

BOOK 8

HYDROPOWER

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Professor TPA

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TPA

Sharing Experience

Building bridges between the oil industry and academic circles by delivering technical or business-related presentations by professors or experts.



OIL & GAS and ENERGY GLOBAL ISSUES

A Toolbox to understand the World of Energy in the Global Economy

The Toolbox is updated twice a year and benefits from the contributions of TPA Professors:

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Hydroelectricity



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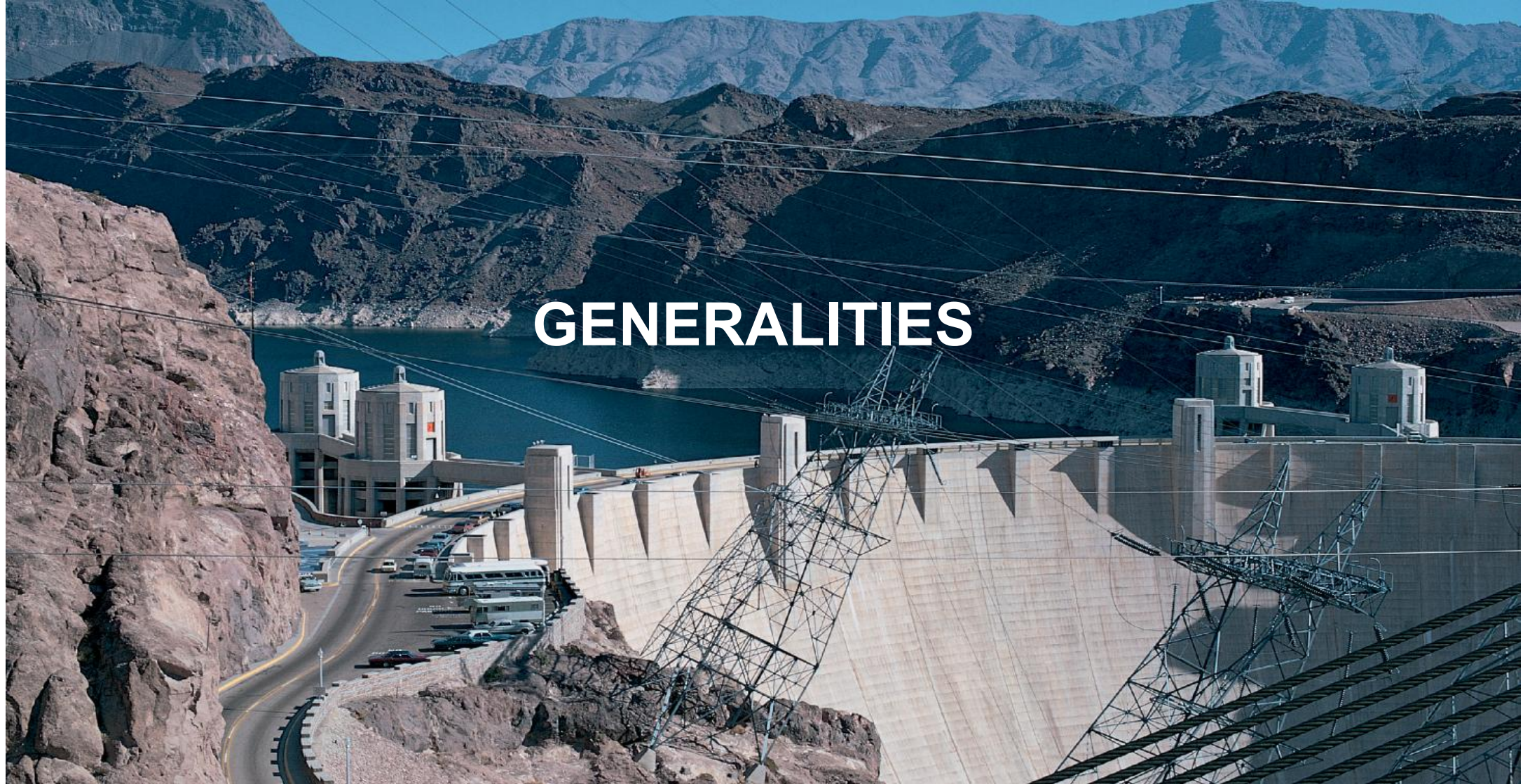
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1. Generalities
2. Hydropower in the world
3. Hydropower in France



PART 1

GENERALITIES

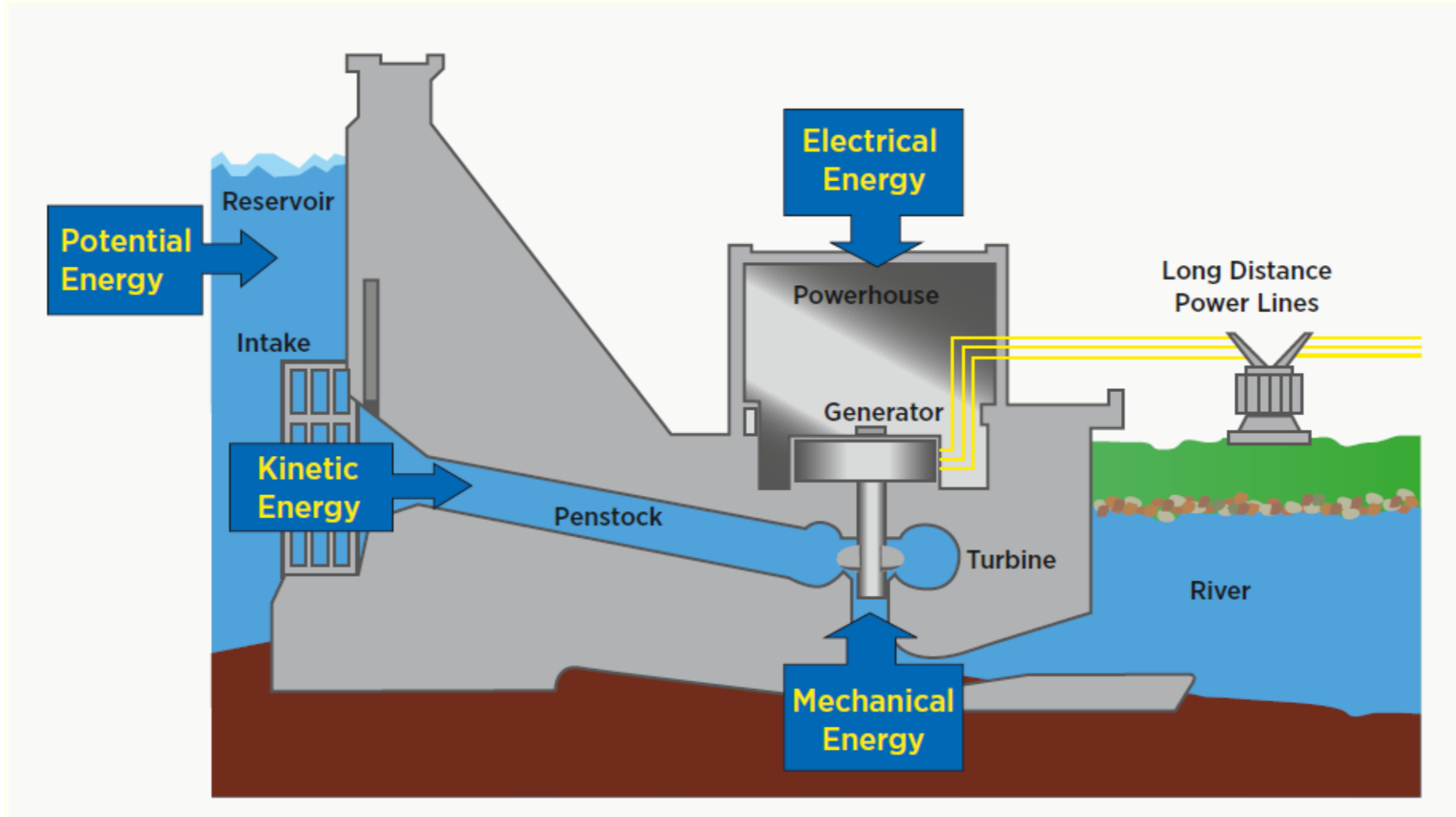


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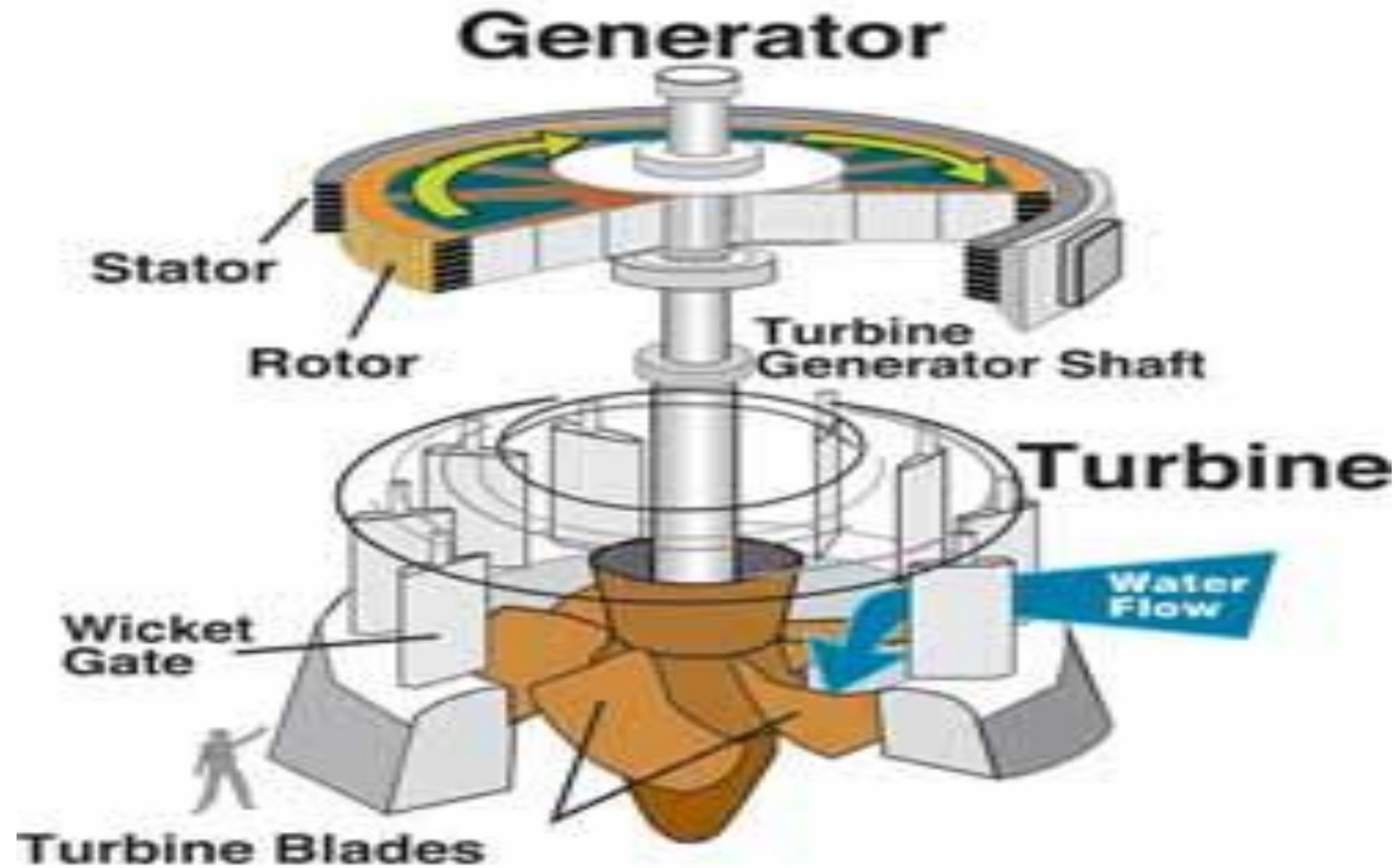
- 1. Generalities**
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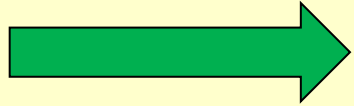
General scheme of a hydroelectric dam



Turbine & Generator



Output Power of a hydroelectric plant (Dam)



$$P_{\max} = \eta \rho g h Q$$

$P_{\max}$ = Maximum Output Power

η = Efficiency of the turbine and installation

ρ = Water density

g = Gravitational constant

h = Head

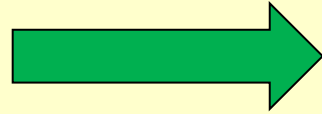
Q = Water flow rate



Output Power of a hydroelectric plant (Run of River)

$$P_{\max} = 1/2\eta\rho Qv^2$$

$$Q = Av$$



$$P_{\max} = 1/2\eta\rho Av^3$$

$P_{\max}$ = Maximum Output Power

η = Efficiency of the turbine and installation

ρ = Water density

A = Swept area of the turbine blades

v = Velocity of water flow



What Dam is it?



