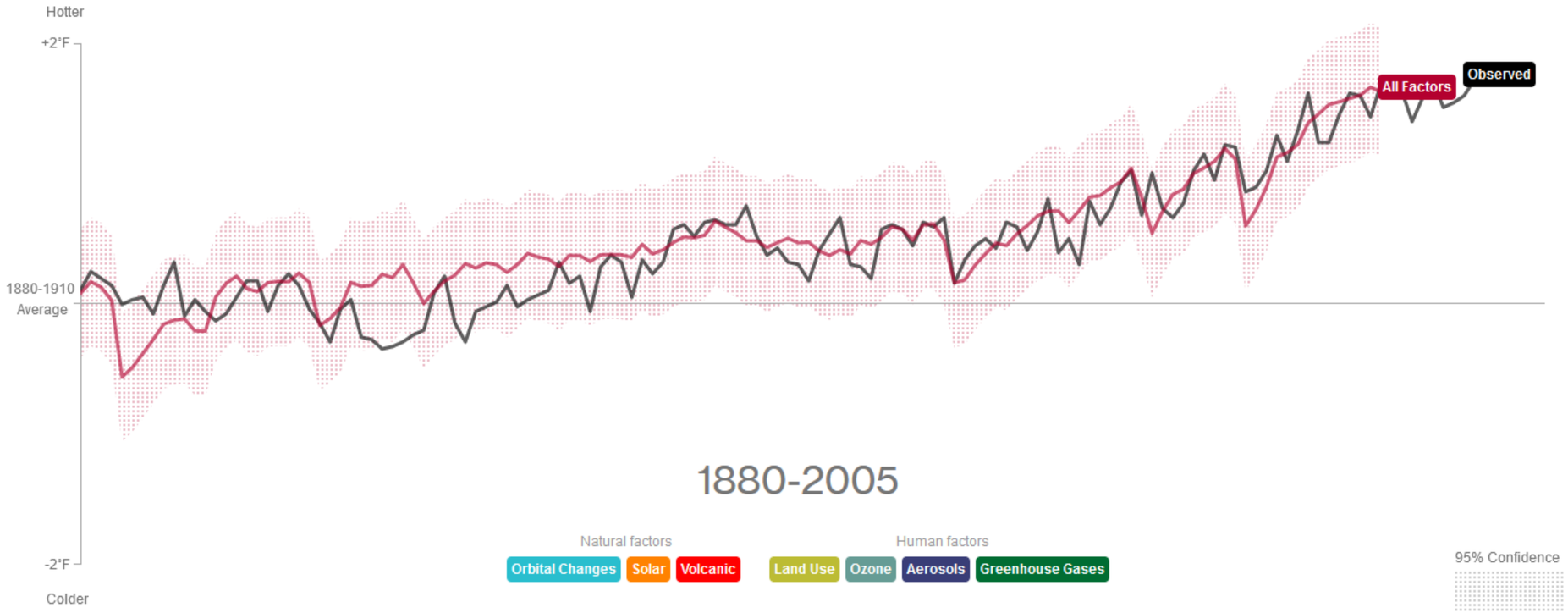


Pages2k
Nature Geoscience 2019

Riscaldamento globale

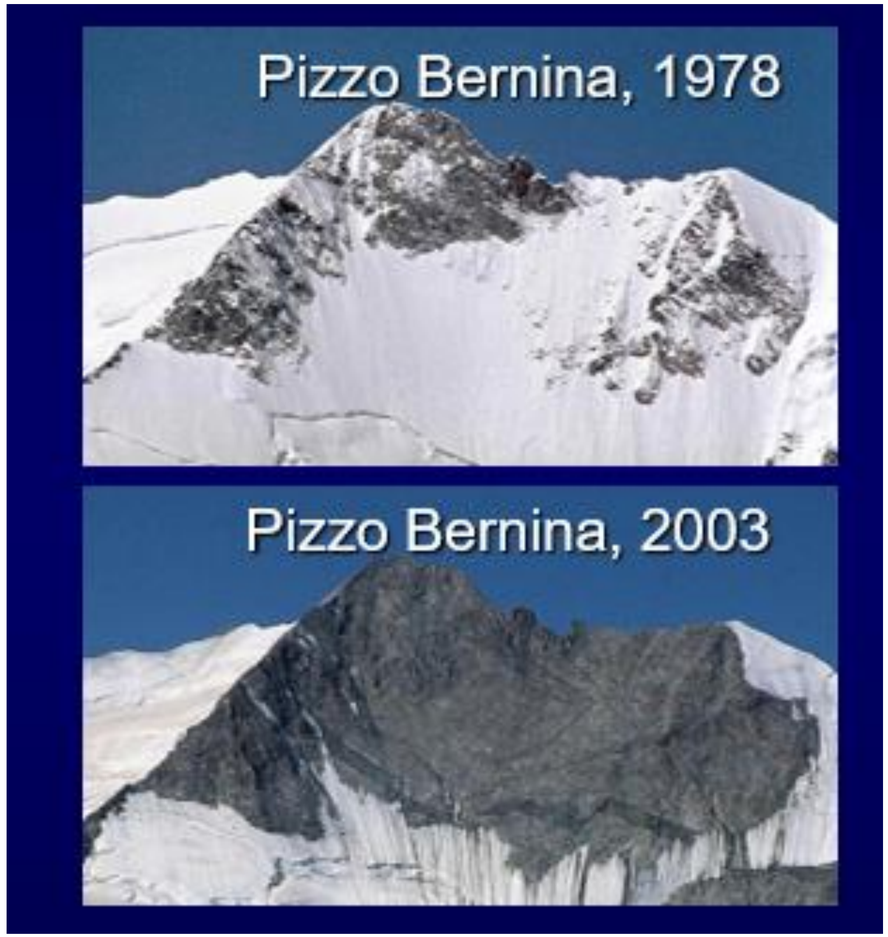


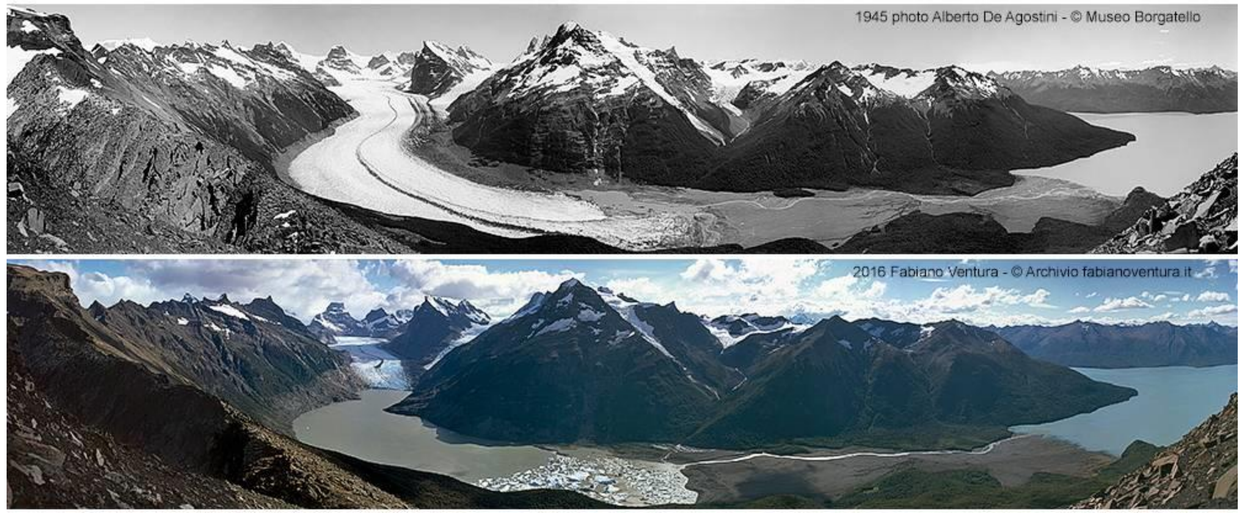
Ma cosa sta realmente scaldando il pianeta?

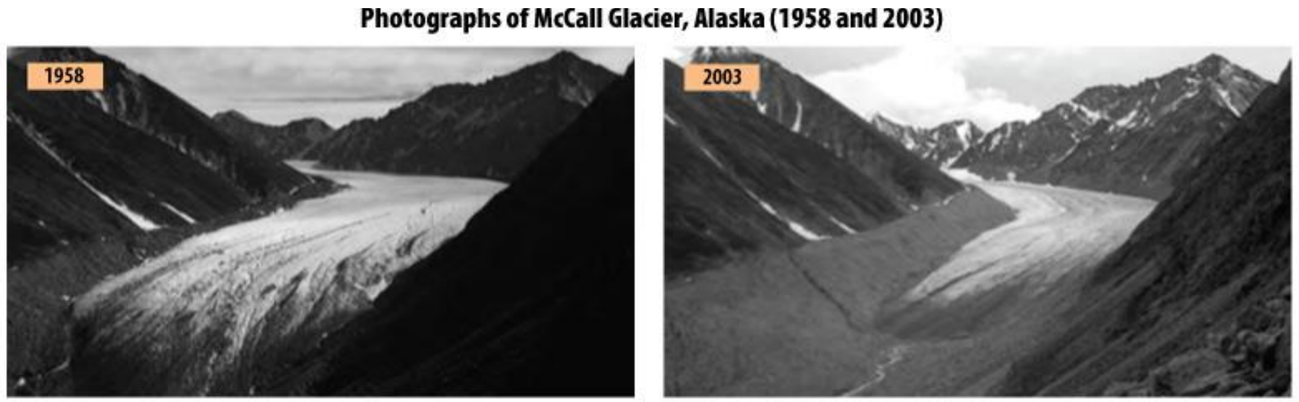


https://www.bloomberg.com/graphics/2015-whats-warming-the-world/

Conseguenze: scioglimento dei ghiacciai

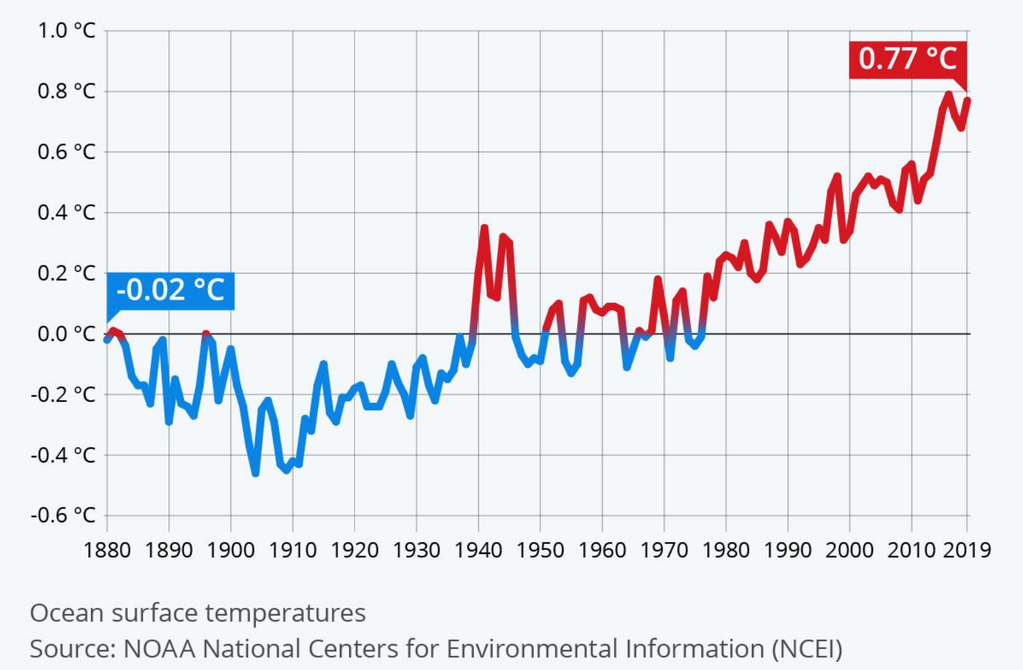




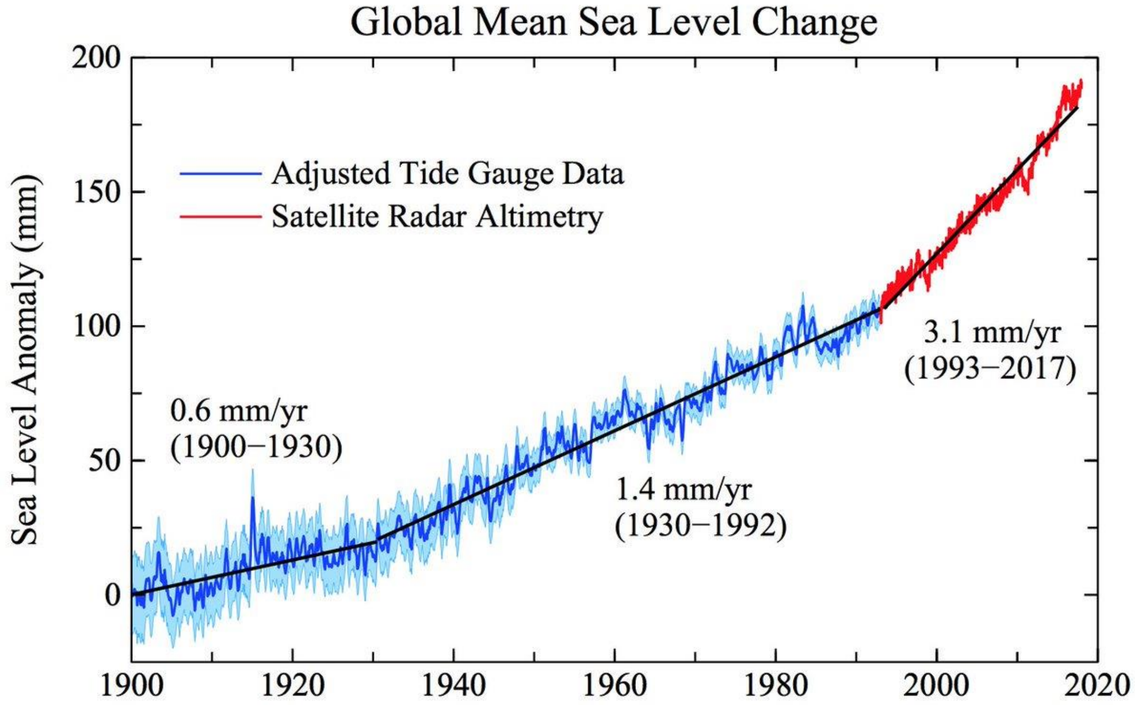


Conseguenze: scioglimento ghiaccio artico e permafrost

Conseguenze: innalzamento del livello del mare



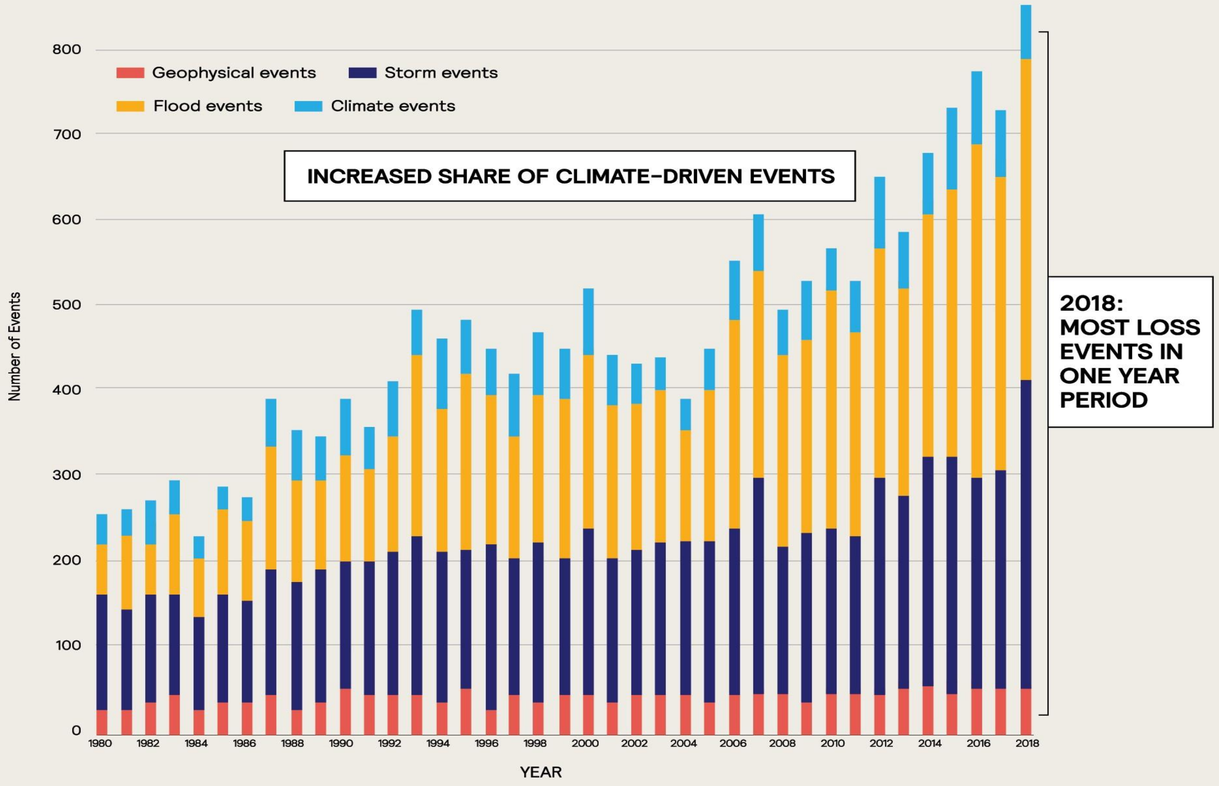
Ocean surface temperatures
Source: NOAA National Centers for Environmental Information (NCEI)



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 ≥ US$ 100k, 300k, 1m, or 3m (depending on the assigned World Bank income group of the affected country).

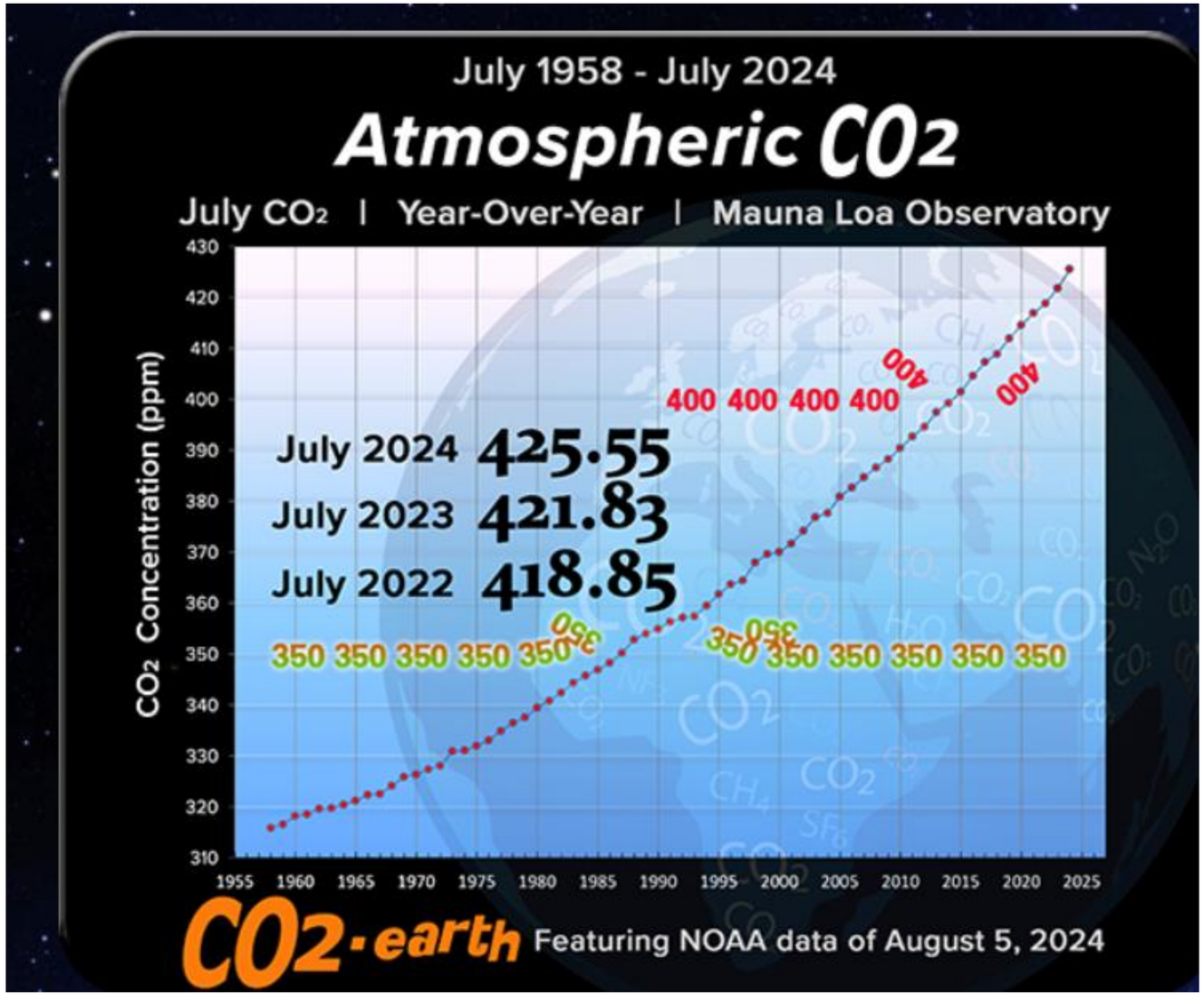
E ancora …

- 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 …


July 1958 - July 2024
Atmospheric CO2
July CO2 | Year-Over-Year | Mauna Loa Observatory
CO2 Concentration (ppm)
July 2024 425.55
July 2023 421.83
July 2022 418.85
CO2.earth Featuring NOAA data of August 5, 2024

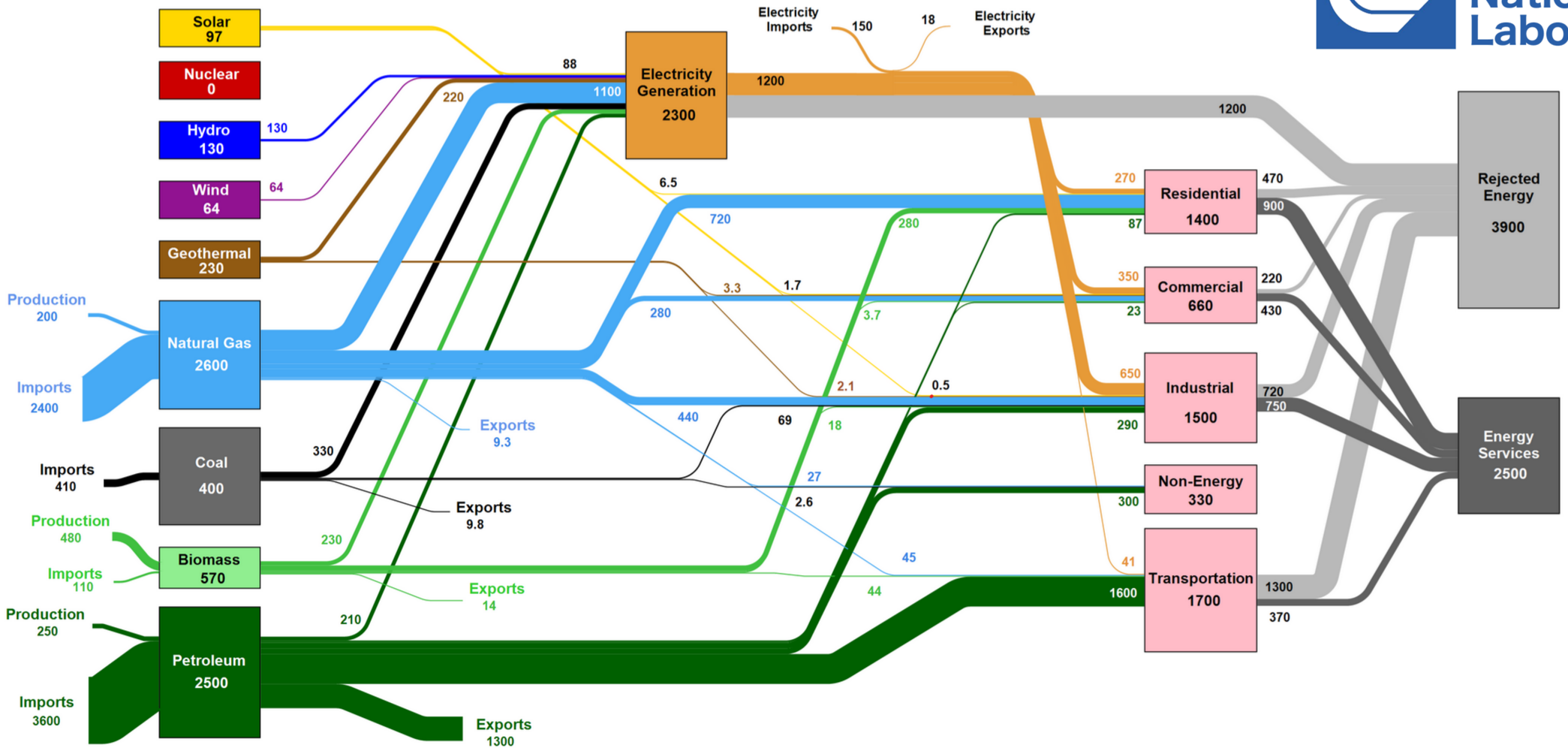
https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_SPM.pdf

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

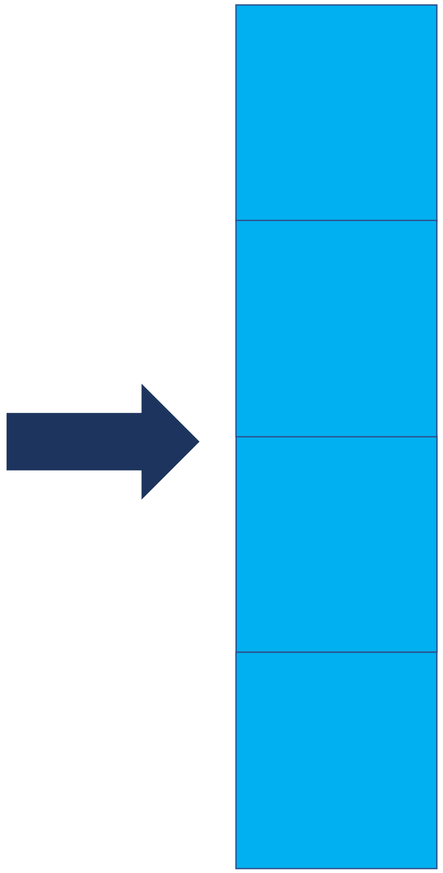
Lawrence Livermore National Laboratory



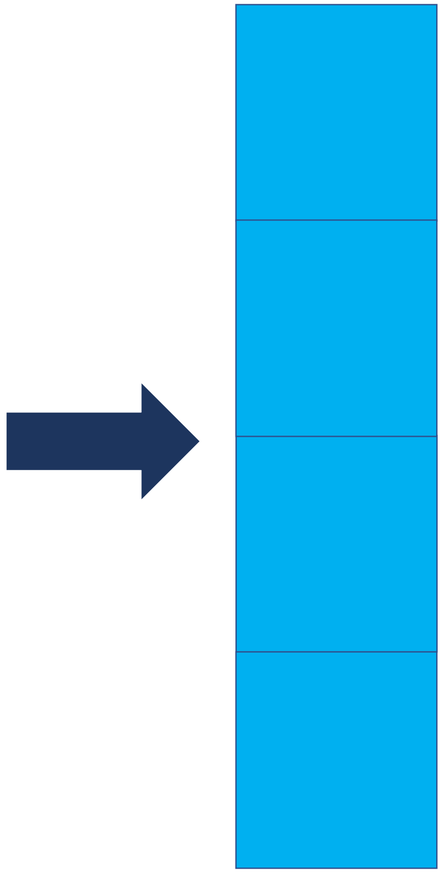
Un sistema inefficiente

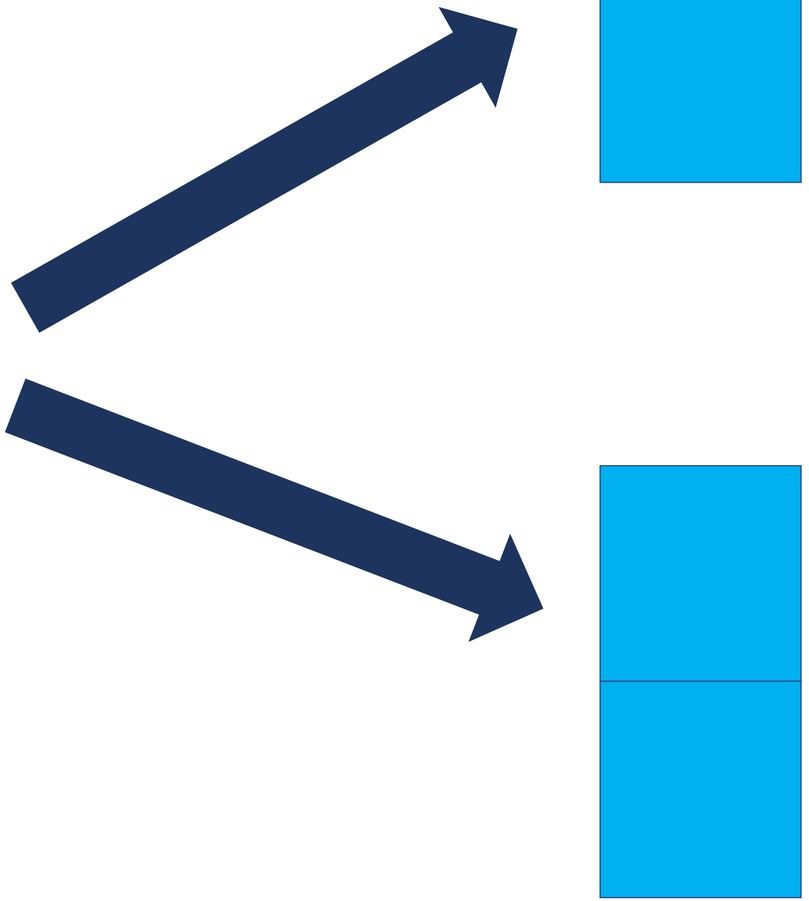
- Energia totale: 6.300 PJ
- Energia non utilizzata («rejected energy»): 3.900 PJ
- Energia utilizzata («energy services»): 2.400 PJ
- **Gettiamo il 62% dell'energia (3.900/6.300)**
- Bruciare combustibili fossili per produrre energia elettrica determina perdite pari al 50%
- Bruciarne per muovere automobili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

Perdite del sistema energetico



Efficientare la catena energetica





Risparmiare energia

Il costo dei combustibili fossili

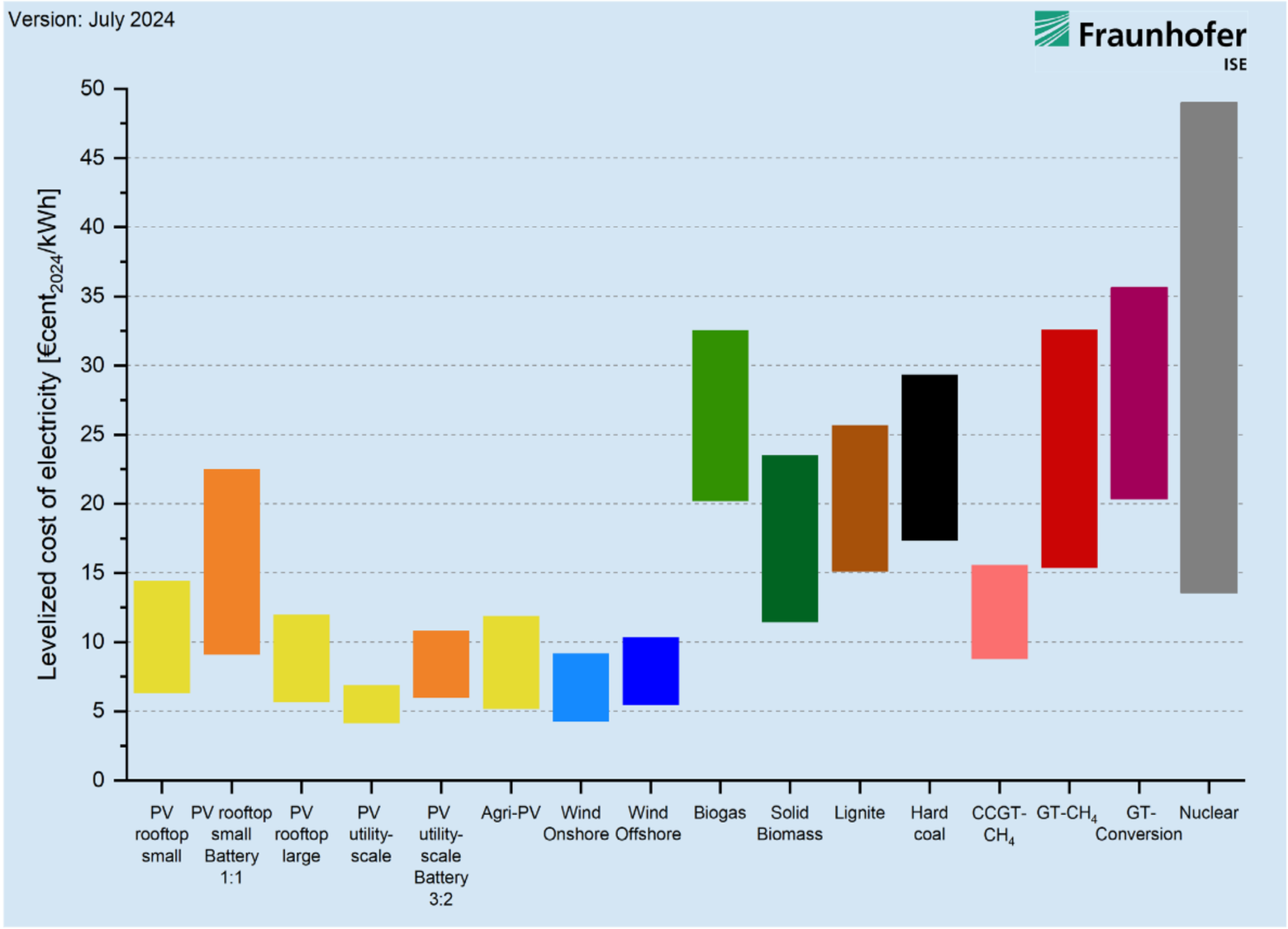
Joule

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

International Energy Agency

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

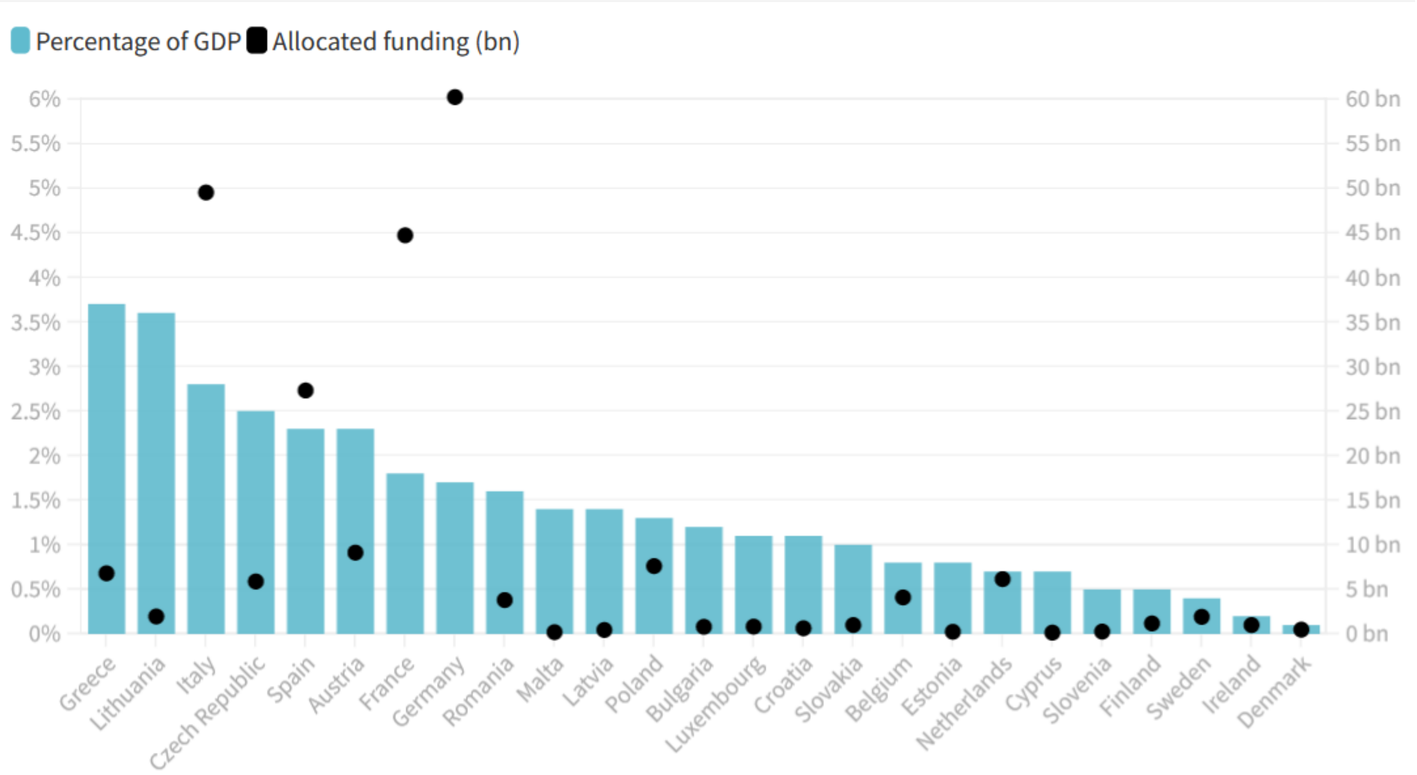
I supporti globali alle fonti rinnovabili nel 2021 non hanno superato i 500 G$ …