Start of operations: 2003, 32 Turbines, Installed Power: 22,5 GW, Max Production: 100 TWh



What Dam is it?



Start of operations: 2003, 32 Turbines, Installed Power: 22,5 GW, Max Production: 100 TWh



Baihetan Dam - China



**Start of operations: June 2021 - 16 turbines, Installed Power: 16 GW,
Production: 62 TWh**



Hydroelectric power disadvantages

(From US Geological Survey)

- **High investment costs**
- **Hydrology dependent (precipitation)**
- **In some cases, inundation of land and wildlife habitat**
- **In some cases, loss or modification of fish habitat**
- **Fish entrainment or passage restriction**
- **In some cases, changes in reservoir and stream water quality.**
- **In some cases, displacement of local populations**
- **Greenhouse gases emissions ??**



Some comments about Hydropower and Greenhouse Gases emissions

- **Hydroelectric dams can produce carbon dioxide and methane,**
- **Carbon tied up in trees and other plants is released when the reservoir is initially flooded and the plants rot. Then plant matter settling on the reservoir's bottom decomposes without oxygen, resulting in a build-up of dissolved methane. This is released into the atmosphere when water passes through the dam's turbines.**
- **Seasonal changes in water depth mean there is a continuous supply of decaying material. In the dry season plants colonize the banks of the reservoir and are engulfed when the water level rises. For shallow-shelving reservoirs these “hydraulic drawdown” regions can account for several thousand square kilometers.**

From New Scientist 2005



PART 2

HYDROPOWER IN THE WORLD



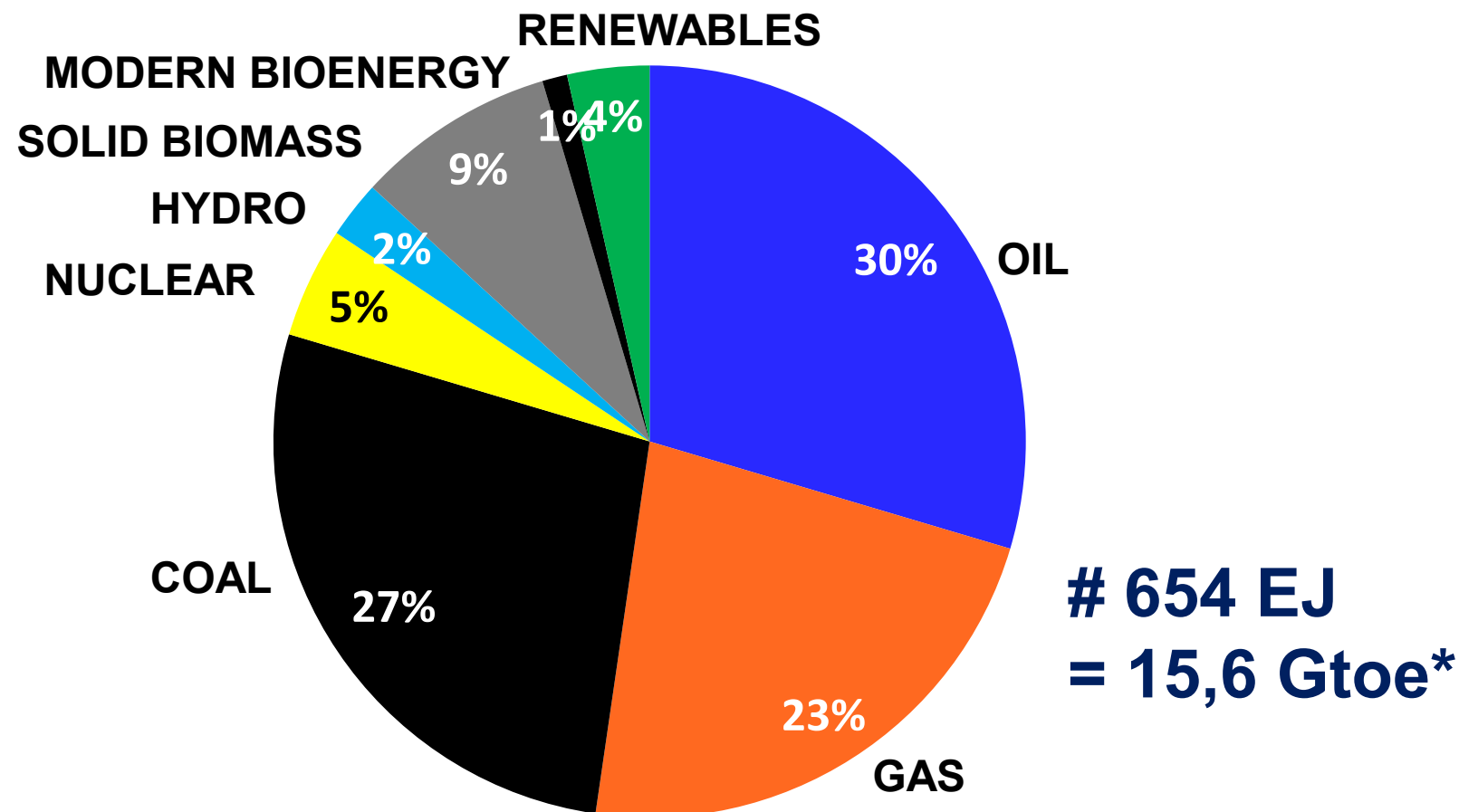
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World Primary Energy Demand – 2024

+ 2,0% vs 2023



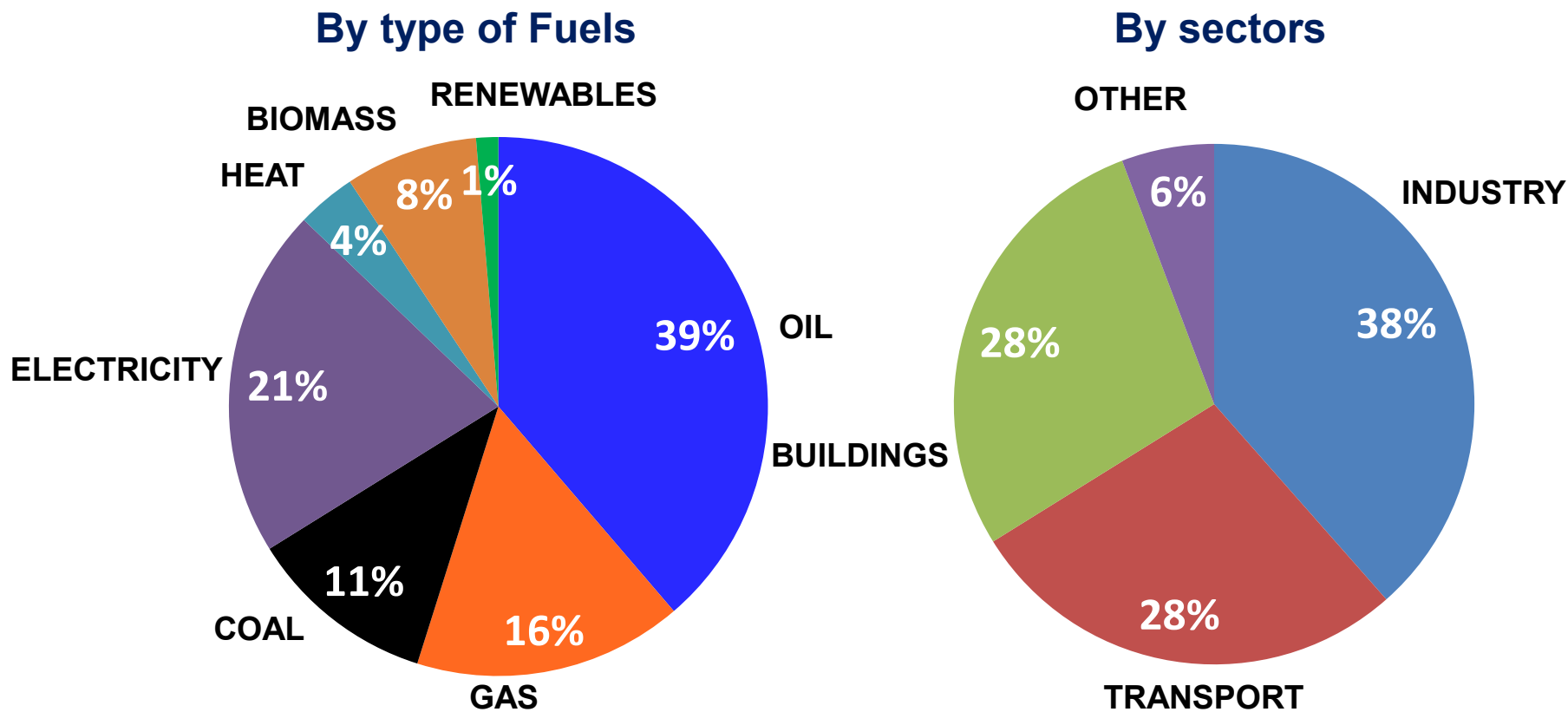
* out of which electricity generation # 6,5 Gtoe # 31 100TWh (eq. Primary Energy)

Source: Data from IEA WEO 2025. Nota: Sums might not be equal to 100% due to rounding

Solid Biomass: tradit. wood & charcoal & solid residues. Modern Bioenergy: liquid & gaseous bioenergy (biofuels & biogases) Renewables: Solar, Wind, Geothermal, Marine Energy,...