Aiuti a pagare le bollette

1 of 2

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



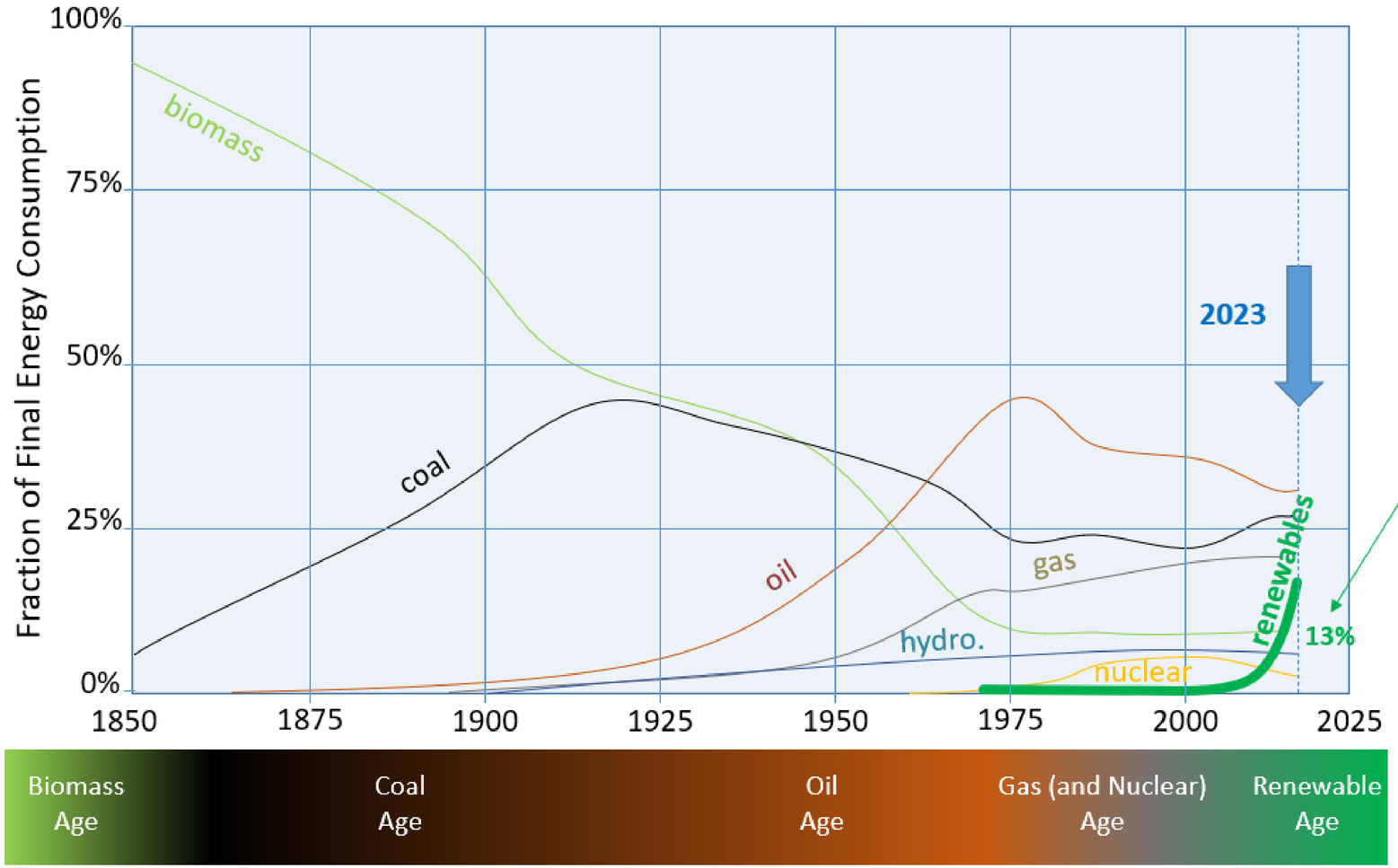
bruegel

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



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

PERSPECTIVE

How to avoid the perfect storm:

Maurizio Fermeglia, Vanni Lughi, and Alessandro Massi Pavan, Department of Engineering and Architecture, University of Trieste, Piazzale Europa 1, 34127 Trieste, Italy

Address all correspondence to Maurizio Fermeglia at maurizio.fermeglia@units.it

(Received 30 May 2020; accepted 31 August 2020)

ENERGY SUSTAINABILITY

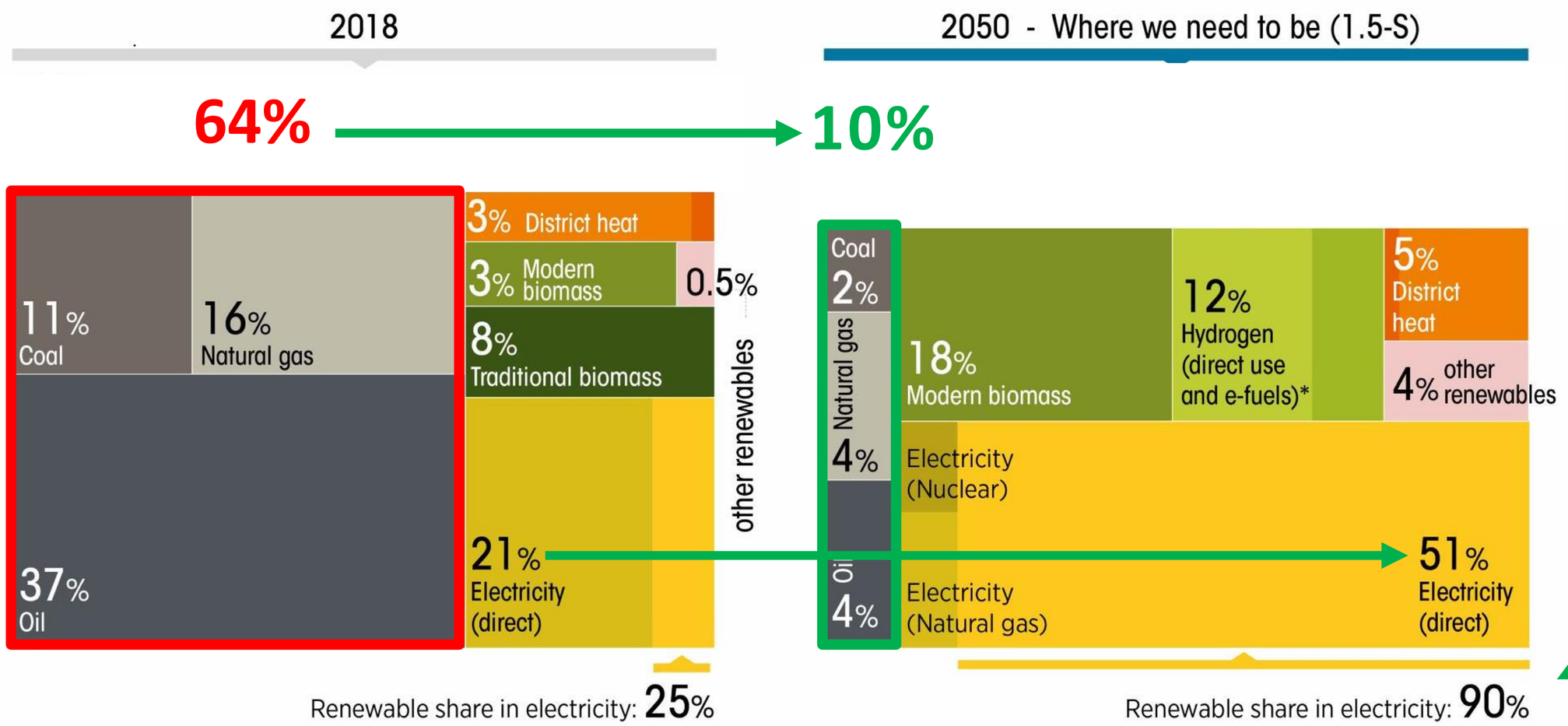
Modern renewables account for

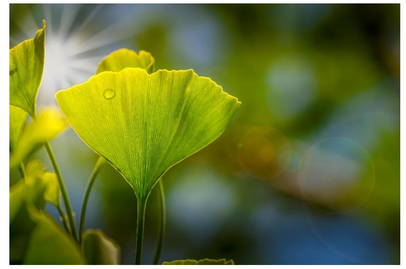
13.0%

of total final energy consumption (2022)

Ren21, 2024 Report

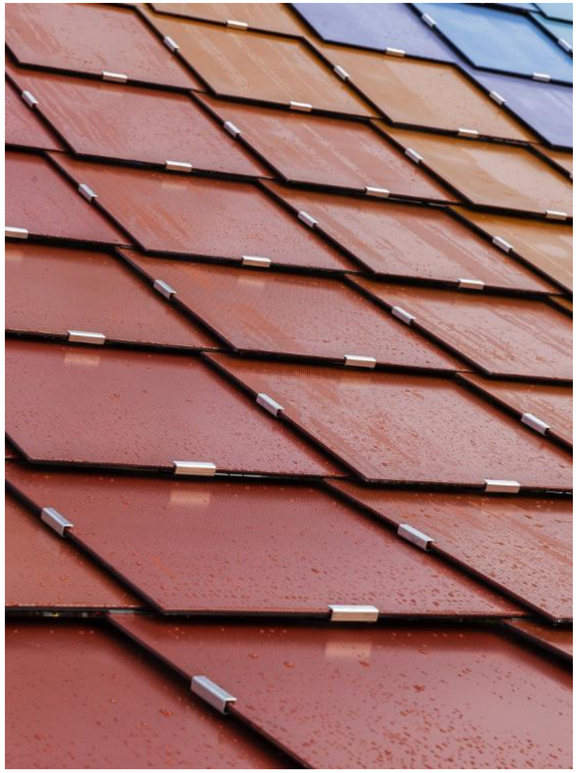
Transizione verso l’energia elettrica





Perché energia elettrica?

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



Perché energia elettrica?

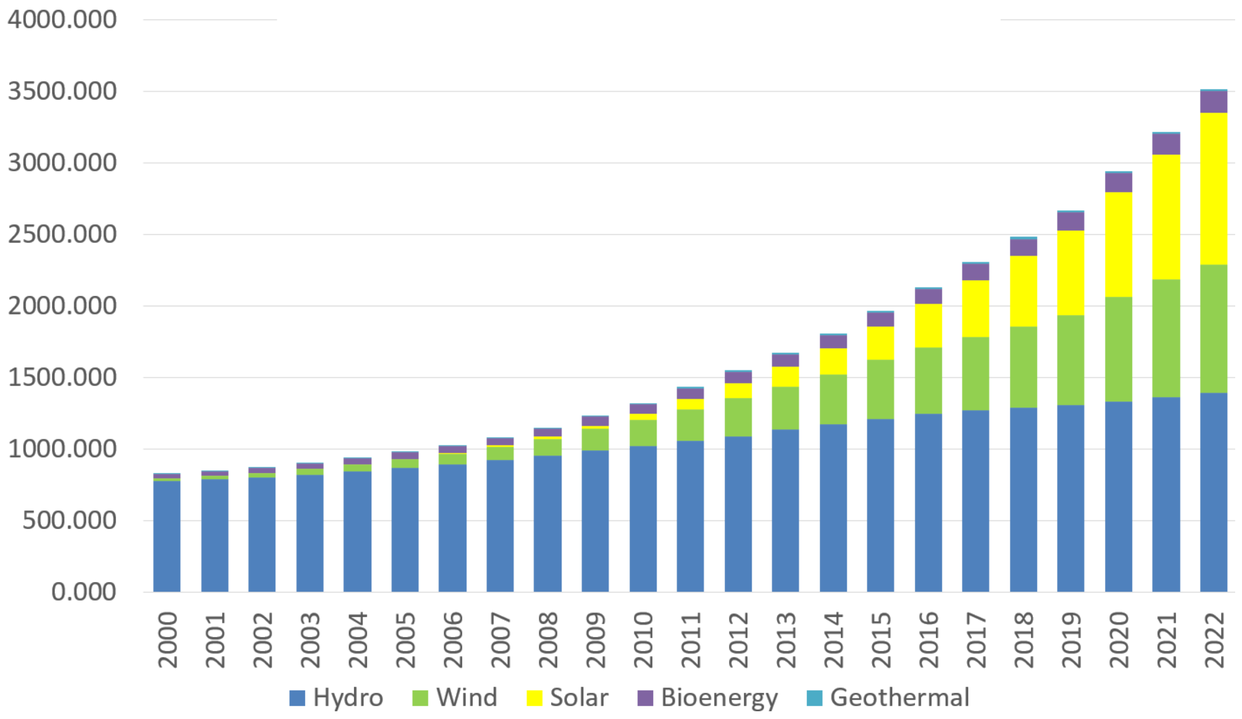
- Nuovi usi «stazionari»: fornelli a induzione e pompe di calore

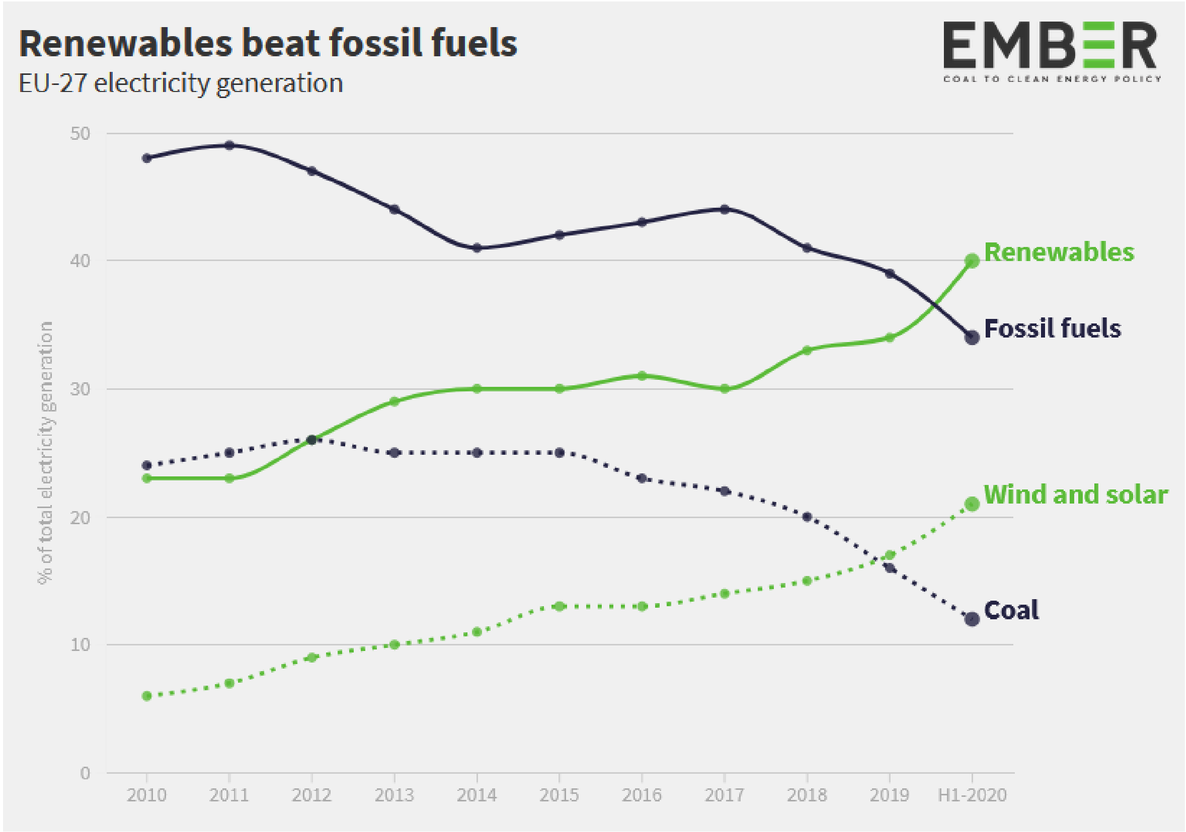
Perché energia elettrica?

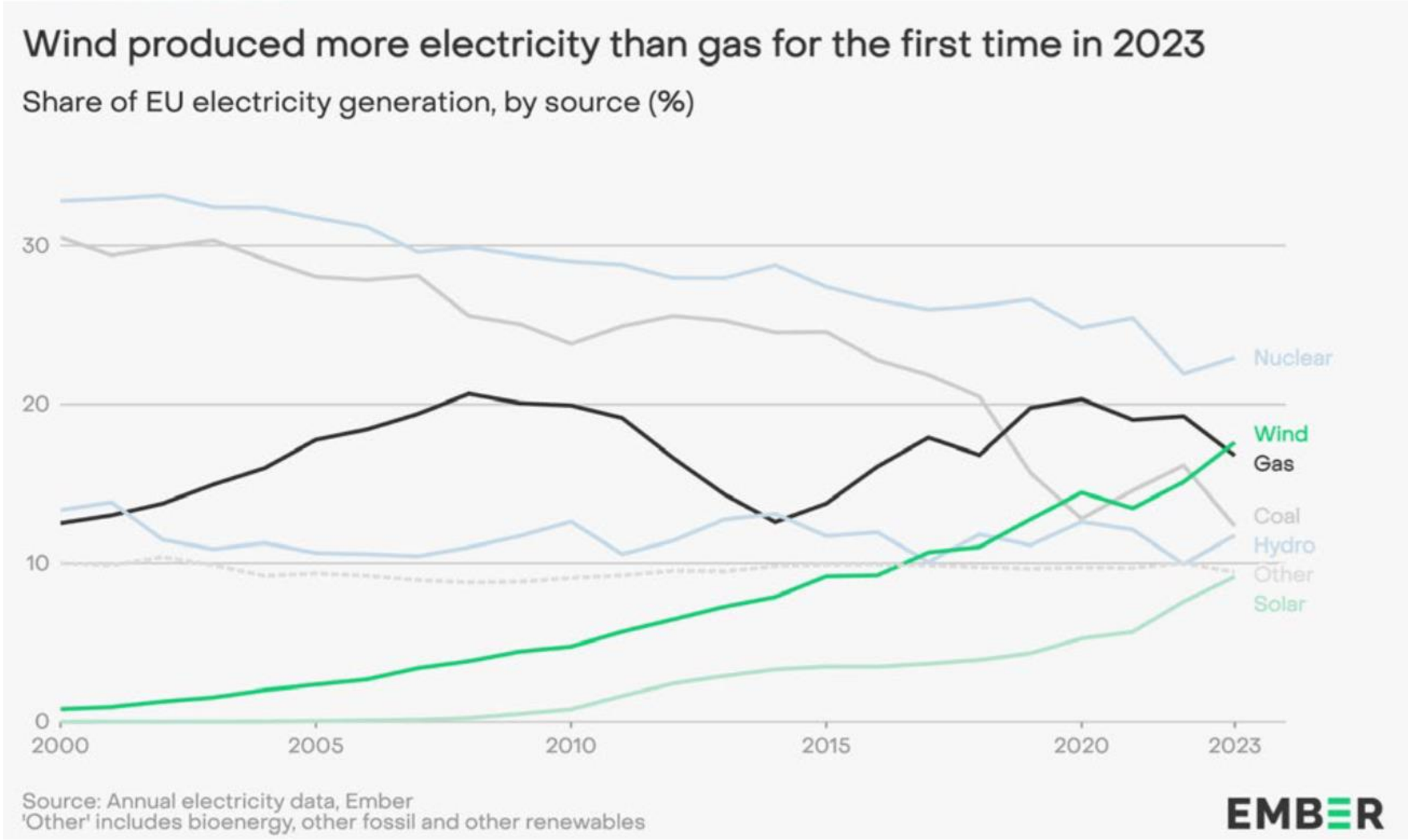
- Nuovi usi: trasporti «leggeri»

Crescita esponenziale delle rinnovabili

IRENA
International Renewable Energy Agency

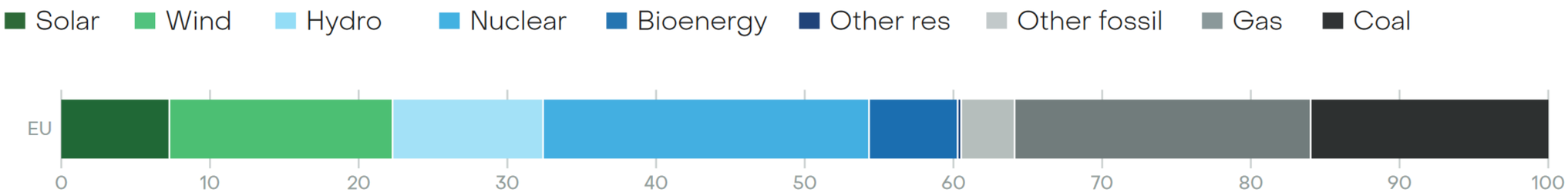


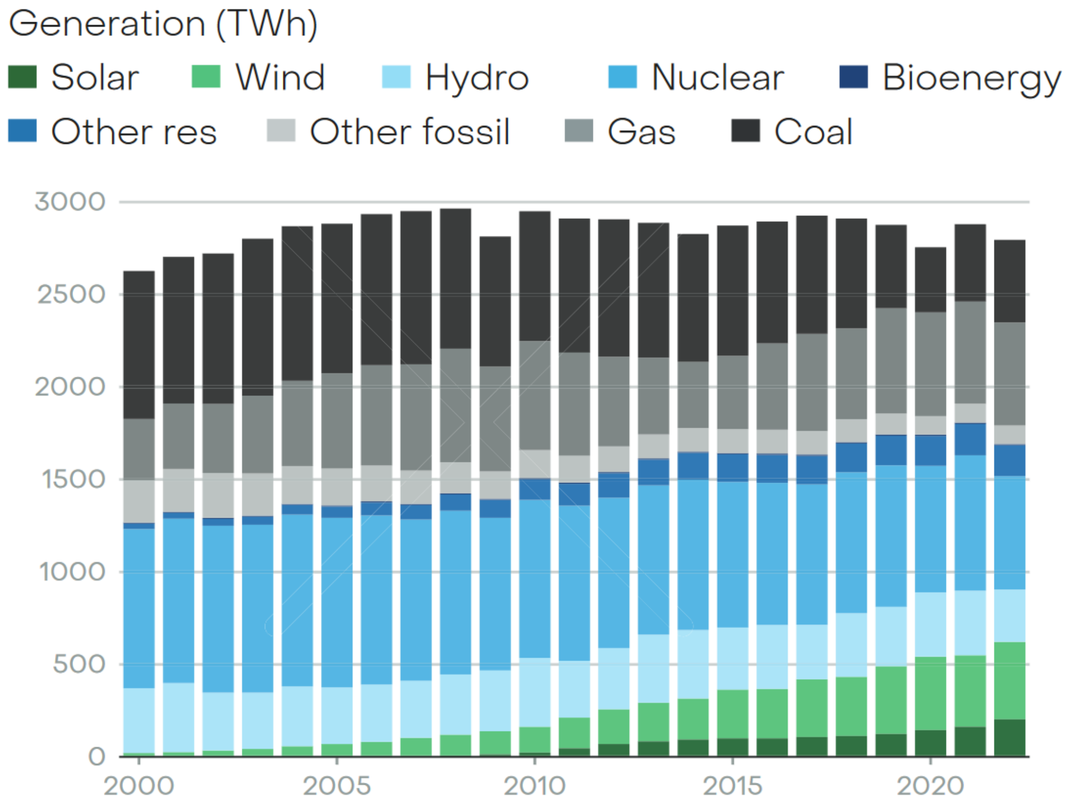



Wind produced more electricity than gas for the first time in 2023
Share of EU electricity generation, by source (%)
30
20
10
0
2000
2005
2010
2015
2020
2023
Nuclear
Wind
Gas
Coal
Hydro
Other
Solar
Source: Annual electricity data, Ember
'Other' includes bioenergy, other fossil and other renewables
EMBER

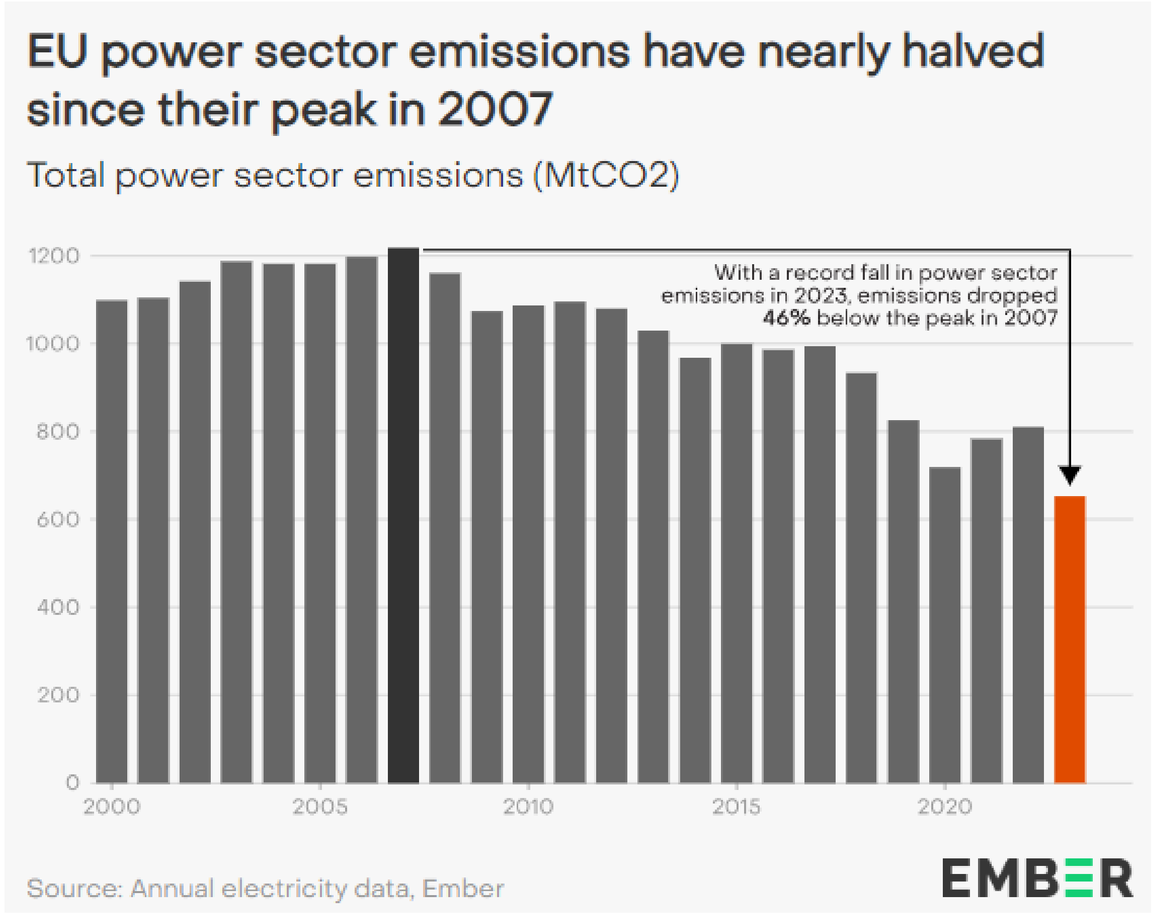
EU electricity mix

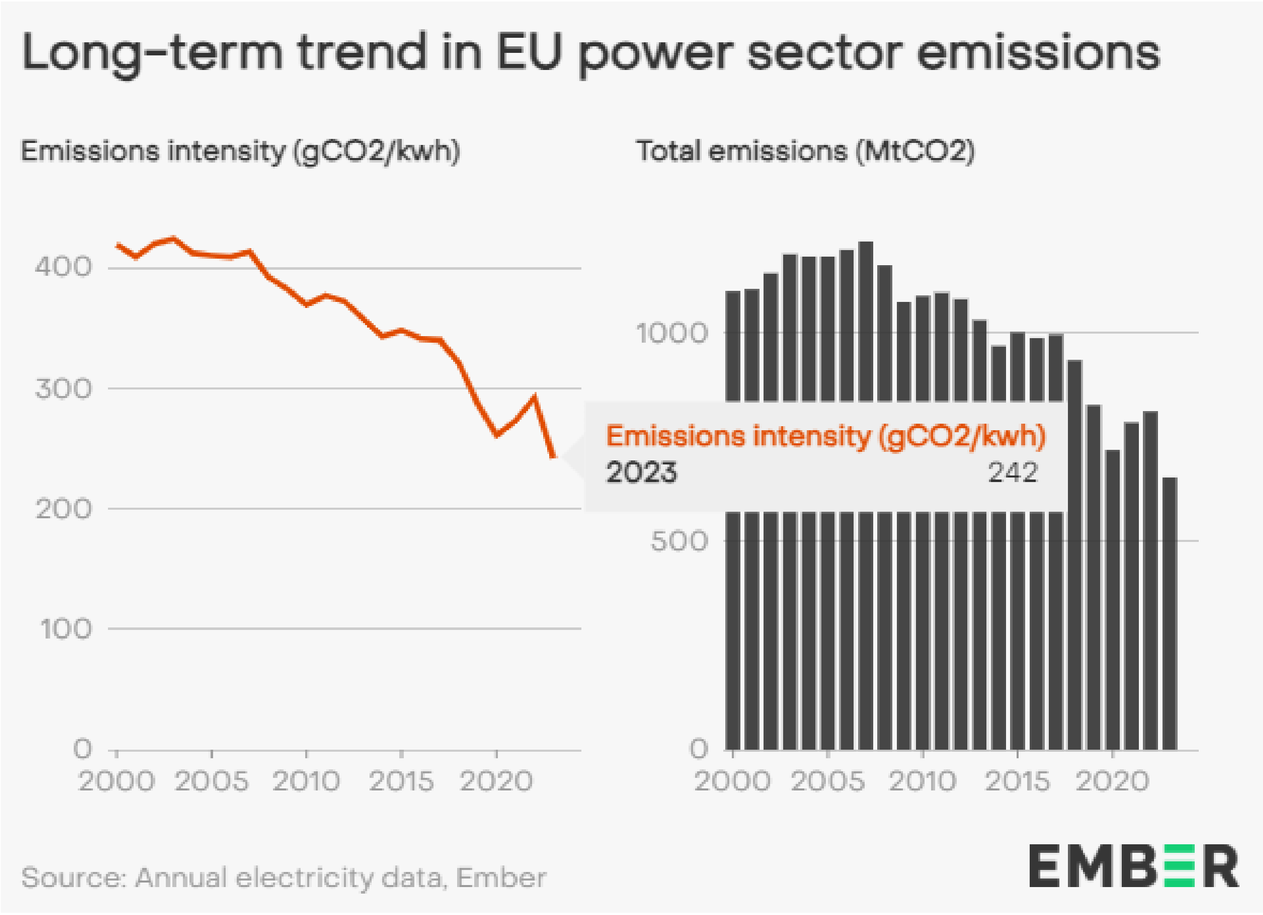
Share of electricity (%)