Total Final Consumption – 2024 + 2,0% vs 2023



453 EJ = 10,8 Gtoe

Nota: Sums might not be equal to 100% due to rounding

OTHER relates to agricultural sector & other non-energy use

Source: Data from IEA WEO 2025



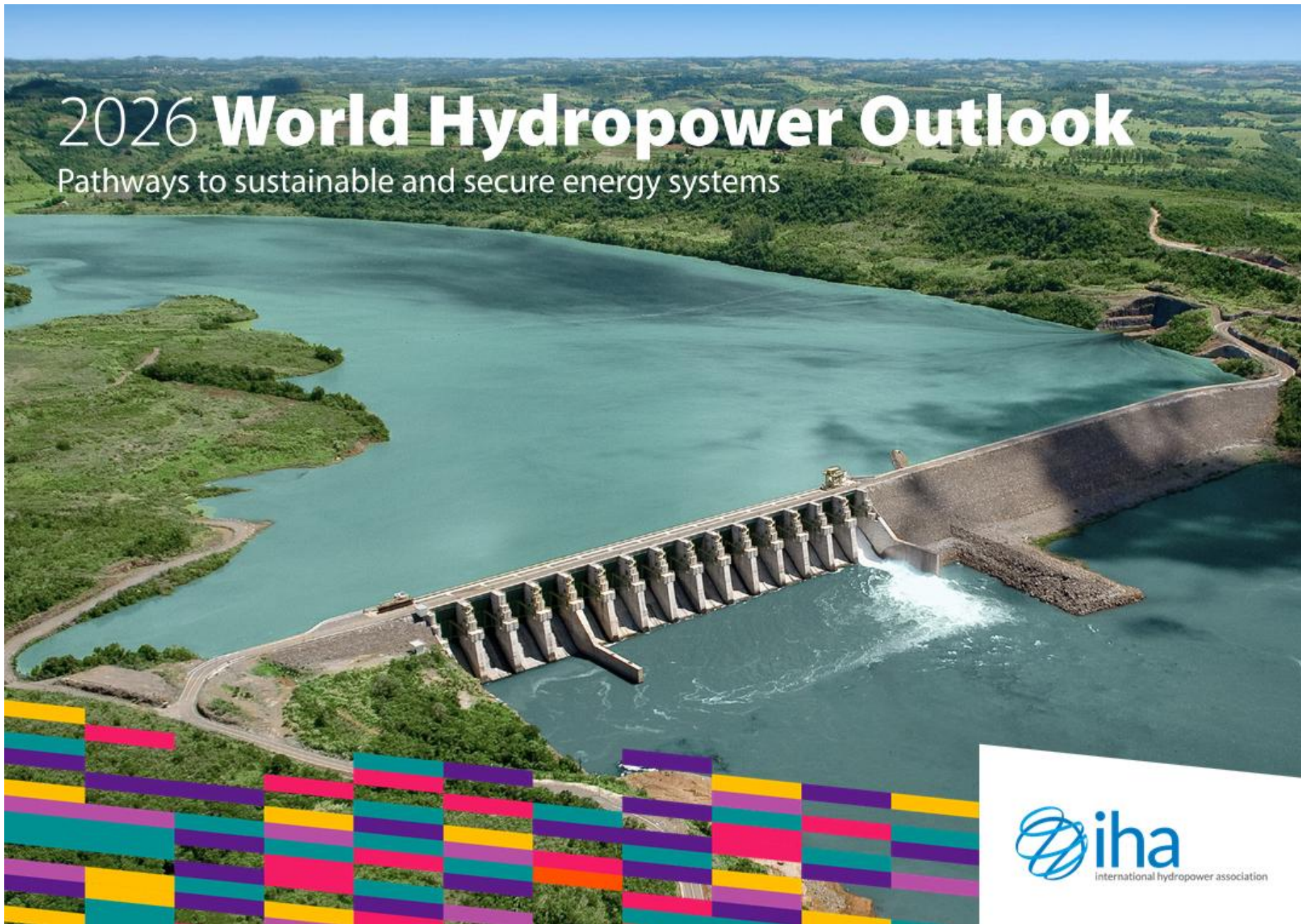


Hydroelectric Power and **Biomass** are today the most important contributors to renewable energy in the primary energy mix (12%)

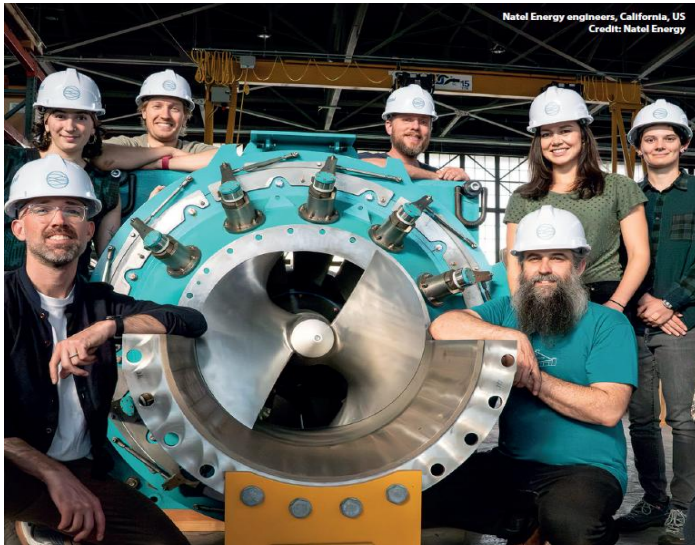


2026 World Hydropower Outlook

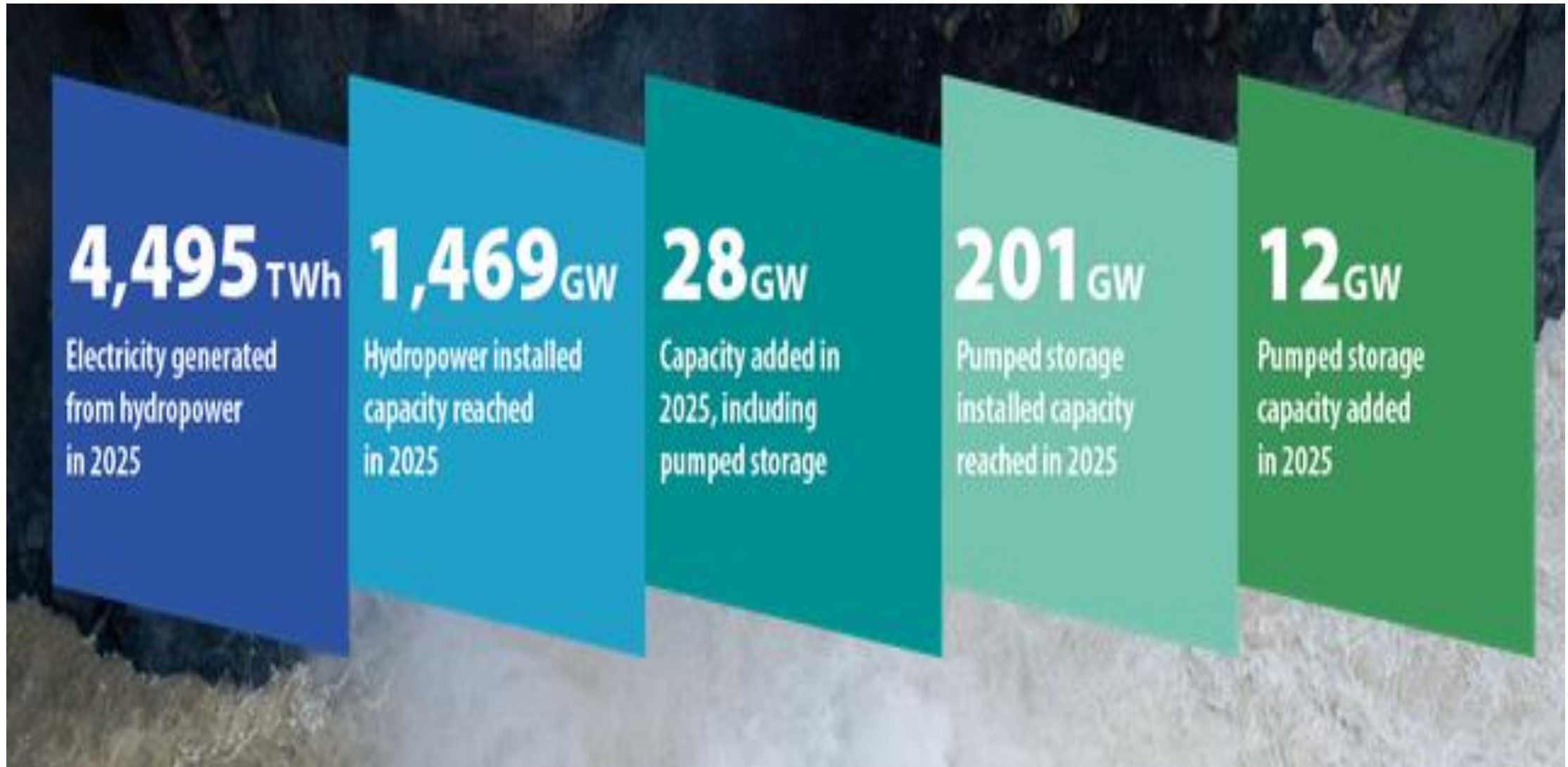
Pathways to sustainable and secure energy systems