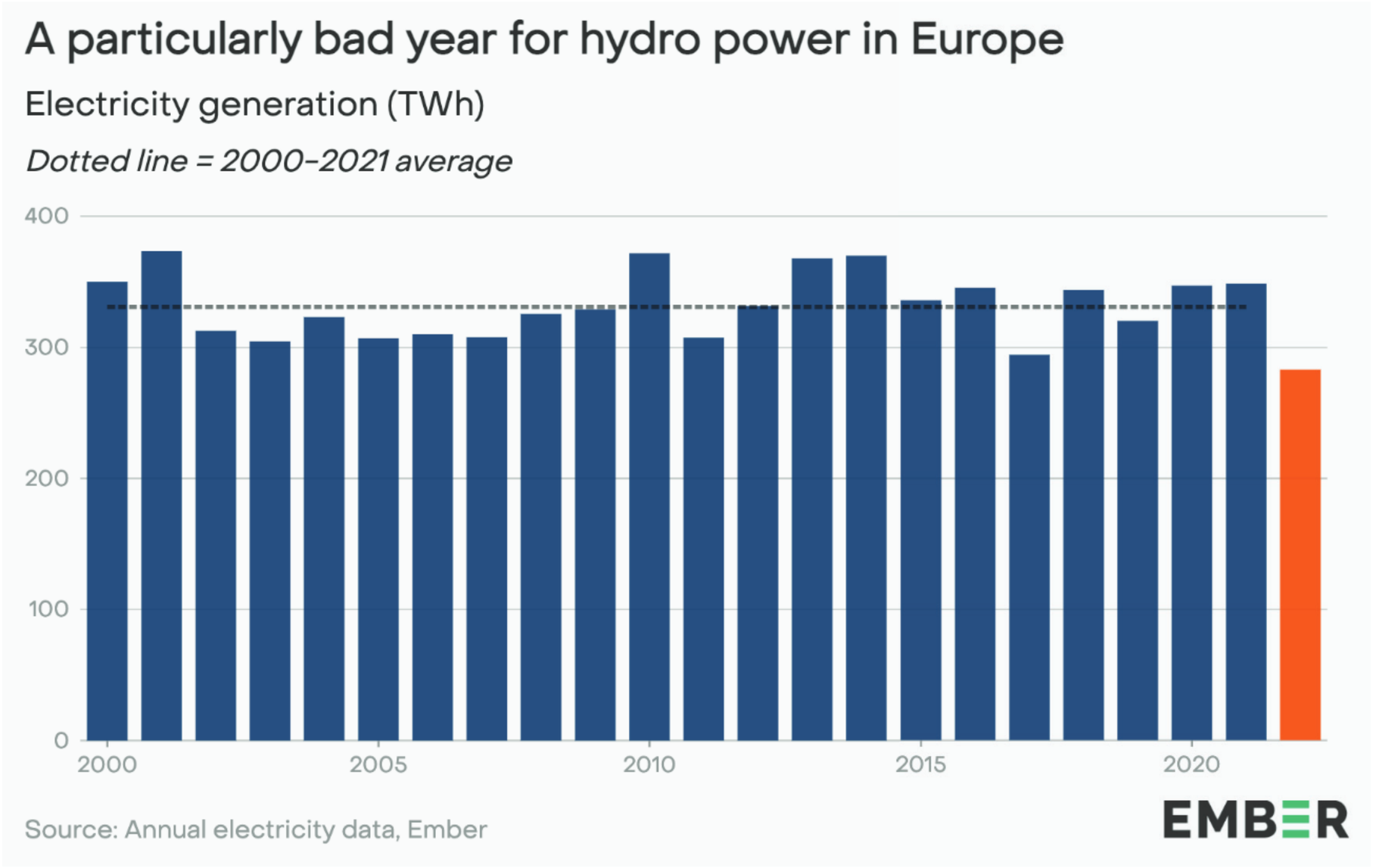


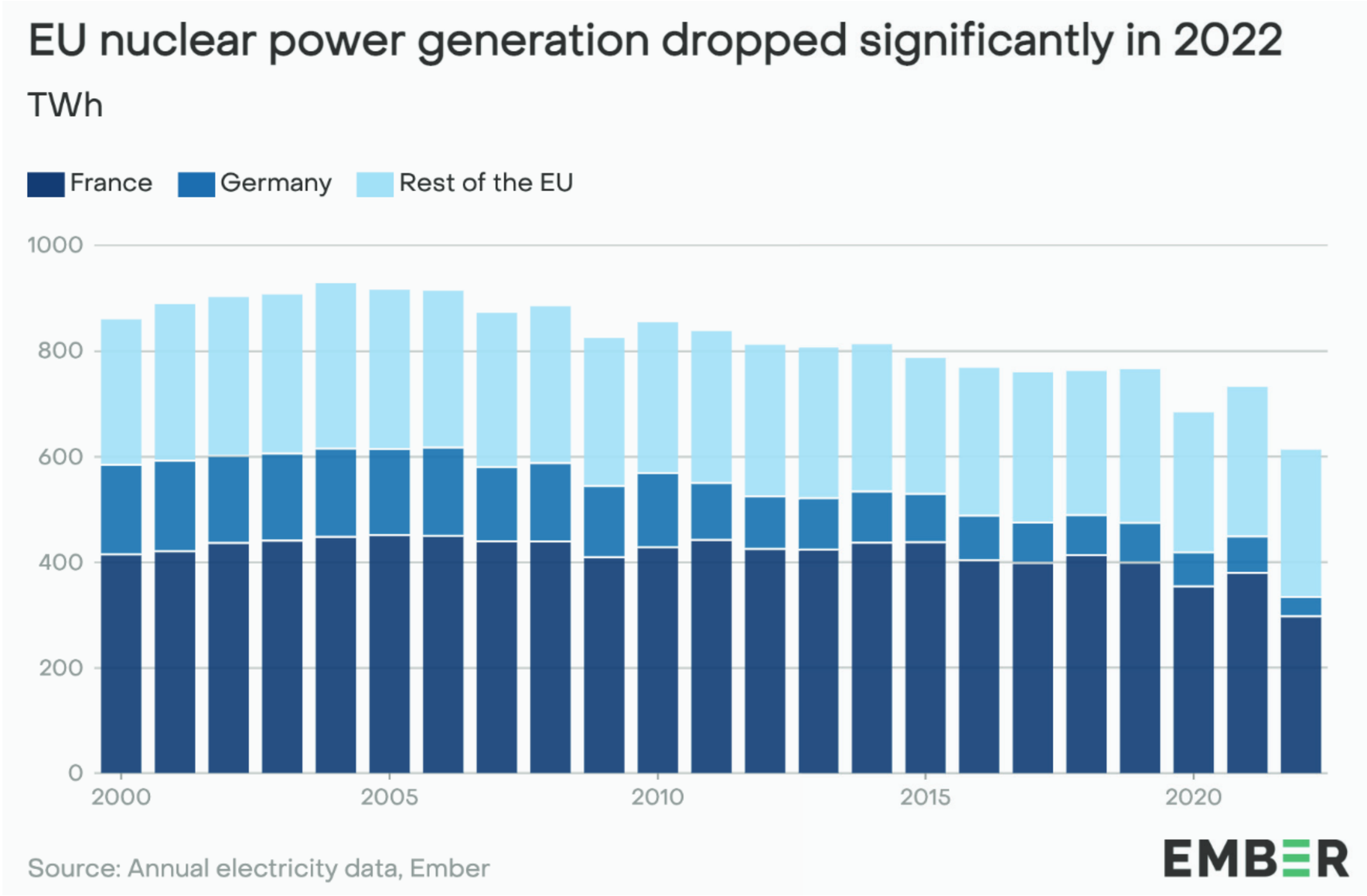


Carbon intensity

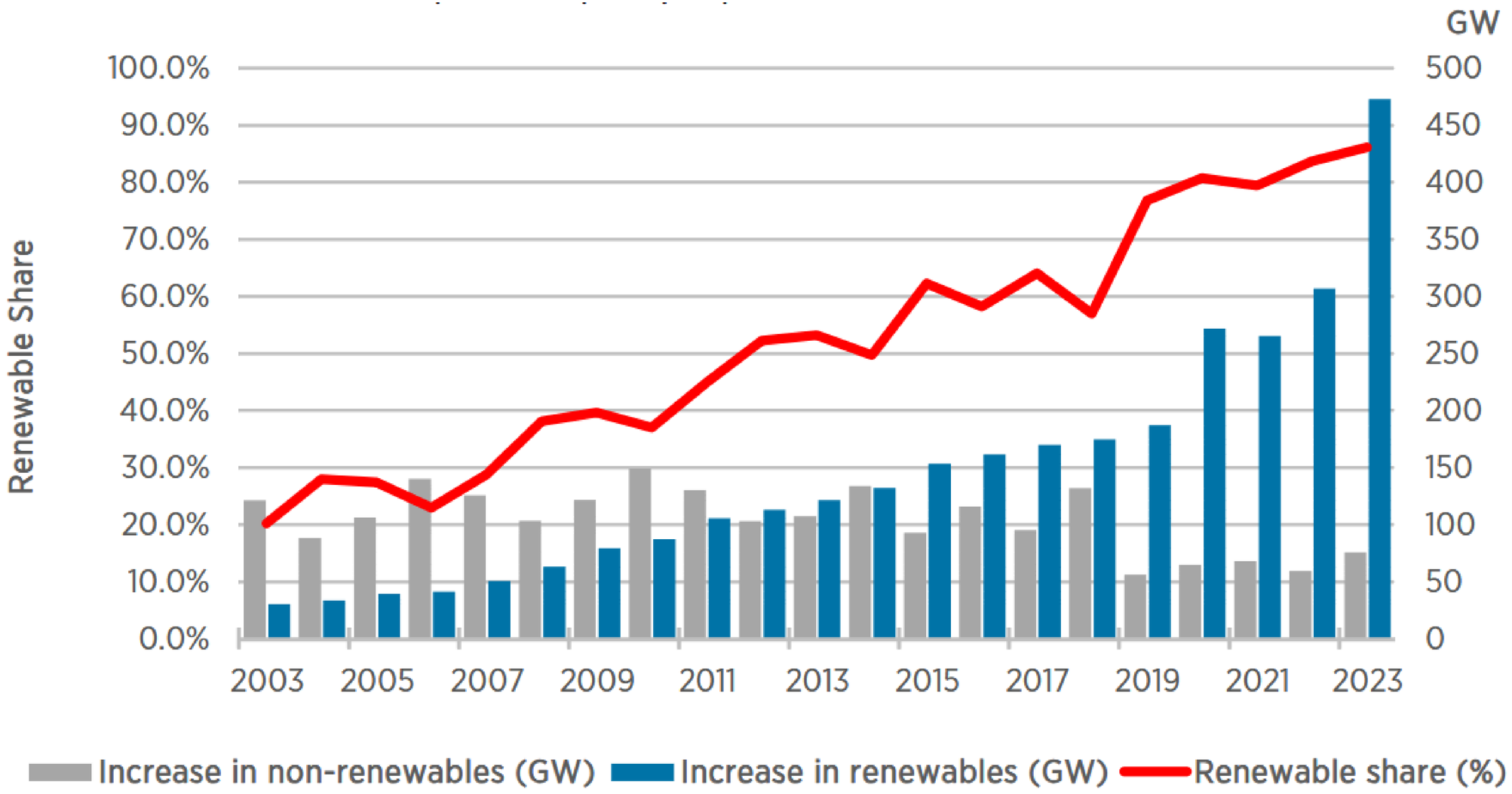




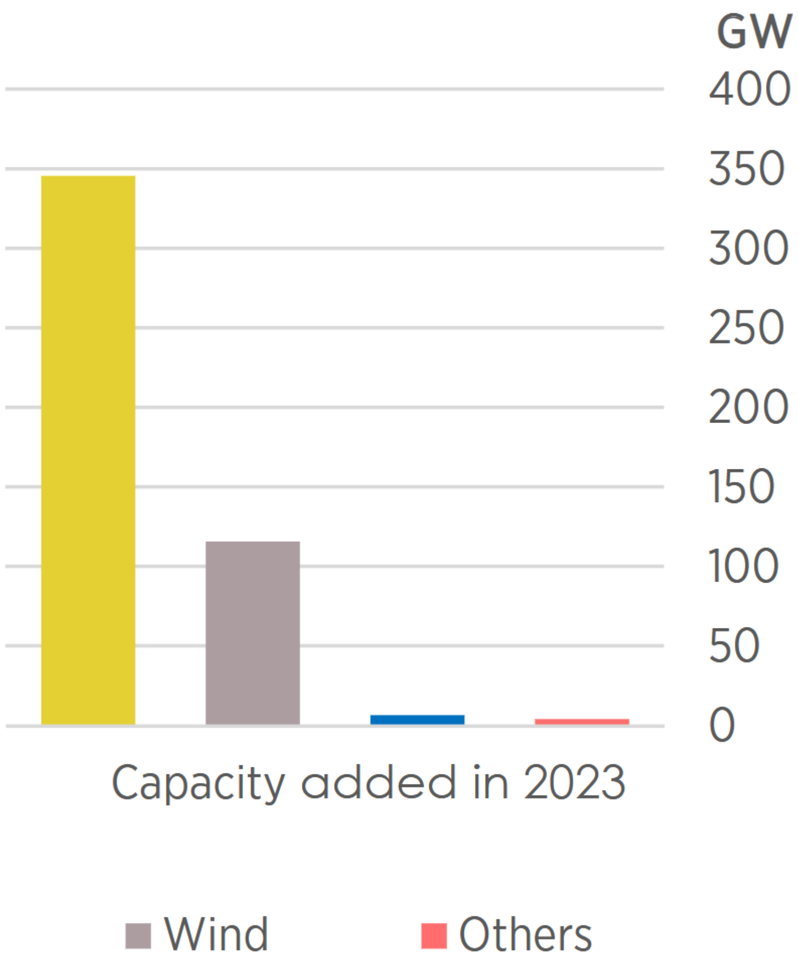

A particularly bad year for hydro power in Europe
Electricity generation (TWh)
Dotted line = 2000-2021 average
400
300
200
100
0
2000
2005
2010
2015
2020
Source: Annual electricity data, Ember
EMBER

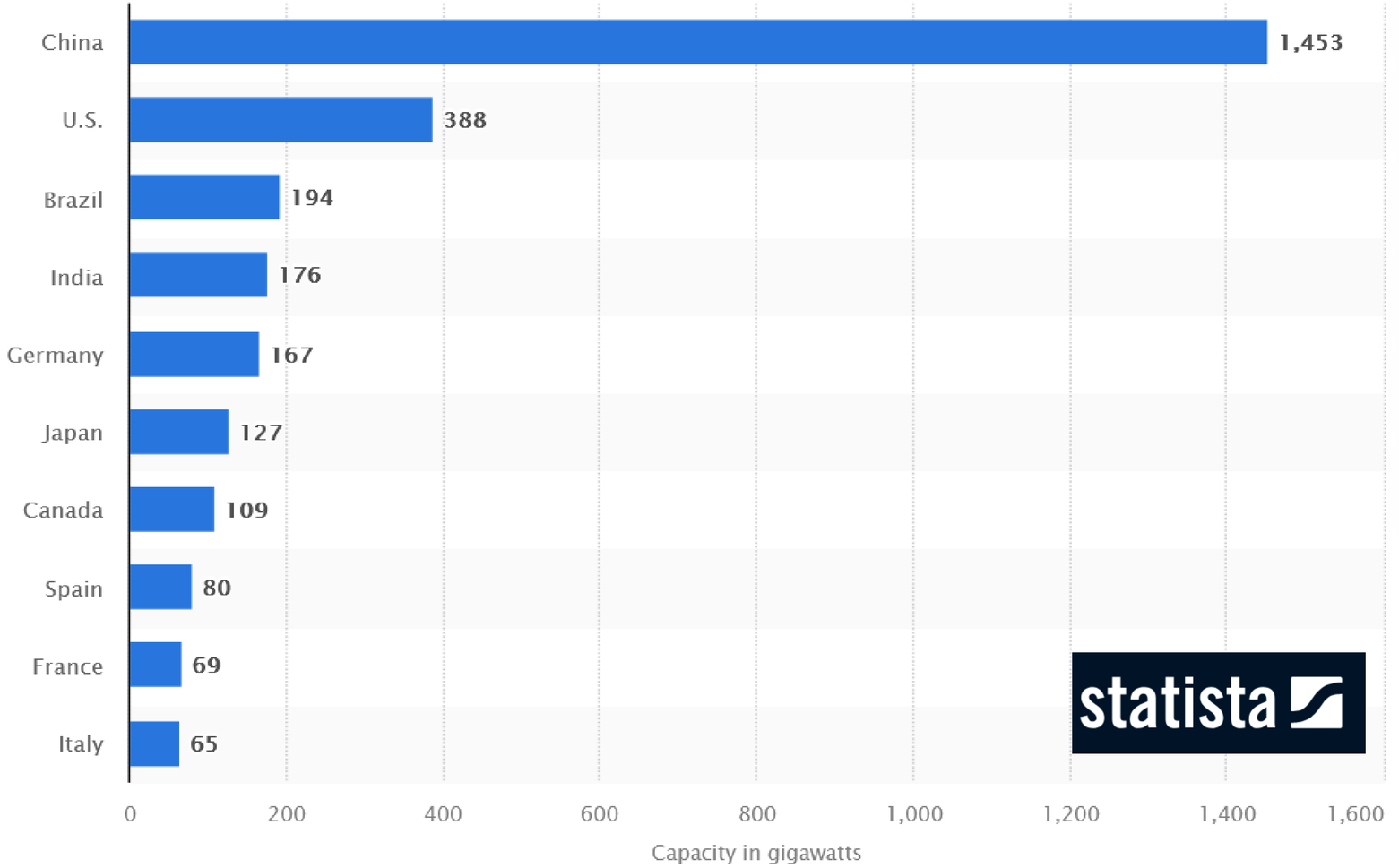

EU nuclear power generation dropped significantly in 2022
TWh
France
Germany
Rest of the EU
1000
800
600
400
200
0
2000
2005
2010
2015
2020
Source: Annual electricity data, Ember
EMBER

A livello globale «solo» rinnovabili!



Investimenti nel settore elettrico



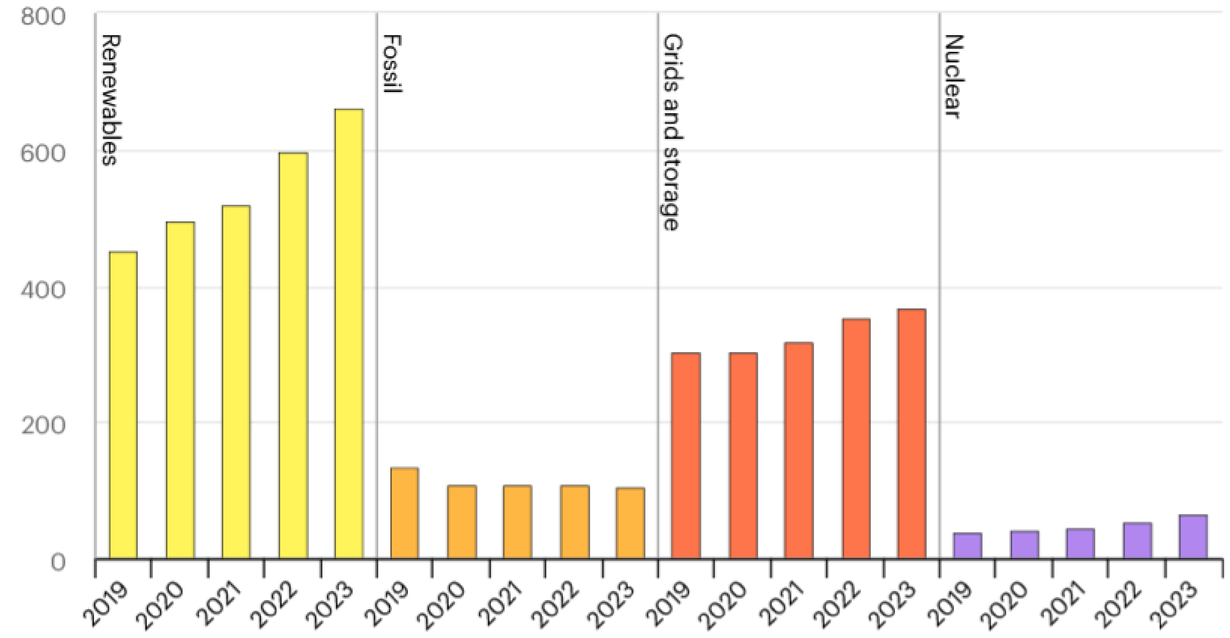


Investimenti nel settore elettrico

Power investment, 2019-2023

Open

billion USD (2022)



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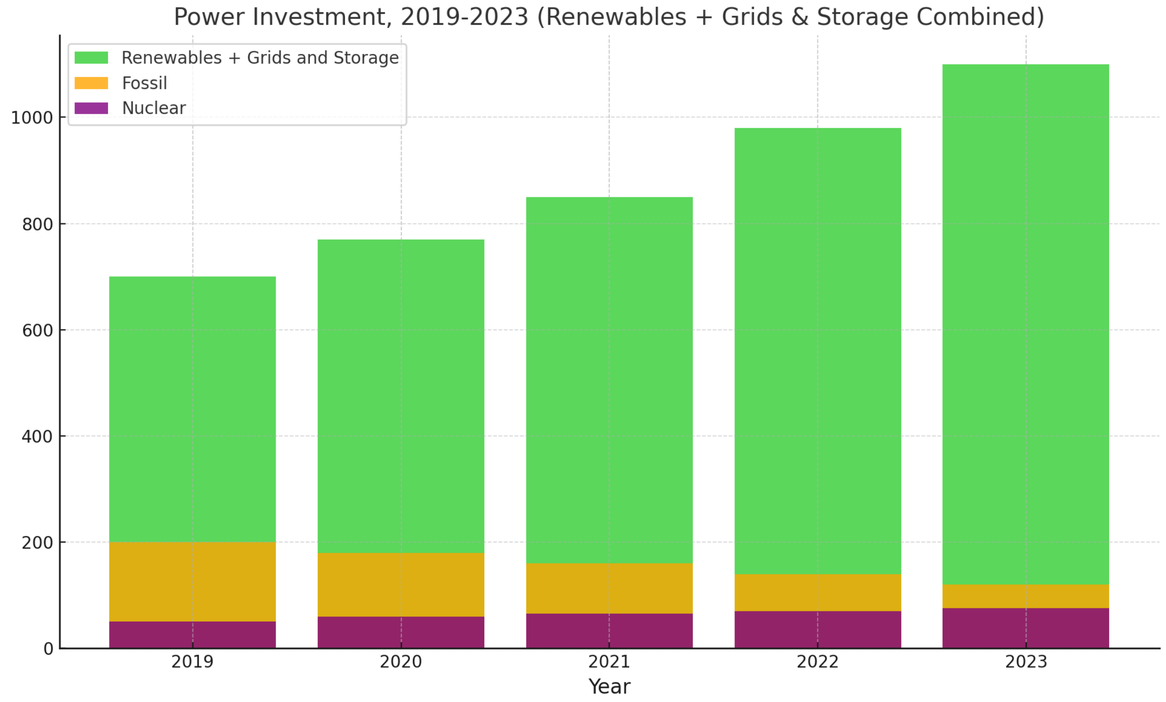
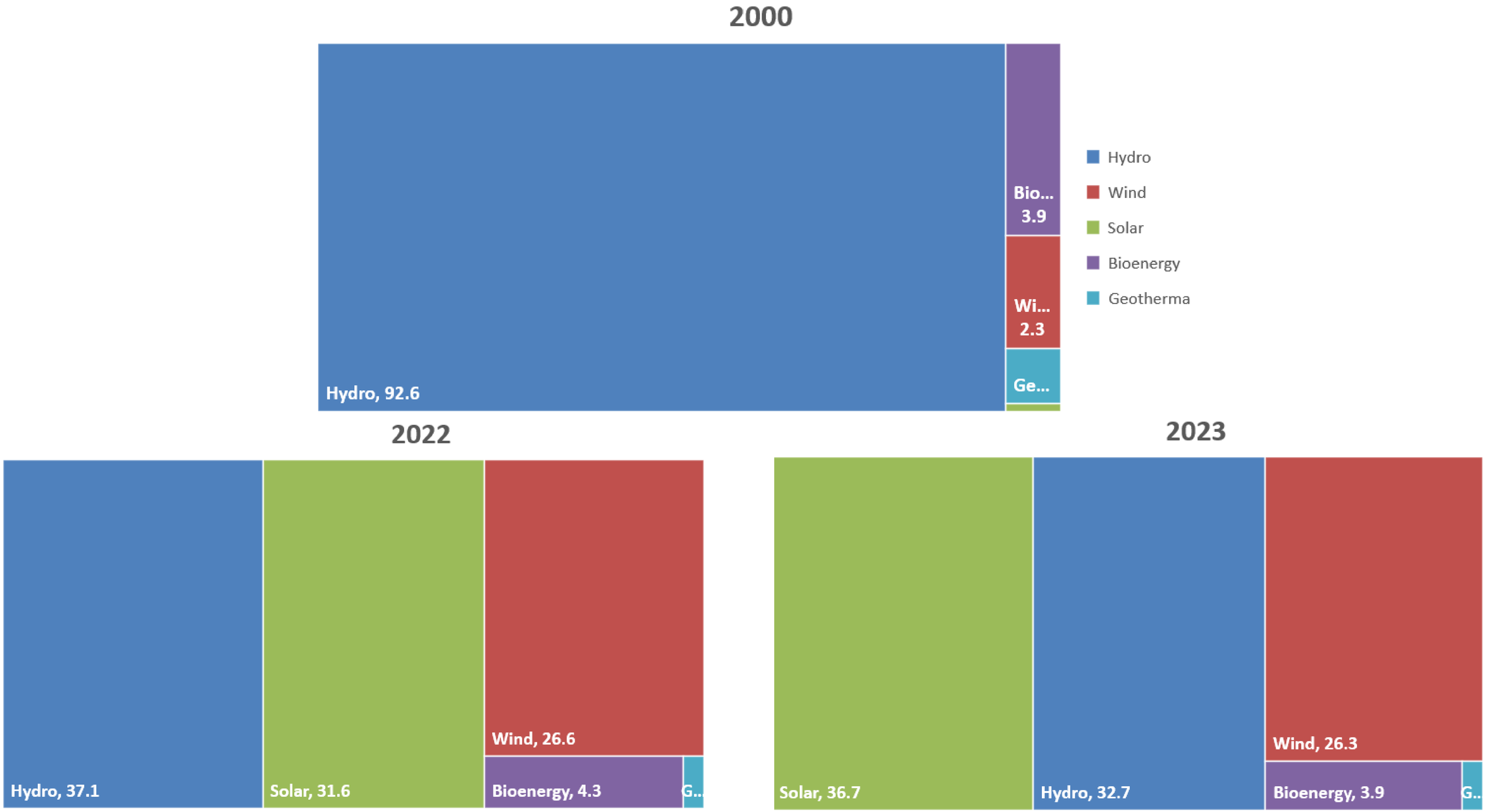
Renewables **Fossil** **Grids and storage** **Nuclear**



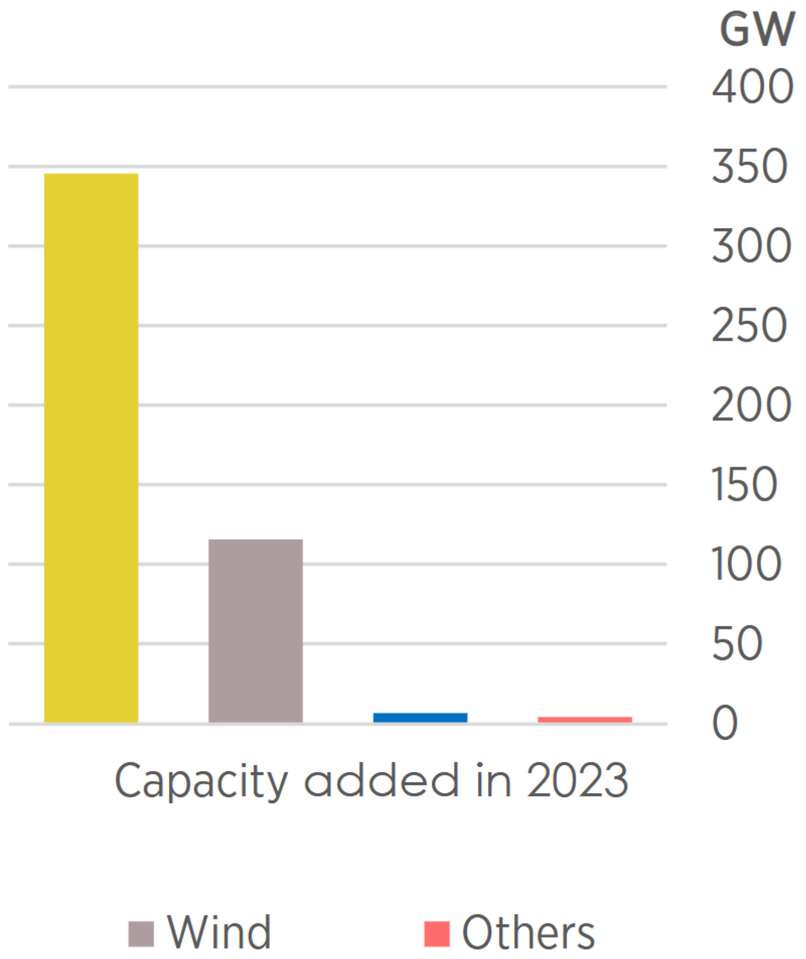

2000
Hydro, 92.6
Bio... 3.9
Wi... 2.3
Ge...
Hydro
Wind
Solar
Bioenergy
Geotherma
2022
Hydro, 37.1
Solar, 31.6
Wind, 26.6
Bioenergy, 4.3
G...
2023
Solar, 36.7
Hydro, 32.7
Wind, 26.3
Bioenergy, 3.9
G..

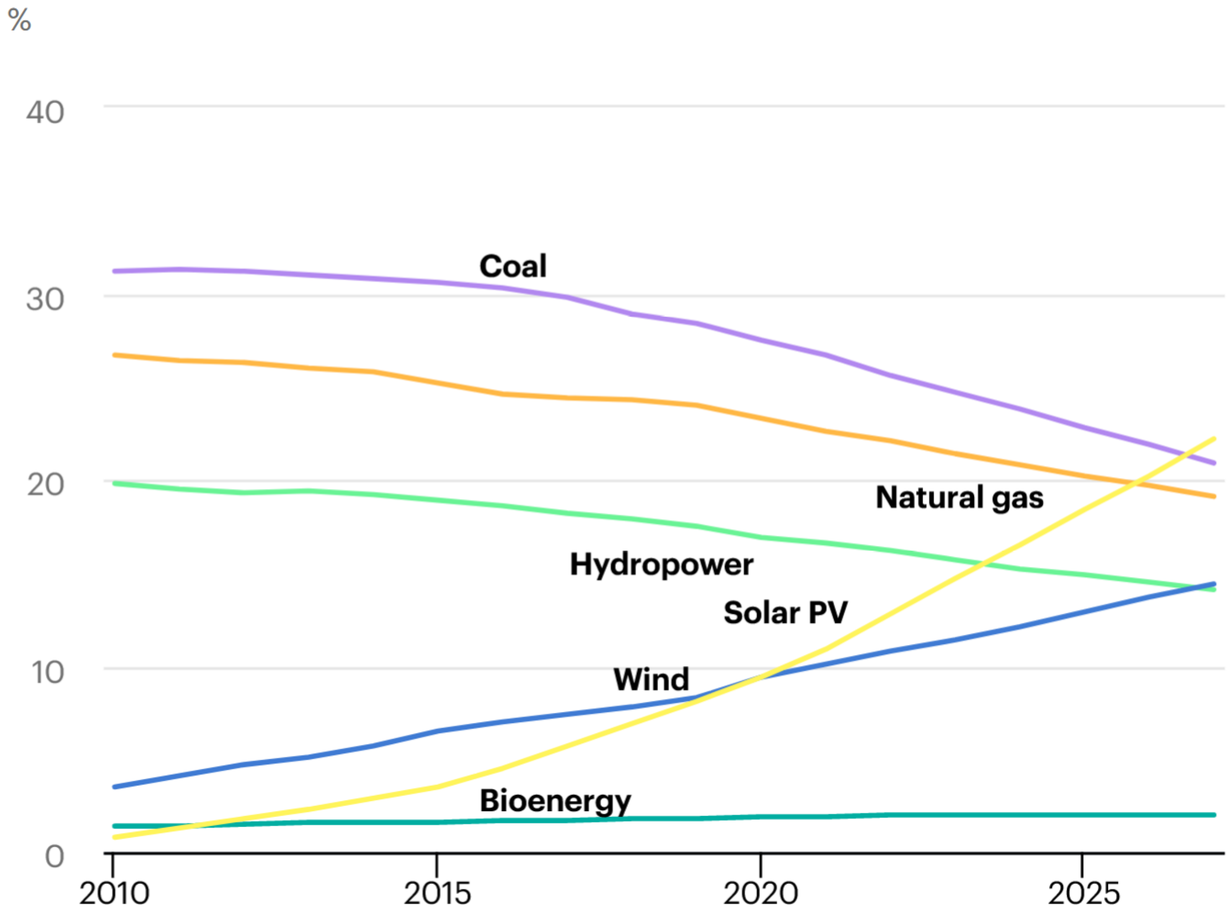
Nuove installazioni

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

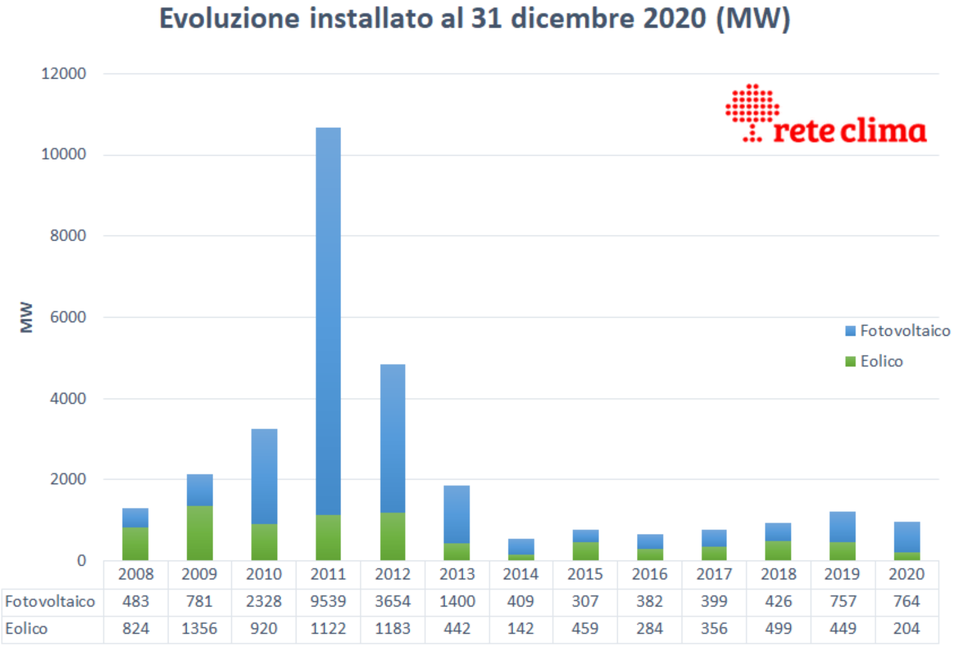
TECHNOLOGY	2005	2020	2022	2023
THERMAL POWER	81%	60%	**67%**	**58%**
HYDROPOWER	15%	17%	**9%**	16%
PHOTOVOLTAICS	0%	9%	9%	12%
WIND POWER	1%	6%	7%	9%
BIOMASS	2%	6%	6%	3%
GEOTHERMAL	2%	2%	2%	2%

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

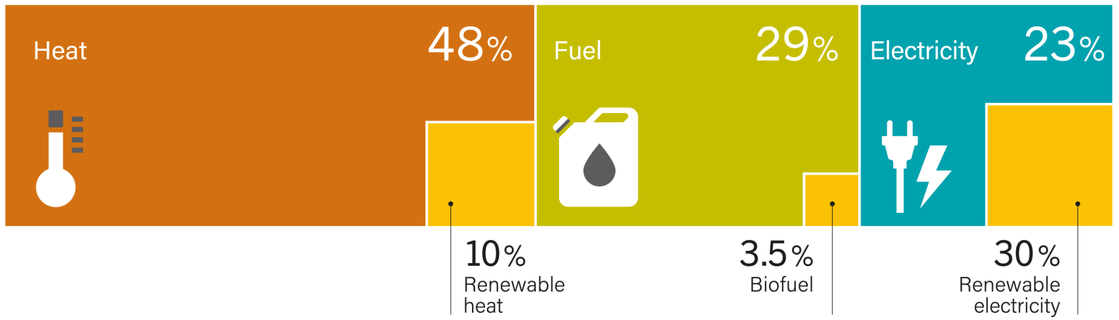
PHOTOVOLTAICS

2,5 GW in 2022, 5,2 GW in 2023, 6.8 in 2024

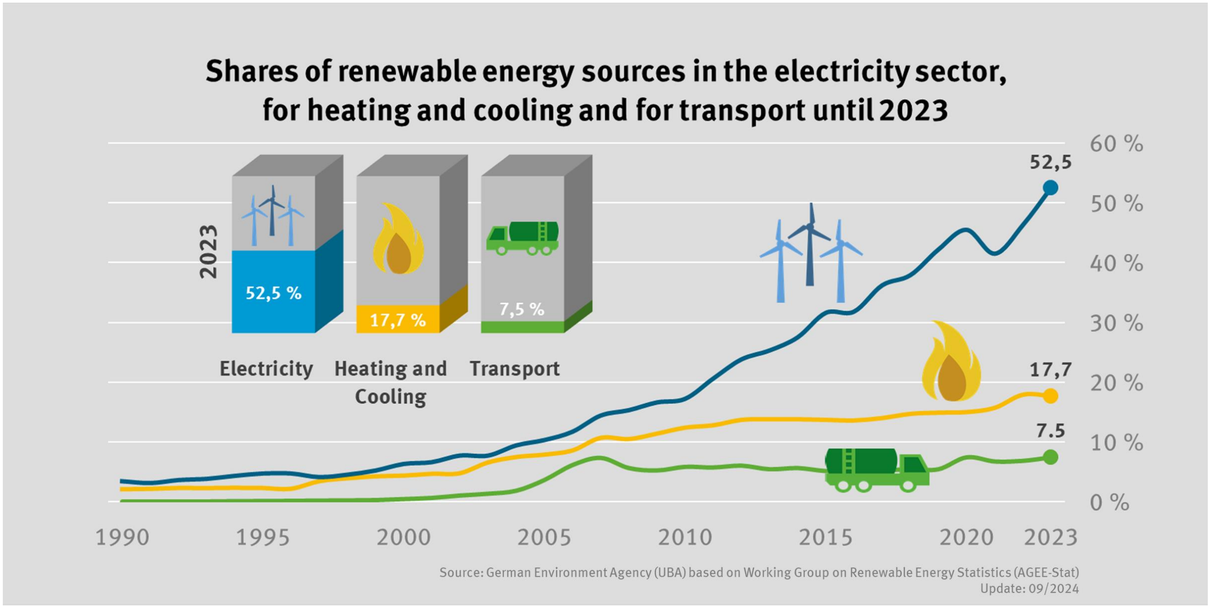
In Germany (7 in 2022, 15 in 2023, 16.2 in 2024!!!!)