Hydropower in 2025



Hydropower in 2025

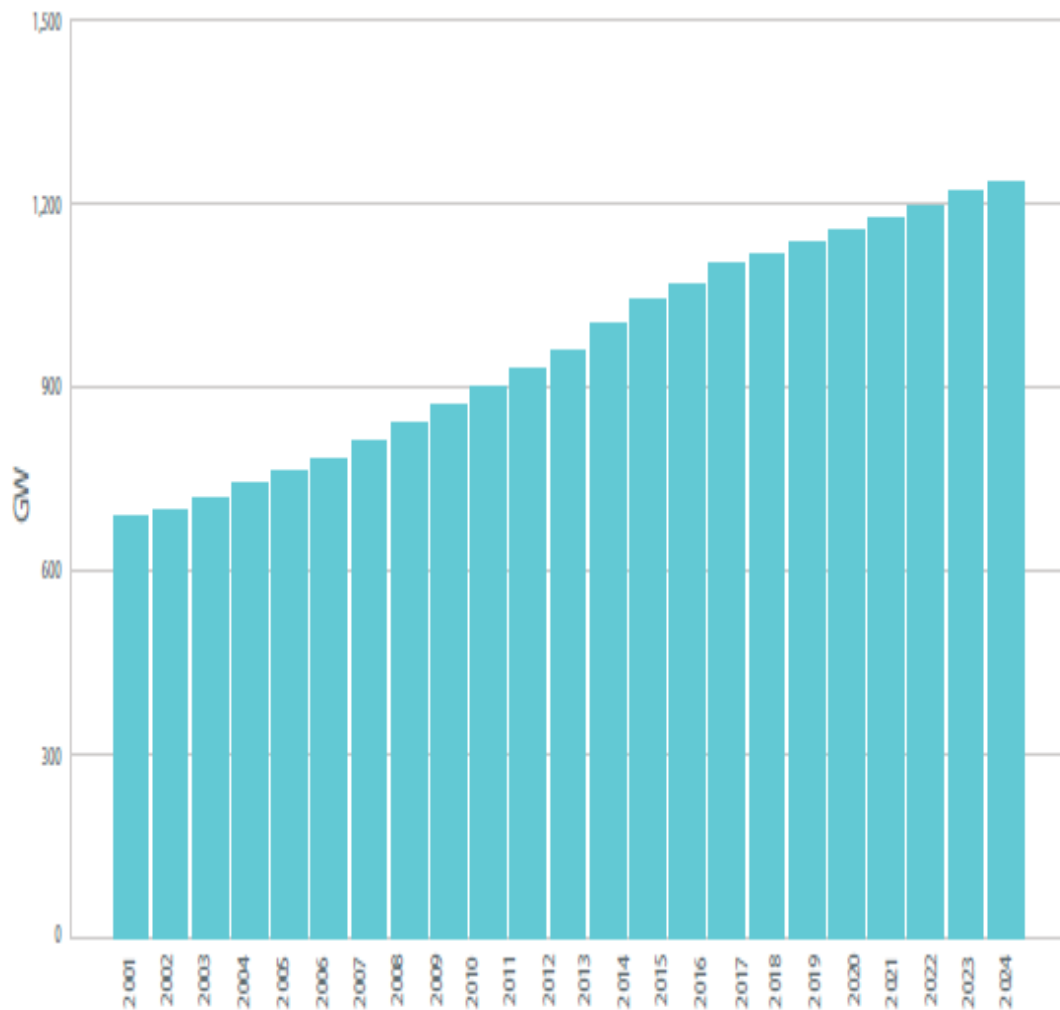


Source: International Hydropower Association
(IHA)World Hydropower Outlook 2026

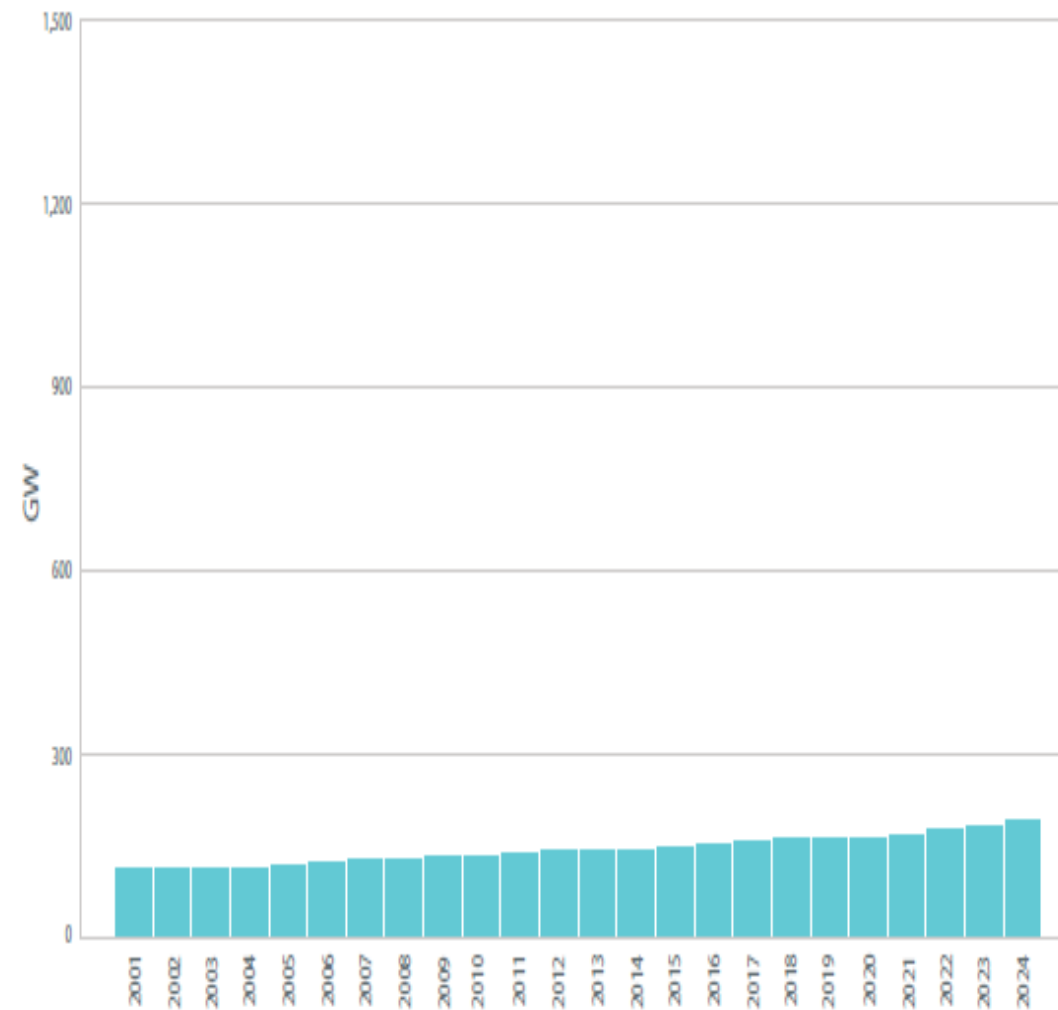


Hydropower – Installed Capacity 2001 – 2024

Conventional hydropower cumulative capacity



Pumped storage hydropower cumulative capacity

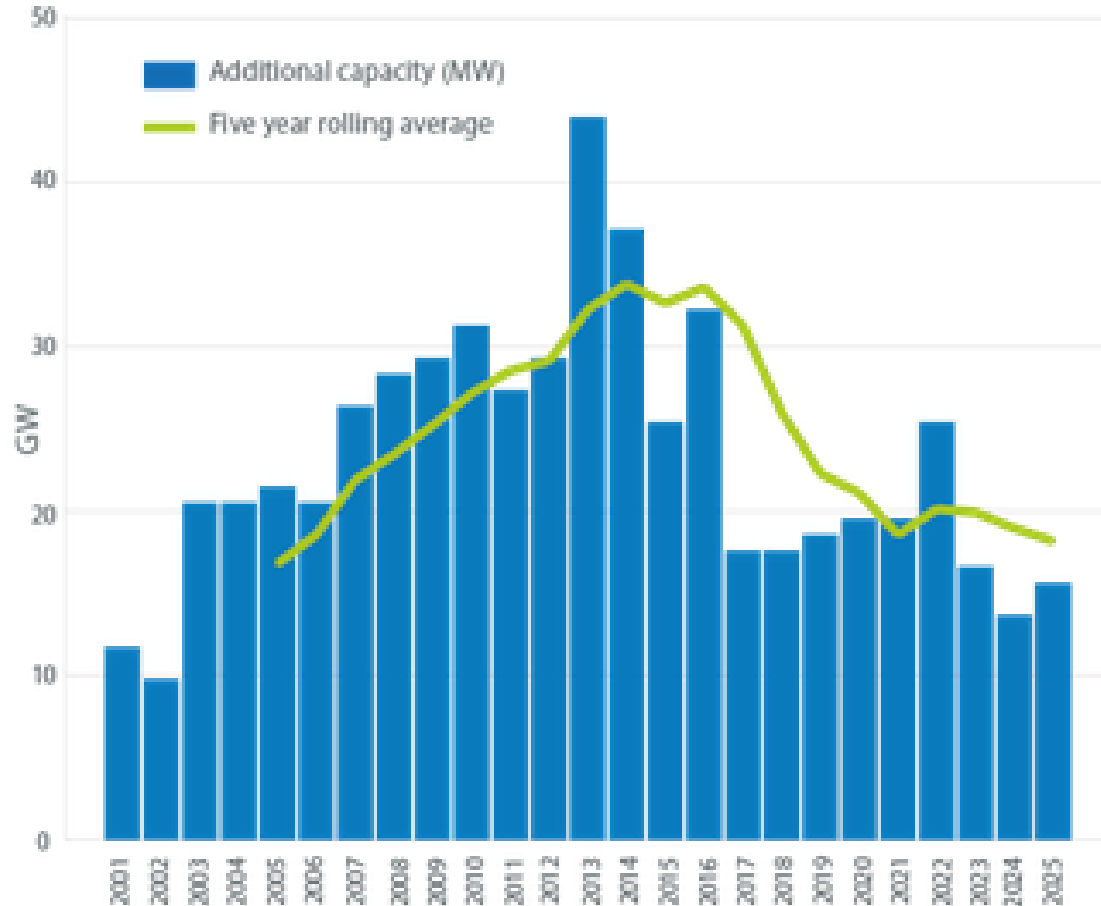


Source: IHA World Hydropower Outlook 2025
PSH: Pumped Storage Hydro

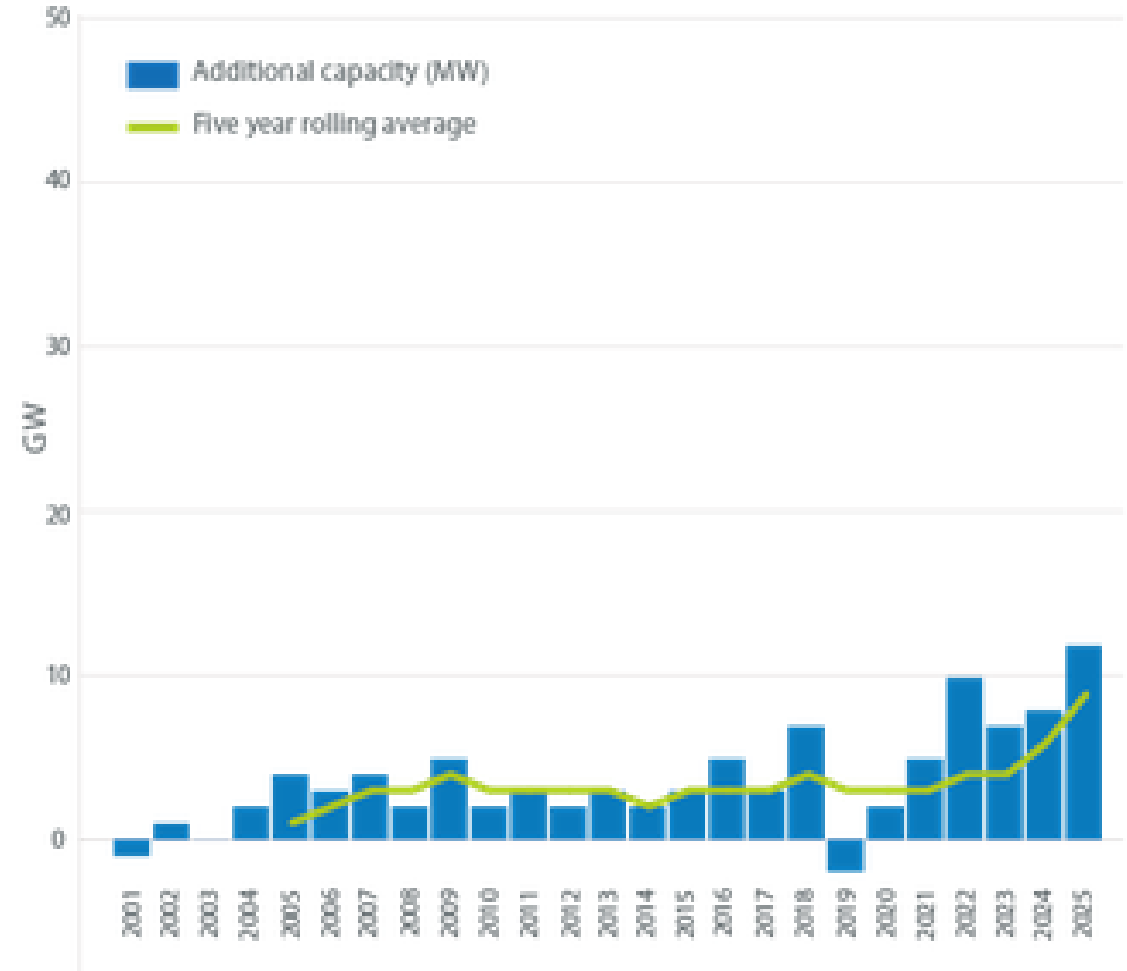


Hydropower – New Installed Capacity 2001 – 2025

Conventional hydropower annual additions and five-year rolling average



Pumped storage annual additions and five-year rolling average



Source: IHA World Hydropower Outlook 2025
PSH: Pumped Storage Hydro

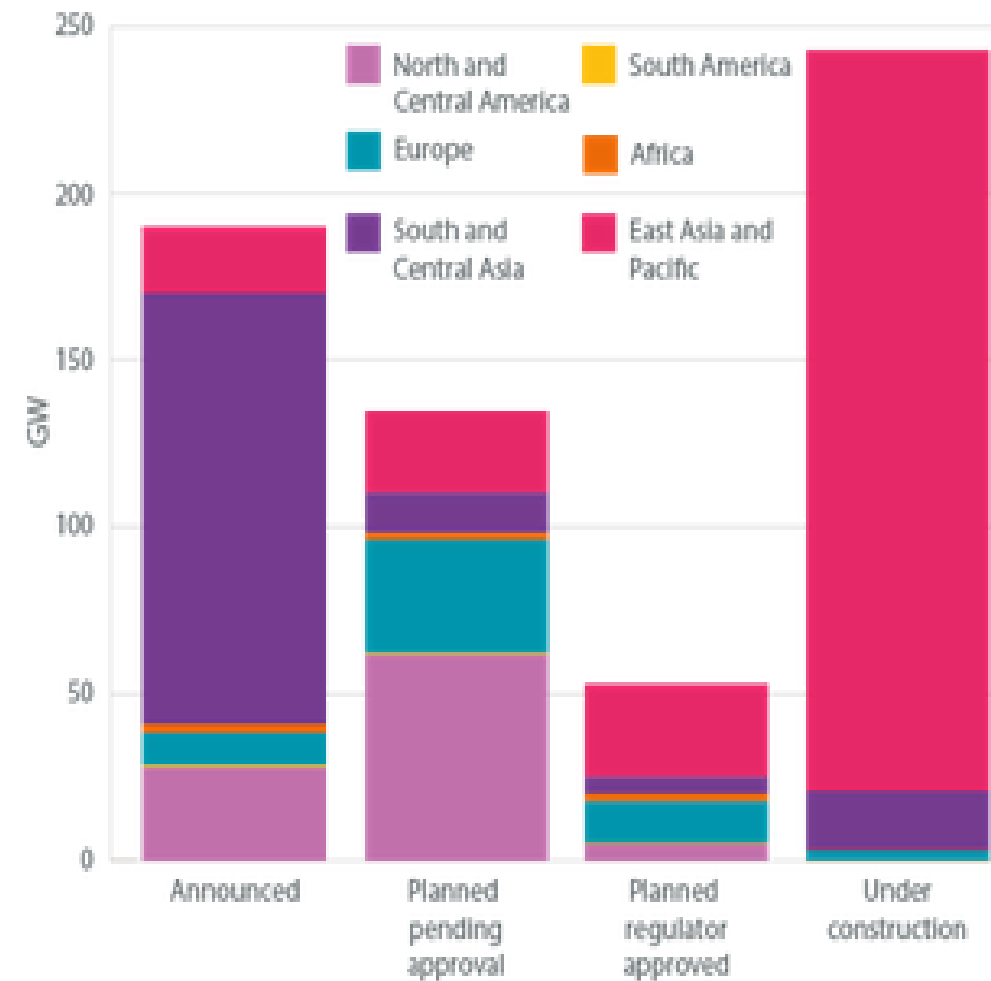


Hydropower – Installed Capacity projections

Conventional hydropower capacity pipeline



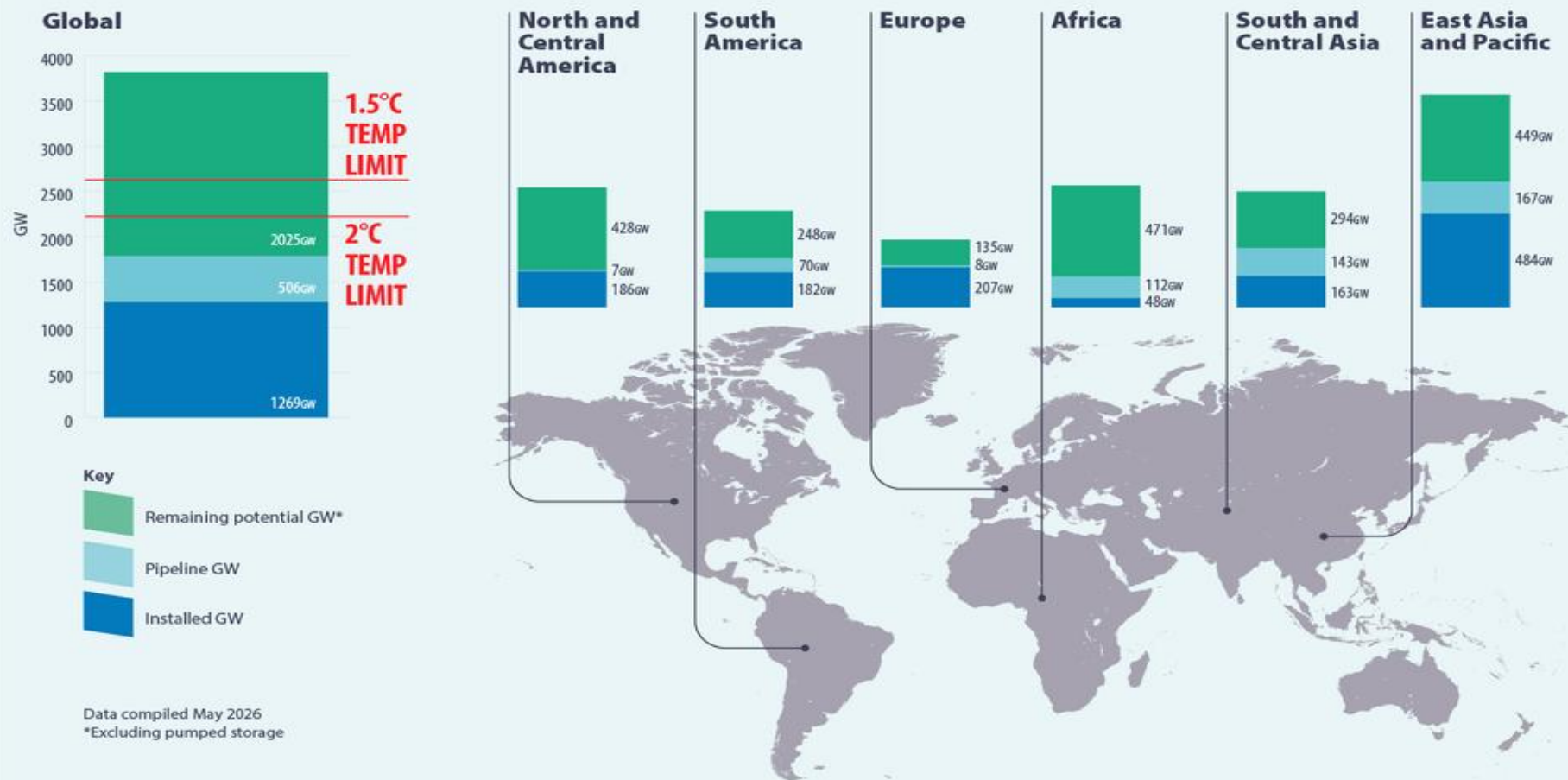
Pumped storage capacity pipeline



Source: IHA World Hydropower Outlook 2026
PSH: Pumped Storage Hydro

Hydropower – Global Capacities vs Climate Change objectives

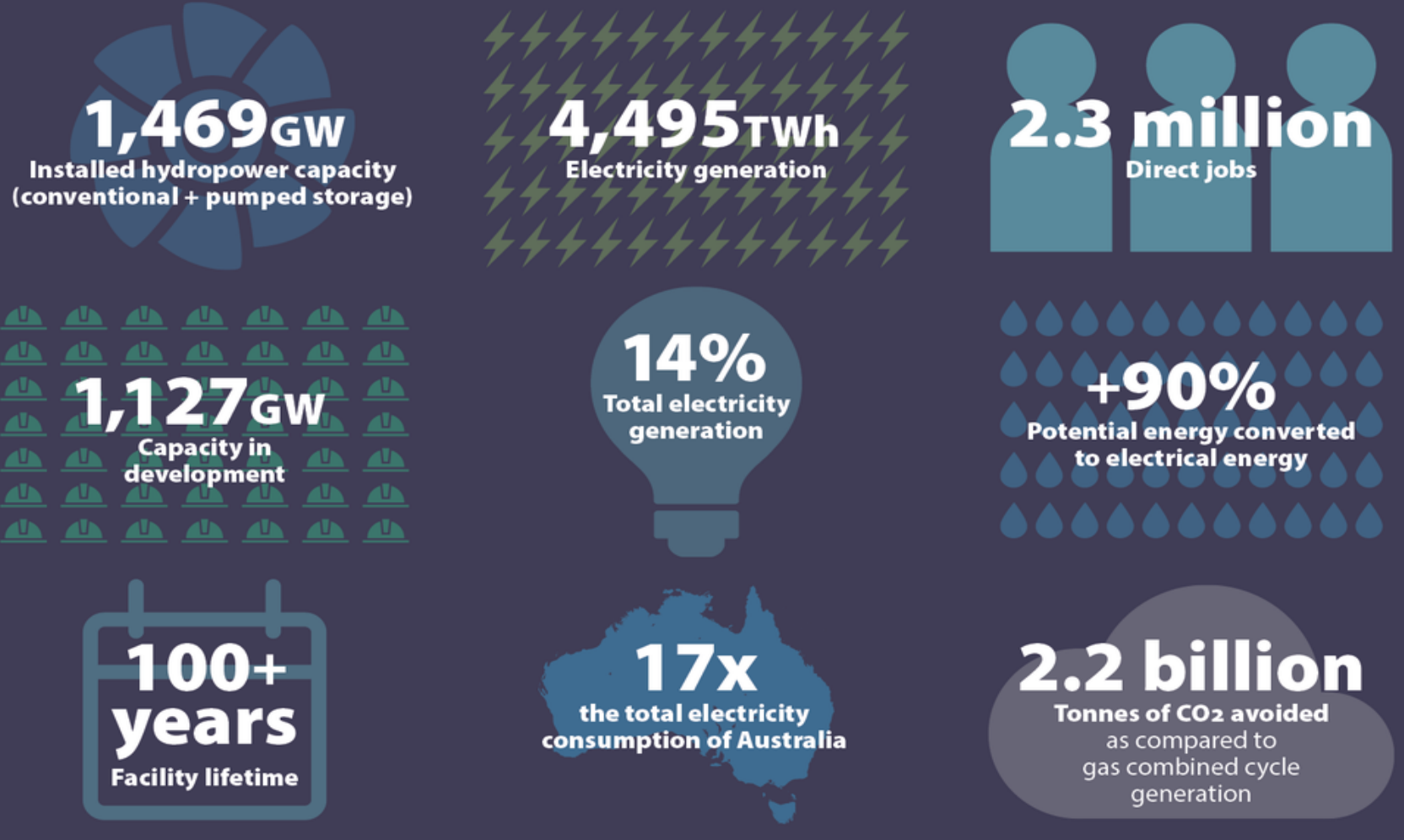
Installed, pipeline and potential for conventional hydropower capacity



Source: IHA World Hydropower Outlook 2026
PSH: Pumped Storage Hydro

Hydropower in 2025

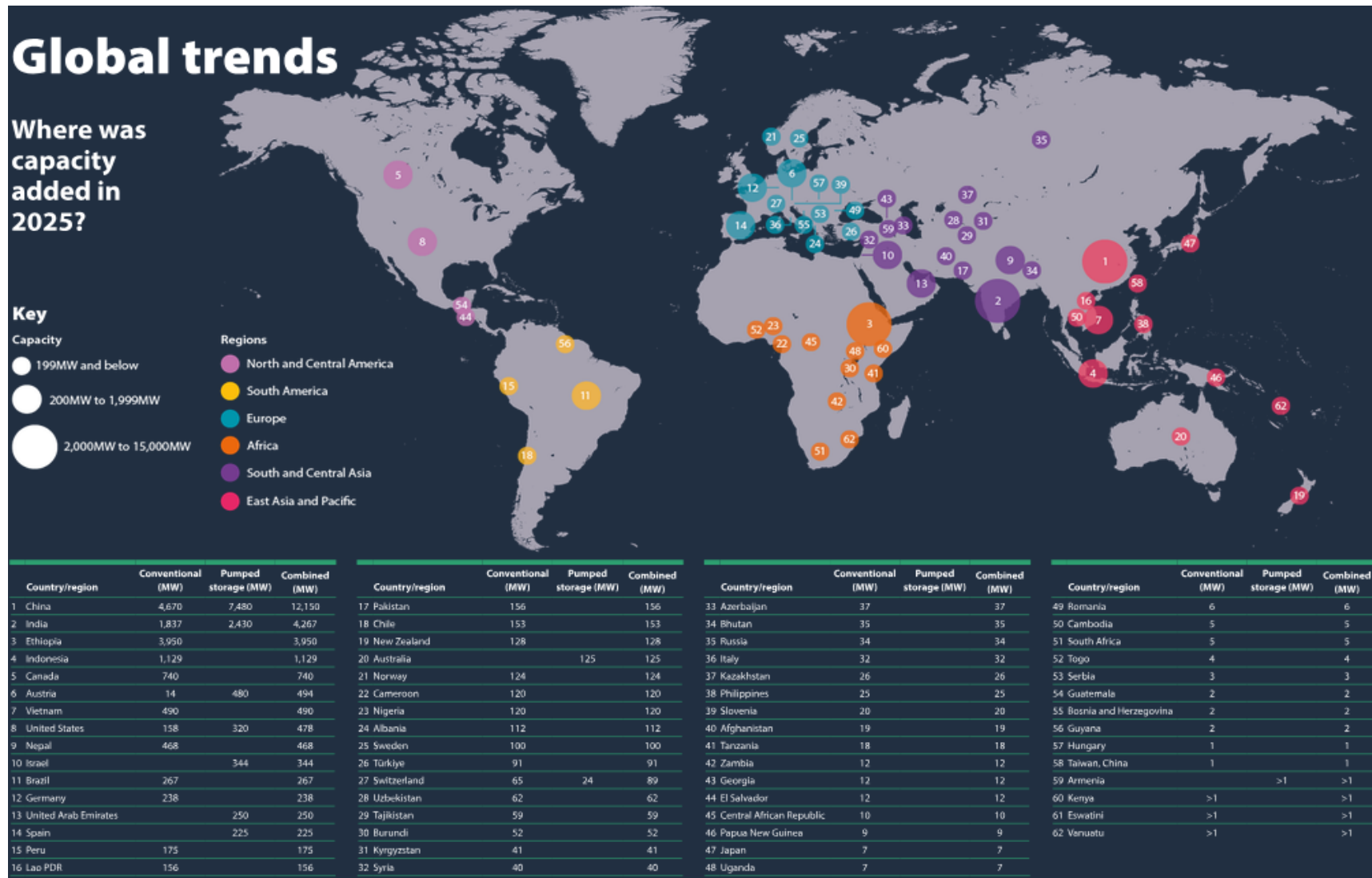
Hydropower's global impact in numbers (2025)