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**

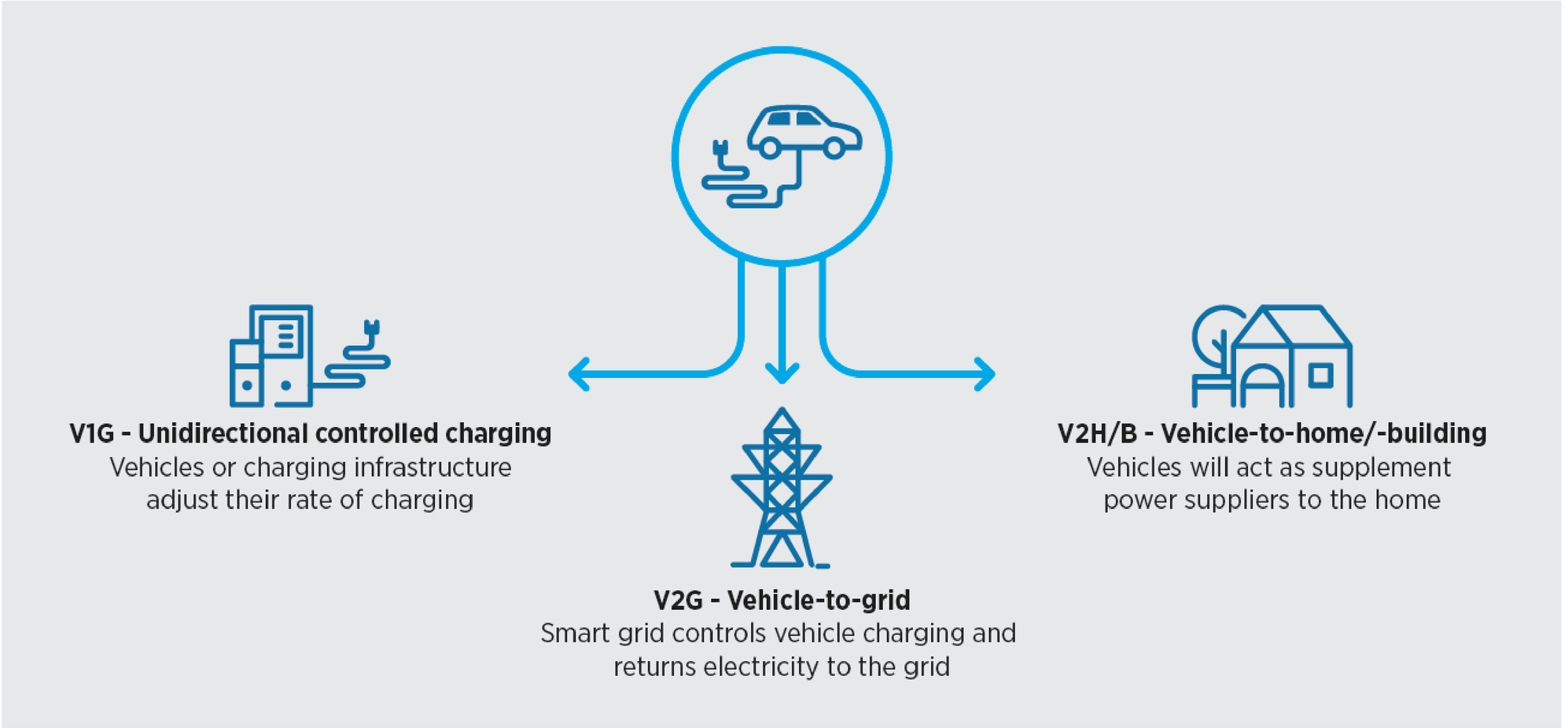


ITALIA

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

Smart grid & Mobility Lab @ UNITS

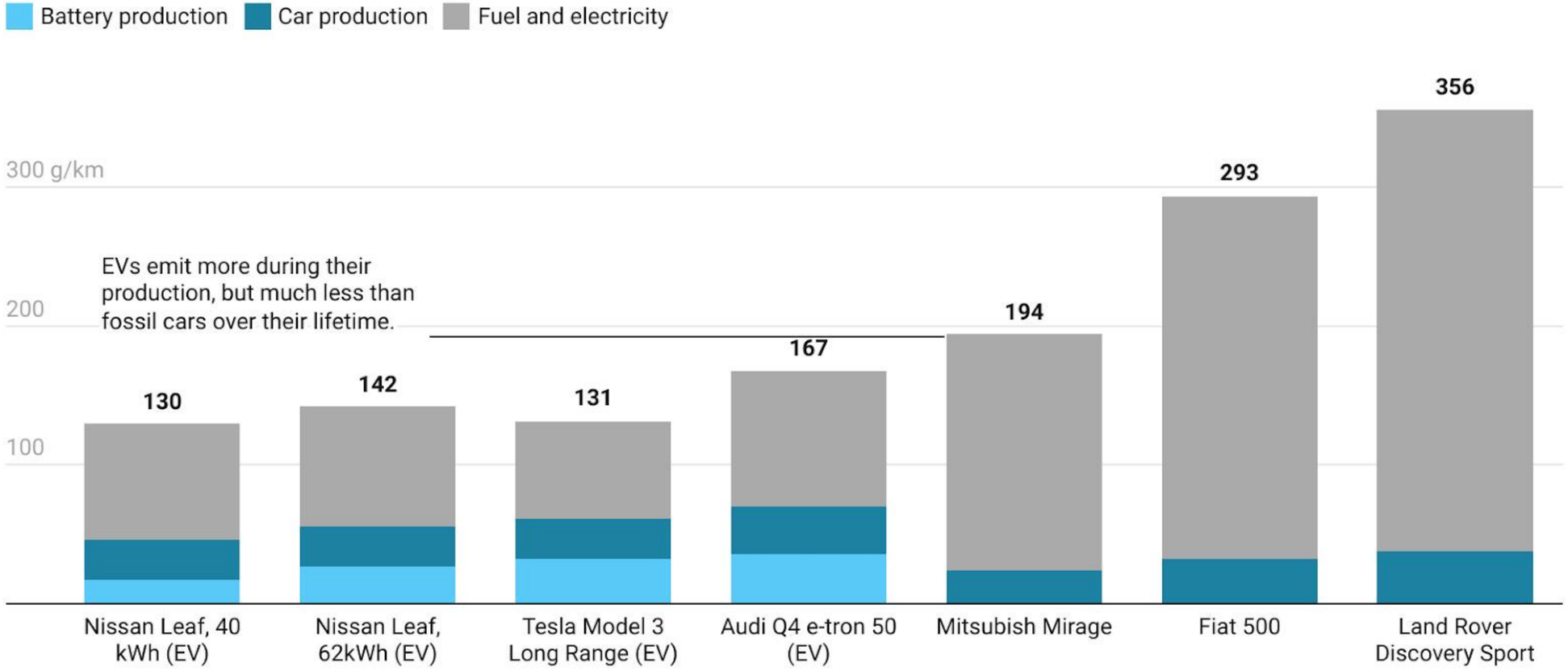
Figure 5 Forms of smart charging of electric vehicles



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 CO_2 per kilometer.



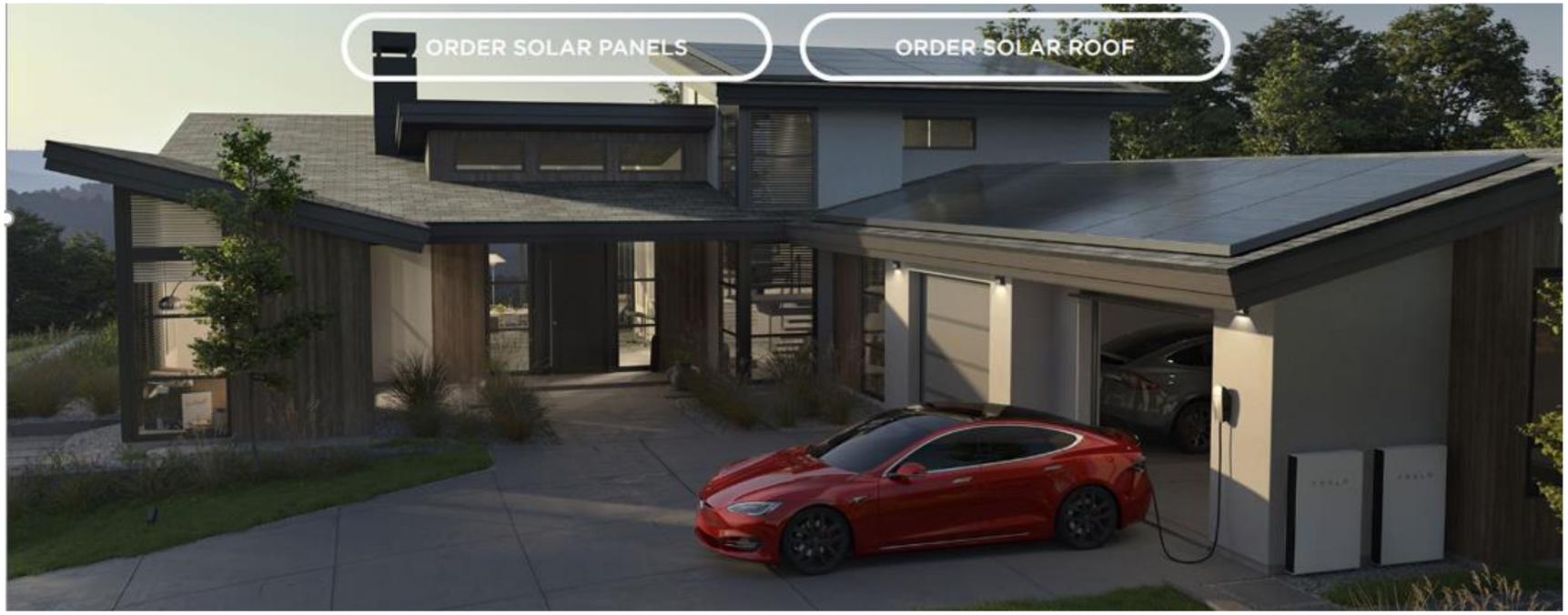
Assumes a mileage of 14,000 miles per year, which is the average in the US, and a car lifetime of 10 years.

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

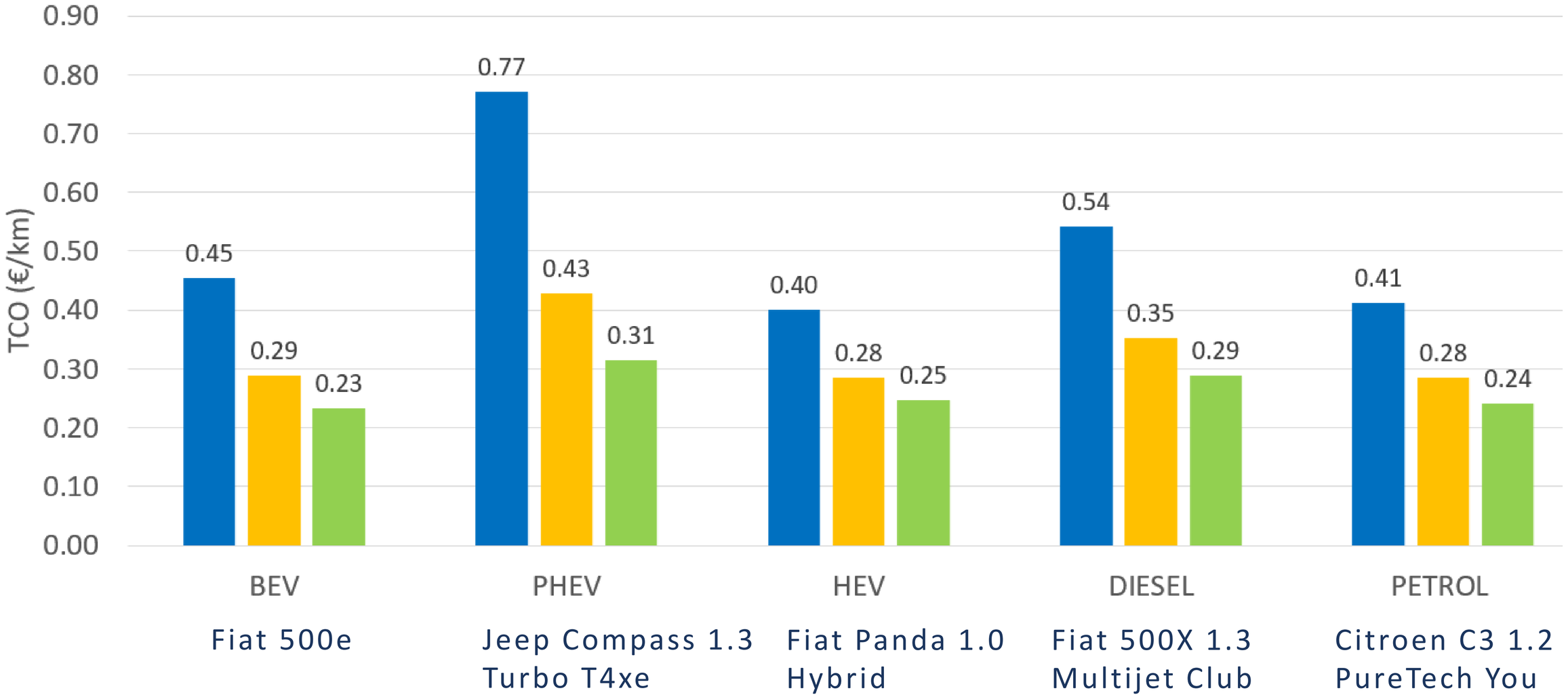
Un milione di case europee sono alimentate a batterie solari

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

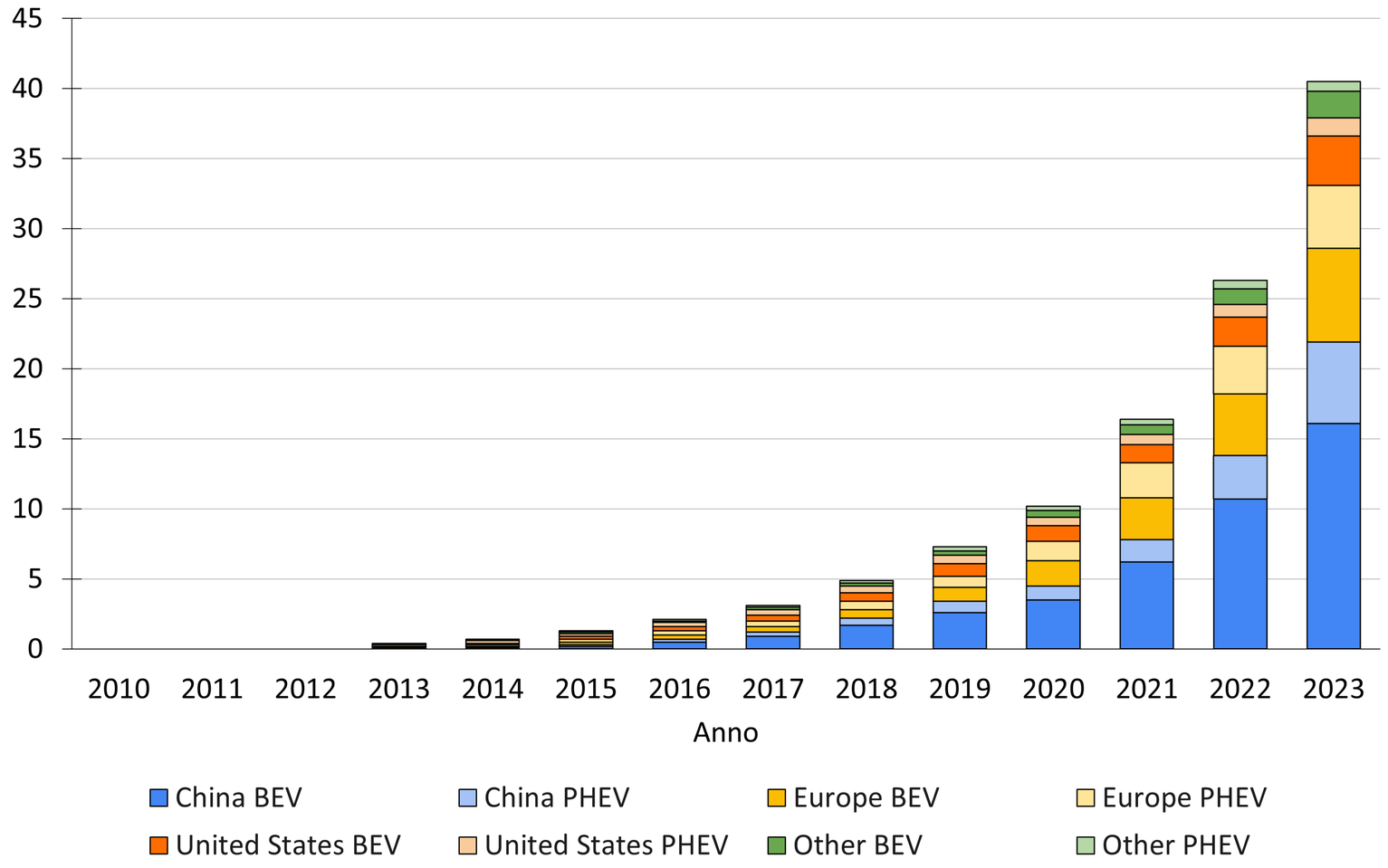
35% of battery e (BEV) e plug-in hydrid (PHEV) in Italy