Source: International Hydropower Association
(IHA) World Hydropower Outlook 2026



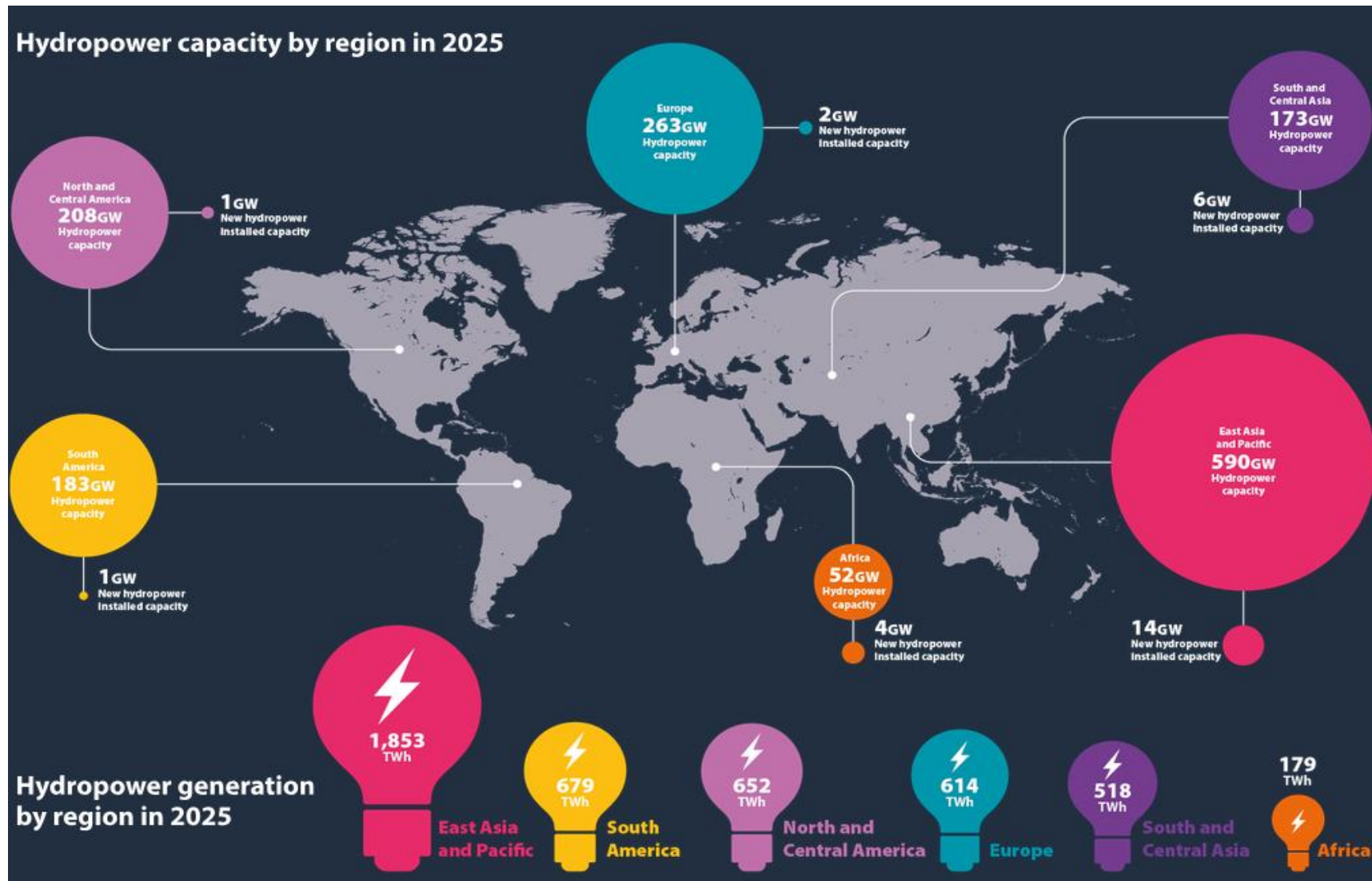
Hydropower in 2025



Source: International Hydropower Association
(IHA) World Hydropower Outlook 2026



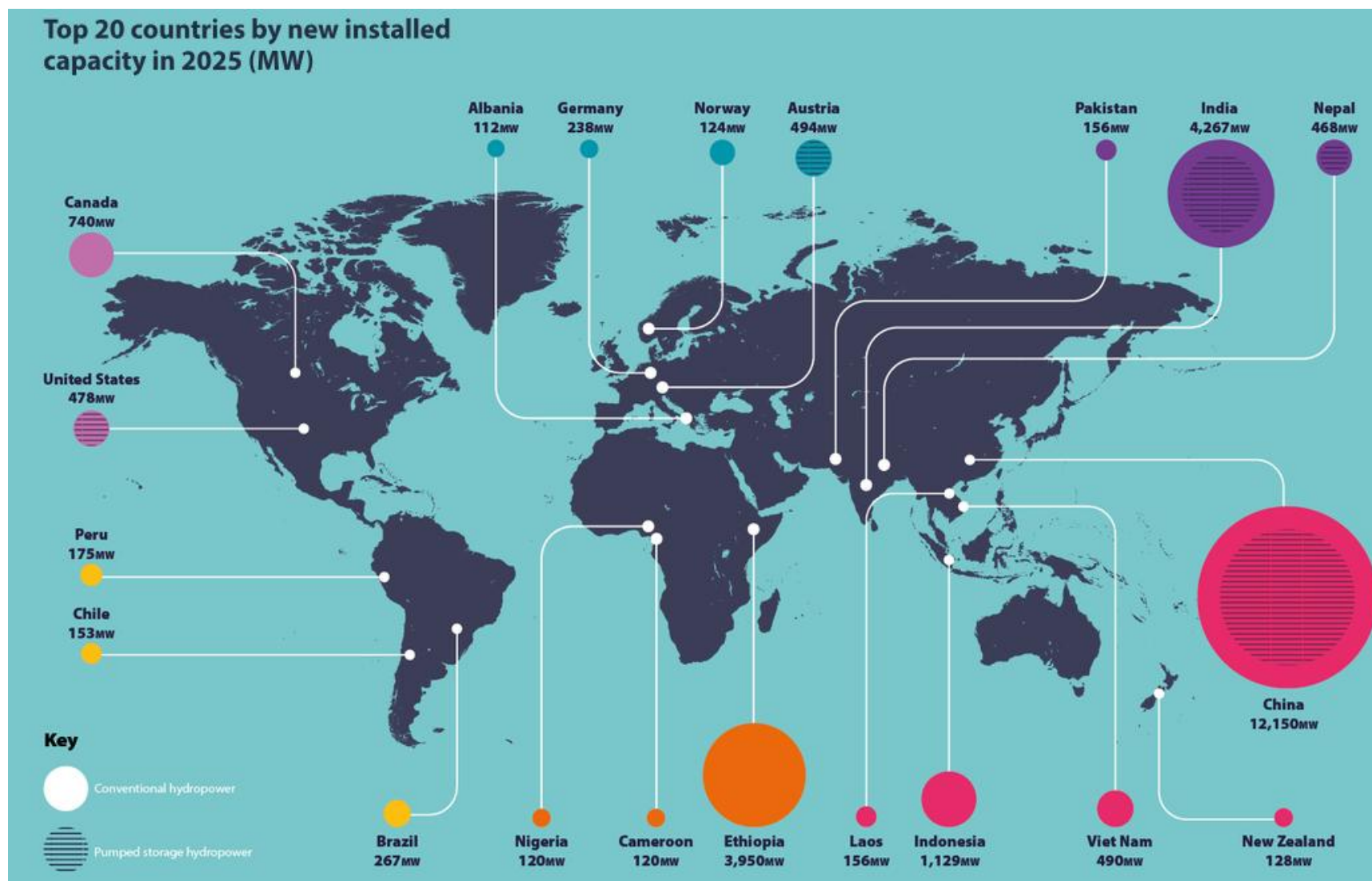
Hydropower in 2025



Source: International Hydropower Association
(IHA) World Hydropower Outlook 2026

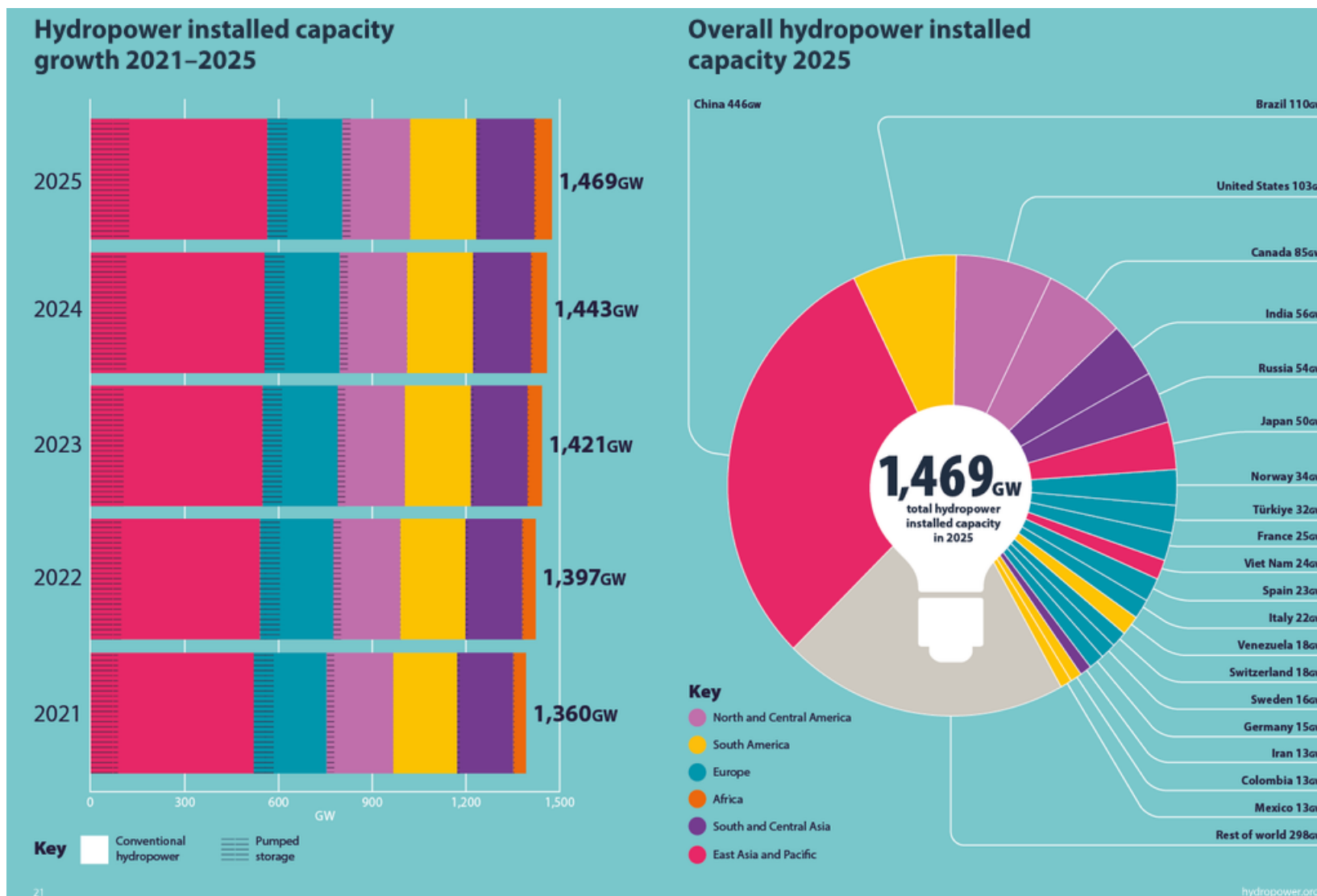


Hydropower in 2025



Source: International Hydropower Association
(IHA) World Hydropower Outlook 2026

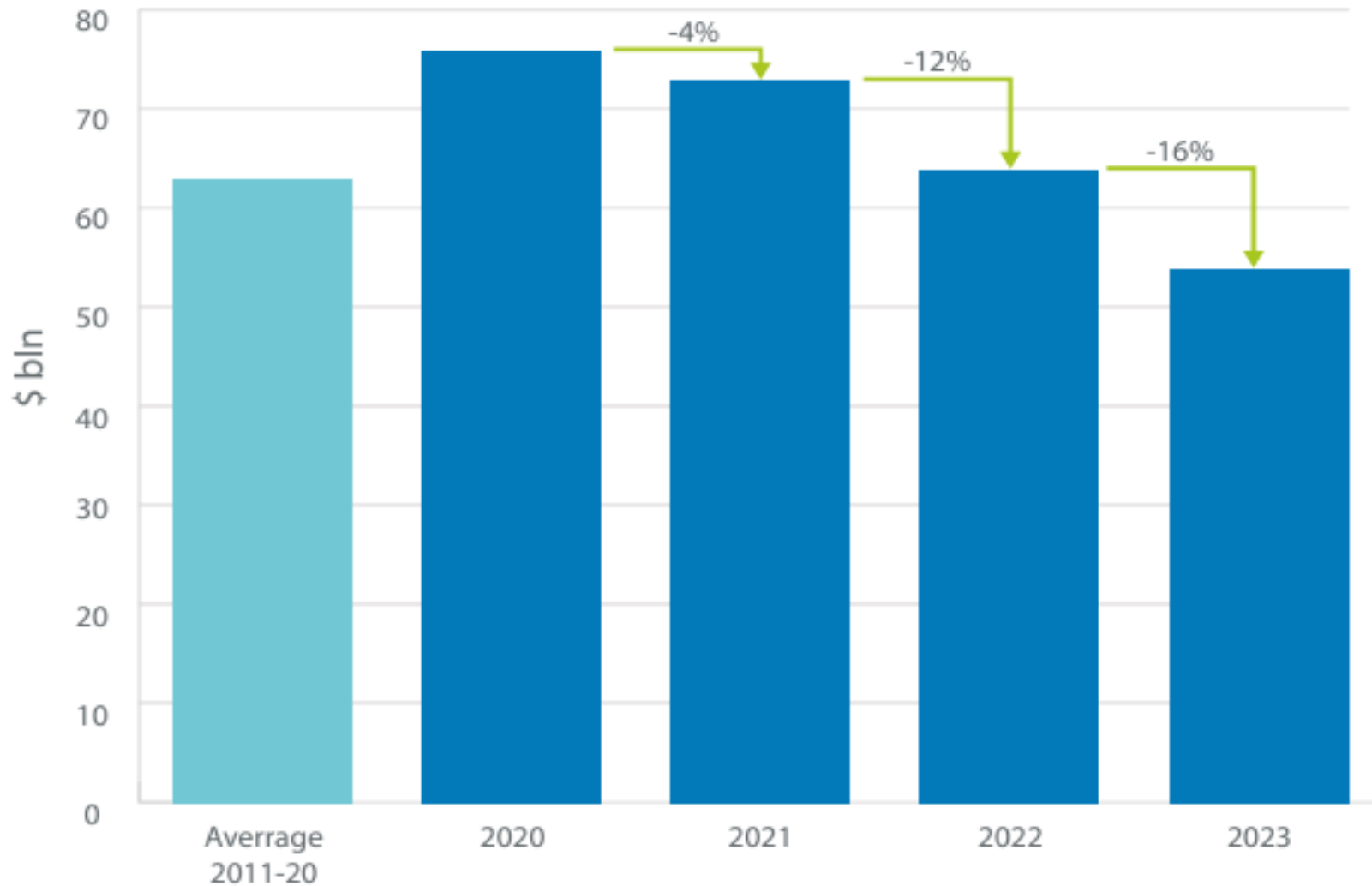
Hydropower in 2025



Source: International Hydropower Association (IHA) World Hydropower Outlook 2026



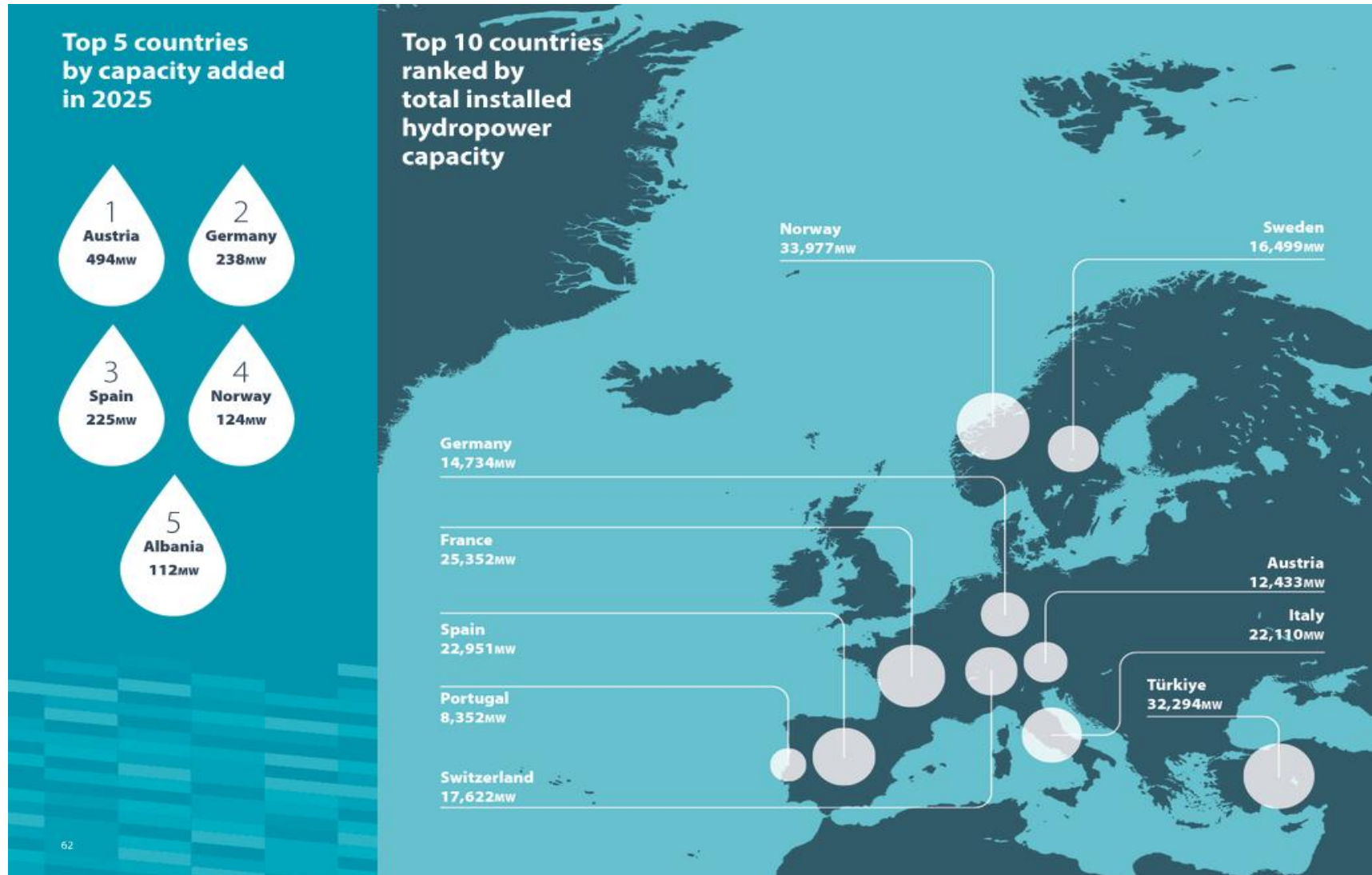
Hydropower Investments 2011 - 2023



Source: International Hydropower Association
(IHA) World Hydropower Outlook 2024



Hydropower in Europe in 2025



Source: International Hydropower Association
(IHA) World Hydropower Outlook 2026

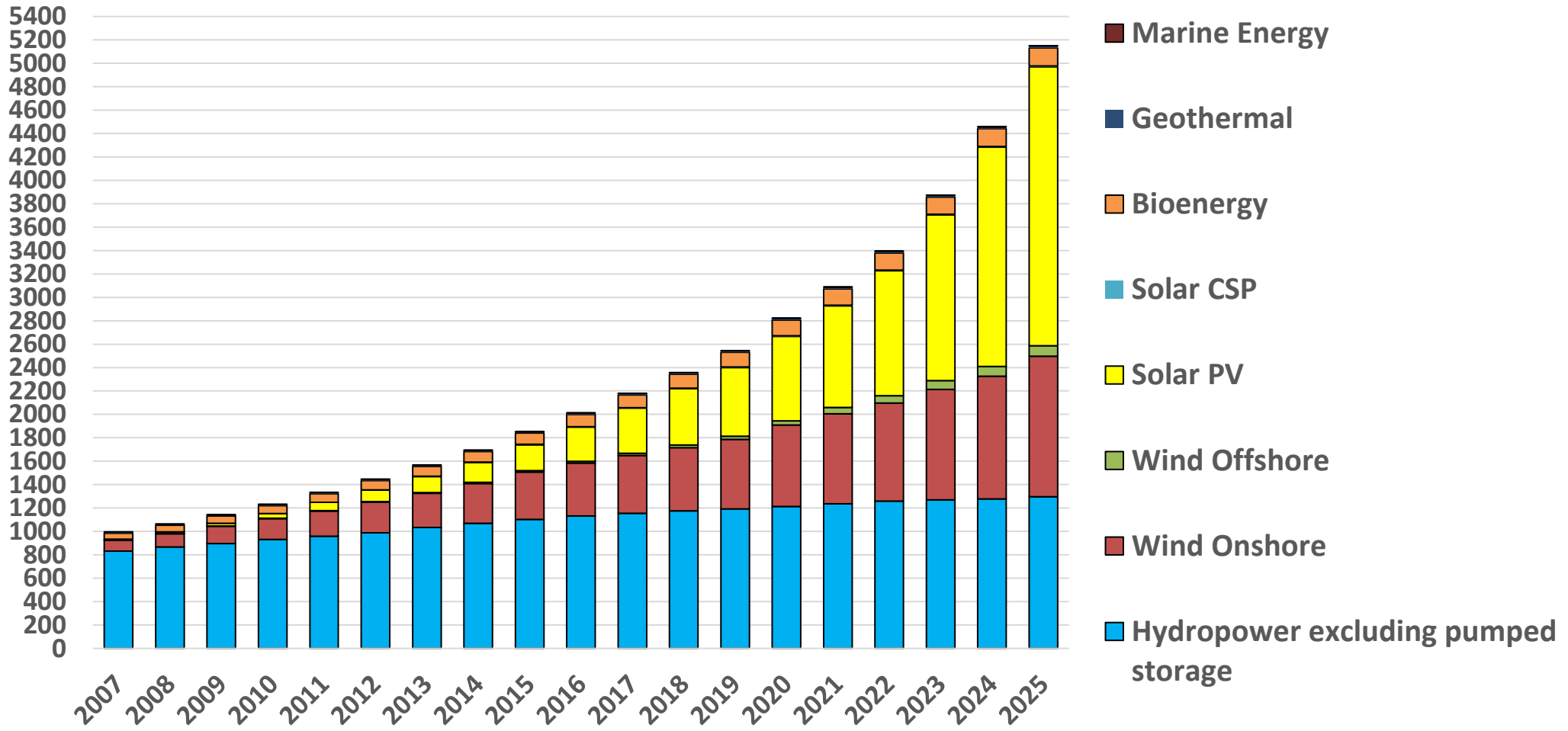
Hydropower is an important part of Renewable Energies