+ 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

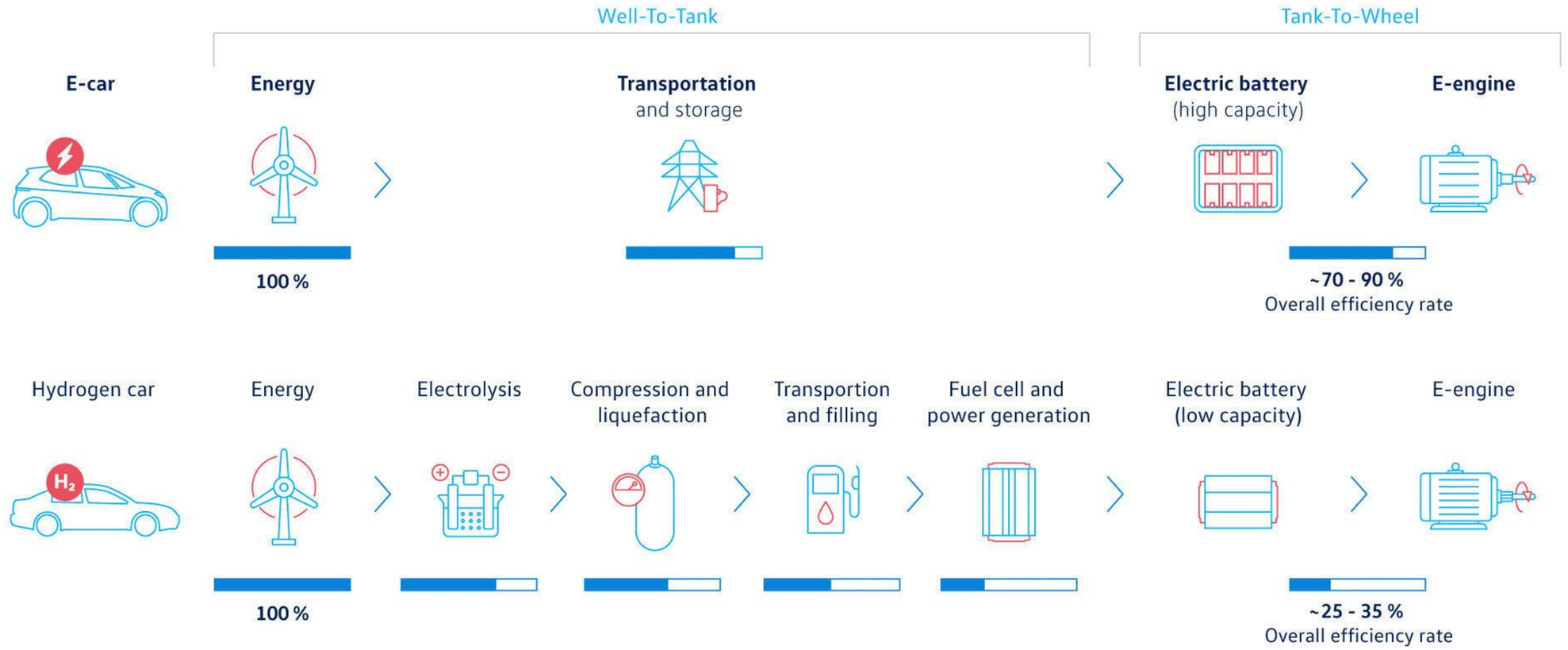


Top selling countries 2023

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**

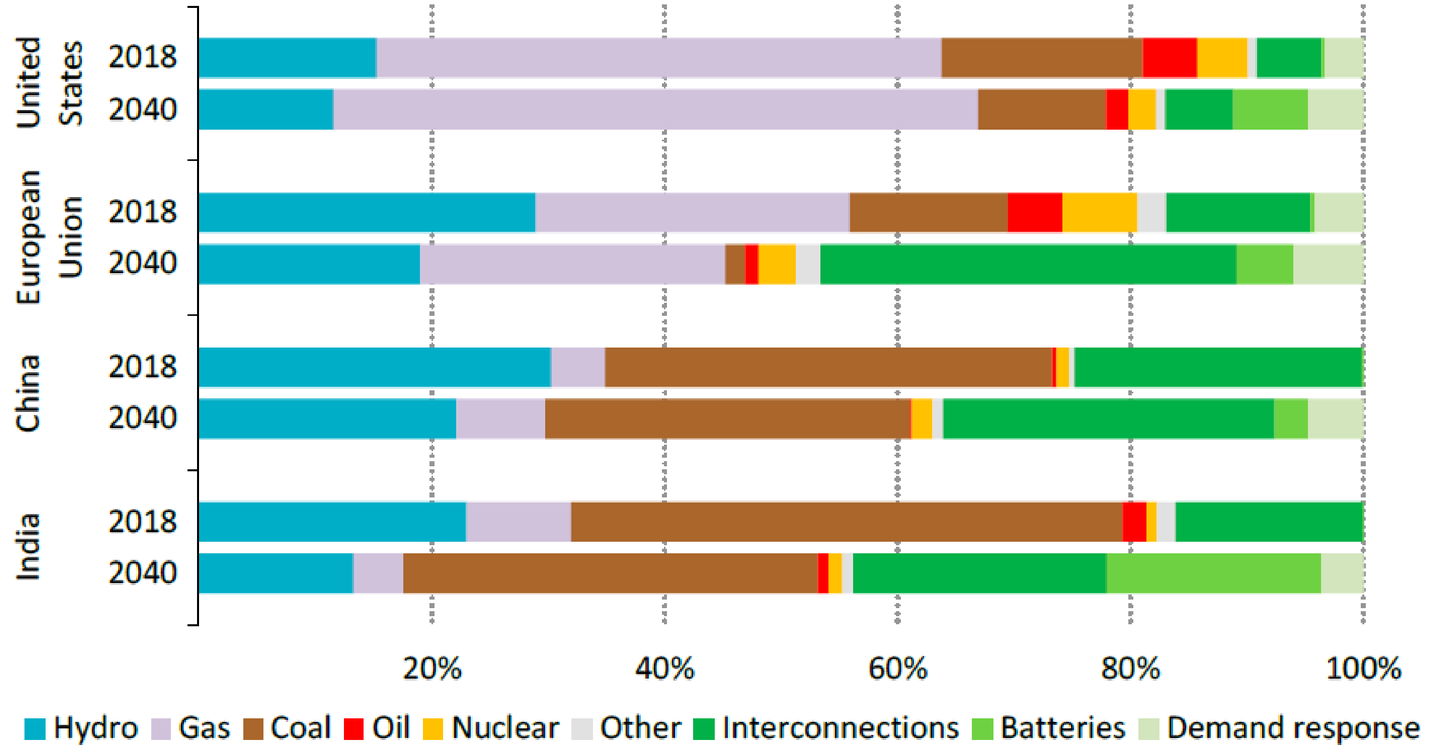
Efficiency rates in comparison using eco-friendly energy



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

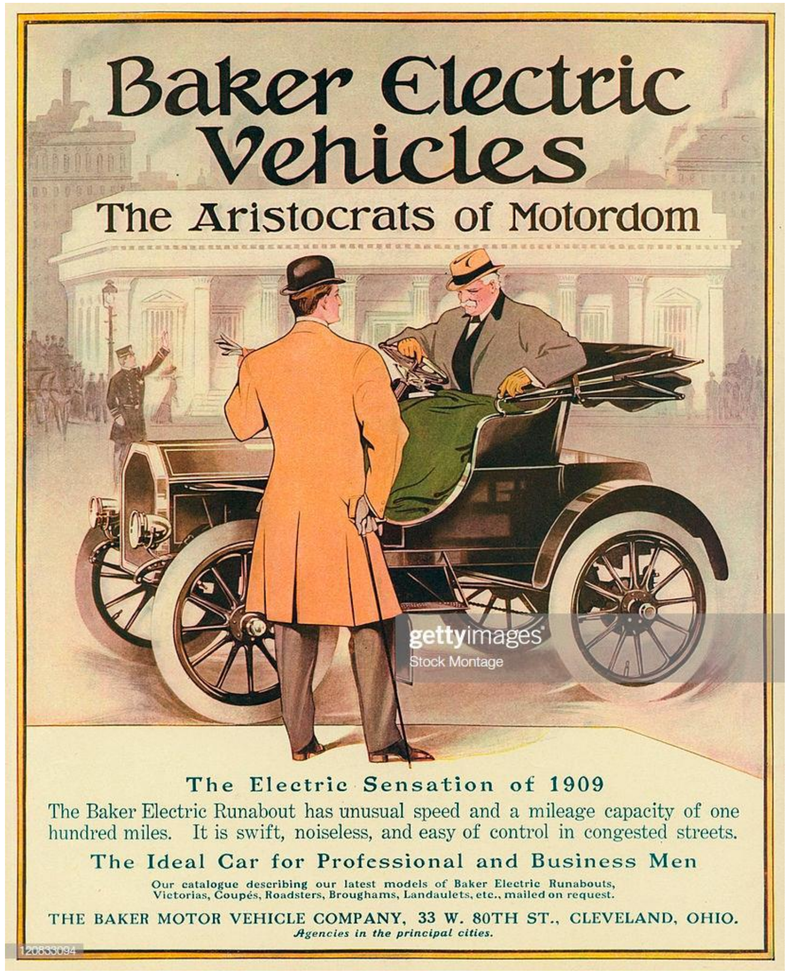
Certo, ma il sistema elettrico è flessibile!!!

Tecnologie abilitanti la transizione 100% rinnovabile

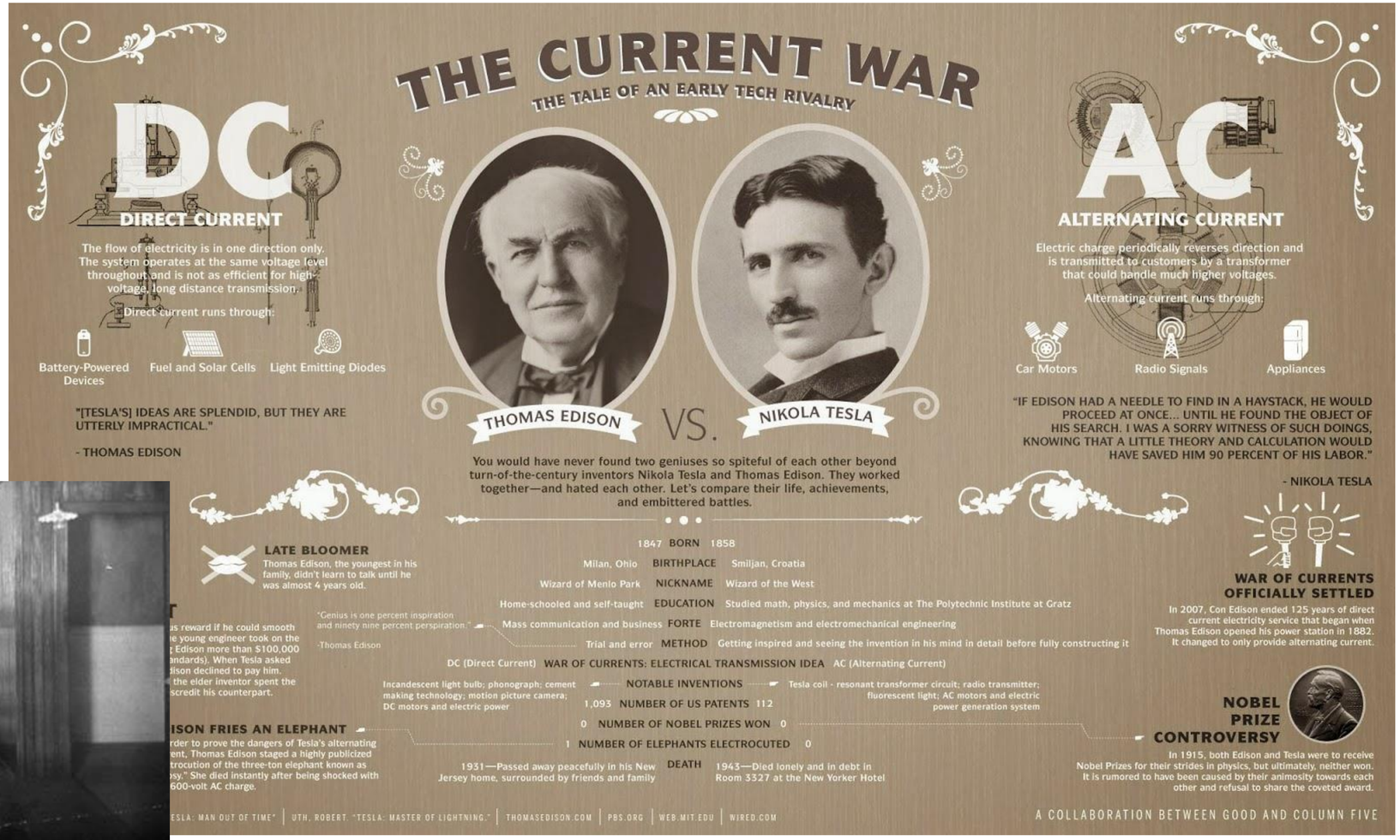
- Fotovoltaico ed eolico sovradimensionati
- Interconnessioni
- Demand response
- Sistemi di stoccaggio (batterie, idroelettrico, termico, …)
- Elettrolizzatori e celle a combustibile (idrogeno)
- Vehicle-to-grid (V2G) and Vehicle-to-home (V2H)
- Corrente continua e generazione distribuita
- Smart Grid (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

Ritorno alla corrente continua

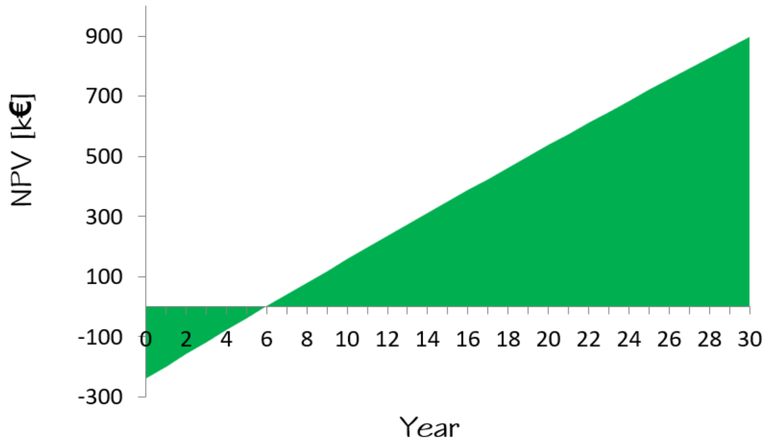


La guerra delle correnti

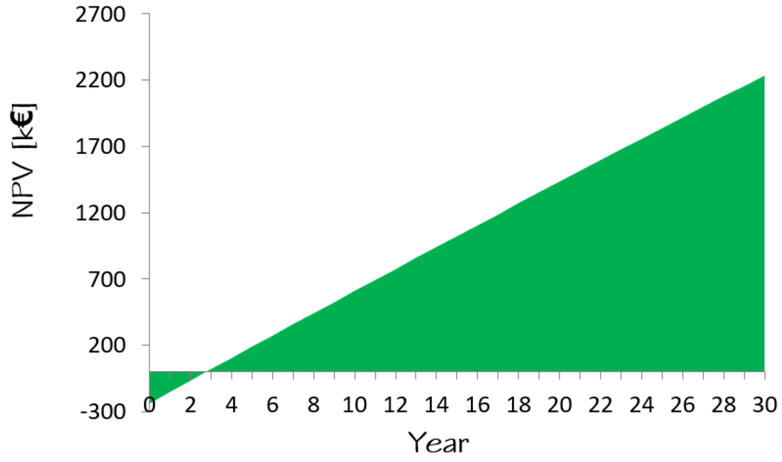


Il ruolo dell’autoconsumo

- 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%

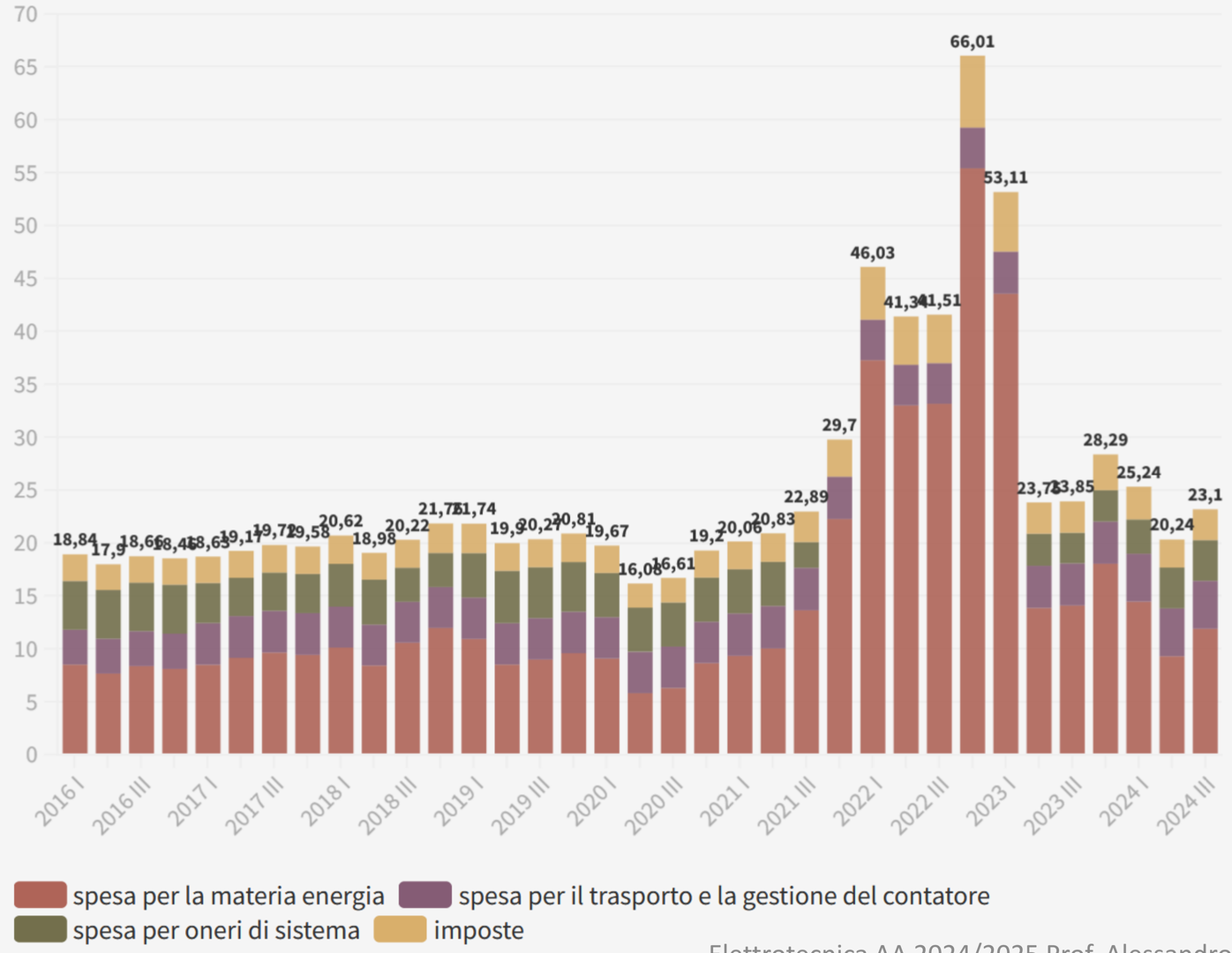


- Potenza 200 kWp
- Autoconsumo 100%
- Prezzo energia elettrica **0.30 €/kWh**
- Costo energia fotovoltaica 0.04 €/kWh
- Tempo di ritorno 2.8 anni
- Rendimento investimento 35%



Il ruolo dell’autoconsumo

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



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 C02 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**