- Total world electricity generation in 2025 # 31 200 Twh. Total installed capacity # 10 200 GW.
- Hydropower is the 3rd source of energy in the World for Electricity generation (15%) after coal (34%) and gas (22%) # 5 400 TWh in 2024 with installed capacity # 1 460 GW (including pump storage) in 2025.
- Global potential # 16 000 TWh/year (x4)
- In 2024, Hydropower represents 46% of renewable electricity in the world
- Several top countries produce more than # 50% of their electricity from hydropower in 2024:
 - ❖ Bhutan: 100%
 - ❖ Norway: 89%
 - ❖ Venezuela: 76%
 - ❖ Iceland: 70%
 - ❖ Brazil: 60%
 - ❖ Austria: 59%
 - ❖ Canada: 58%
 - ❖ Others: Switzerland, Other Latin America & Africa countries,



Evolution of Renewable Power Capacity, including Hydropower: 1000 GW in 2007, # 5200 GW in 2025

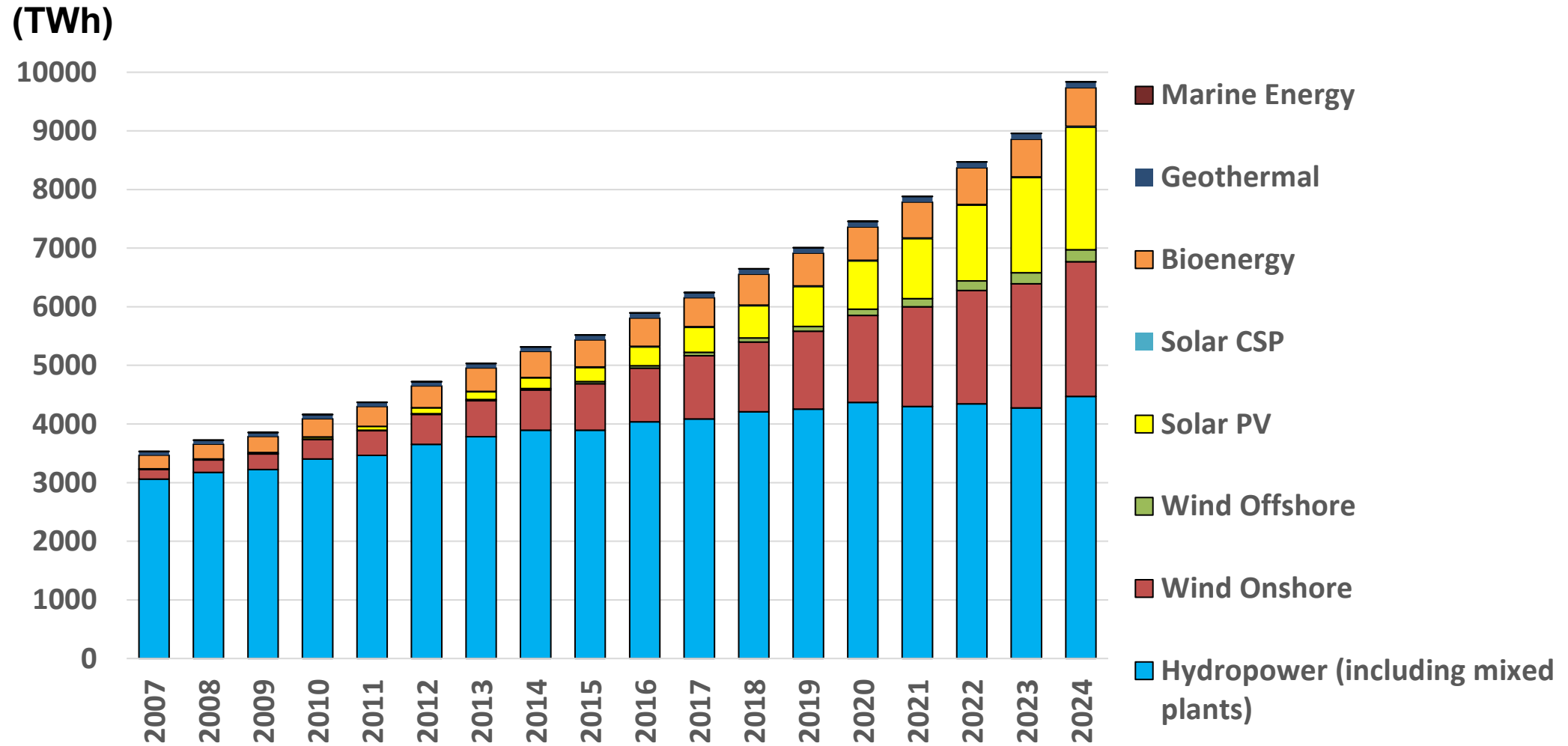
(GW)



Source: ChG/Data from IRENA Renewable Capacity Statistics 2025

Bioenergy includes solid & liquid biofuels, bagasse, renewable waste

Key position of Hydropower in the Renewable Electricity Generation worldwide



Source: Data from IRENA Renewable Energy Statistics 2026

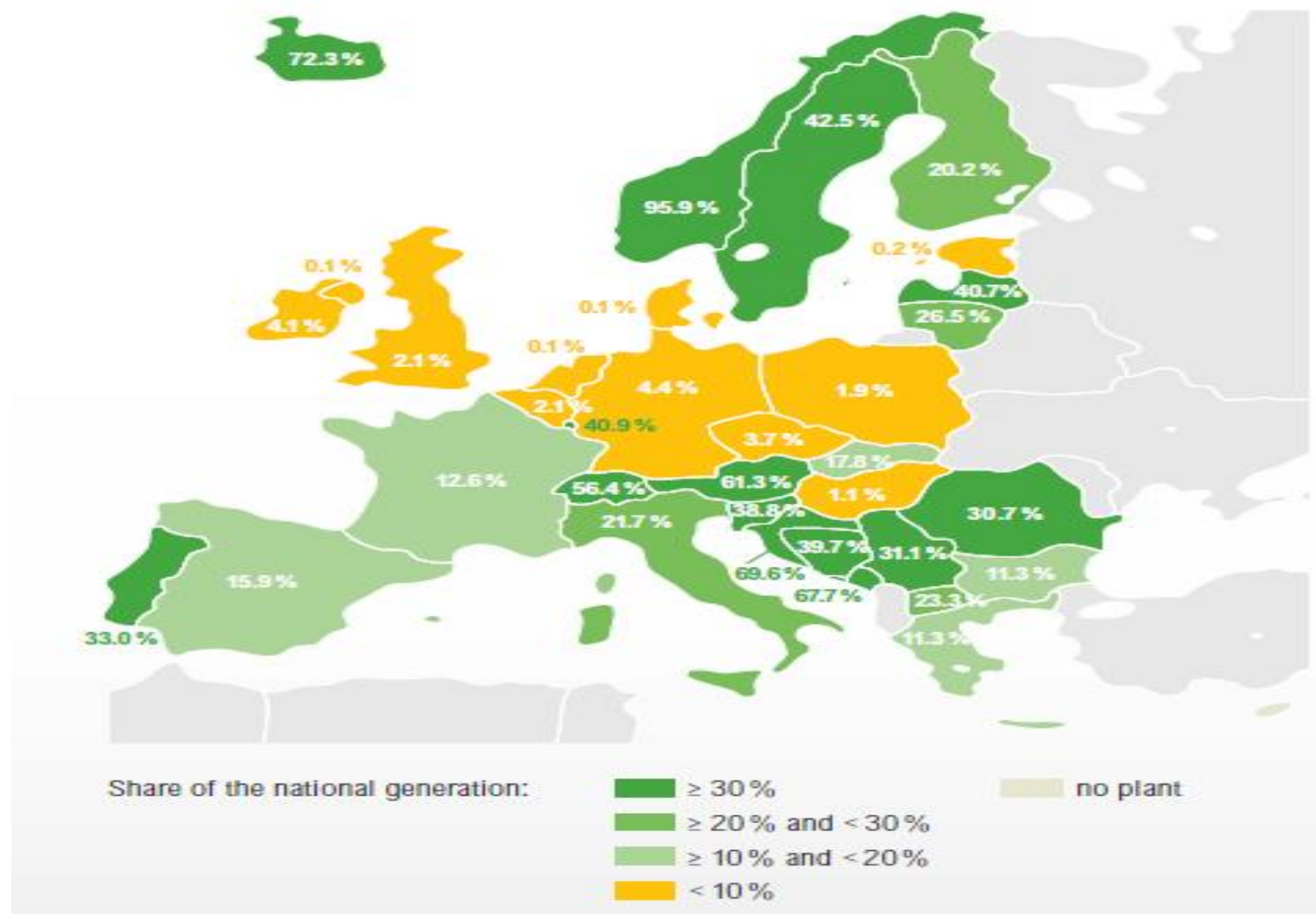
Nota: Hydro excludes pump storage & includes mixed plants

Bioenergy includes solid & liquid biofuels, bagasse, renewable waste



p.m. Hydropower in Europe

Share of Hydropower in Electricity Generation - 2014

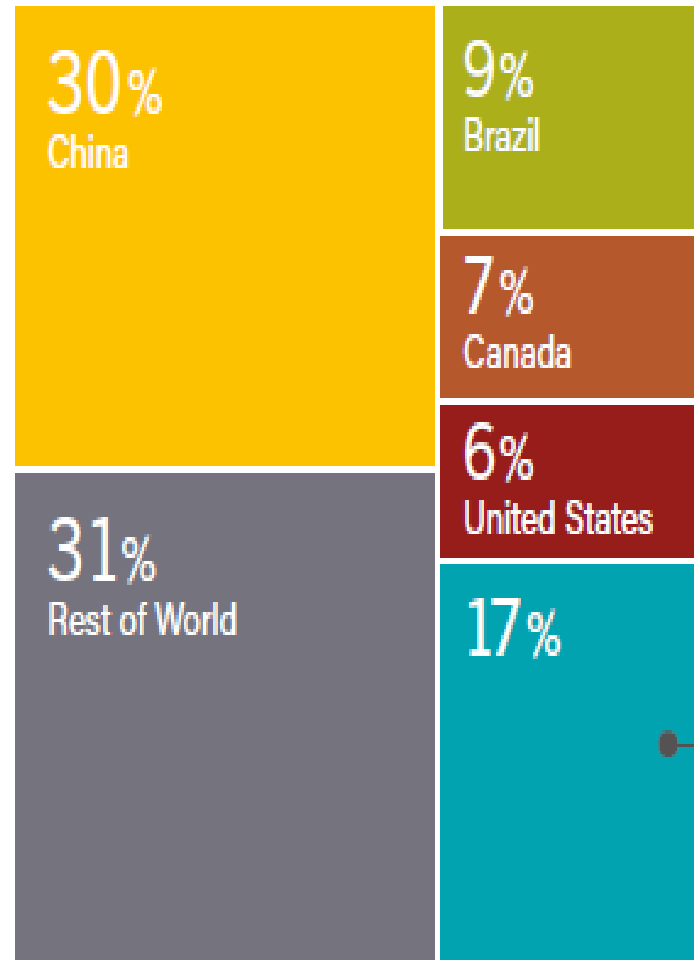


Source: ENTSO-E



Installed hydropower capacity - Year 2023

Top 10 countries N°1 China – N°2 Brazil



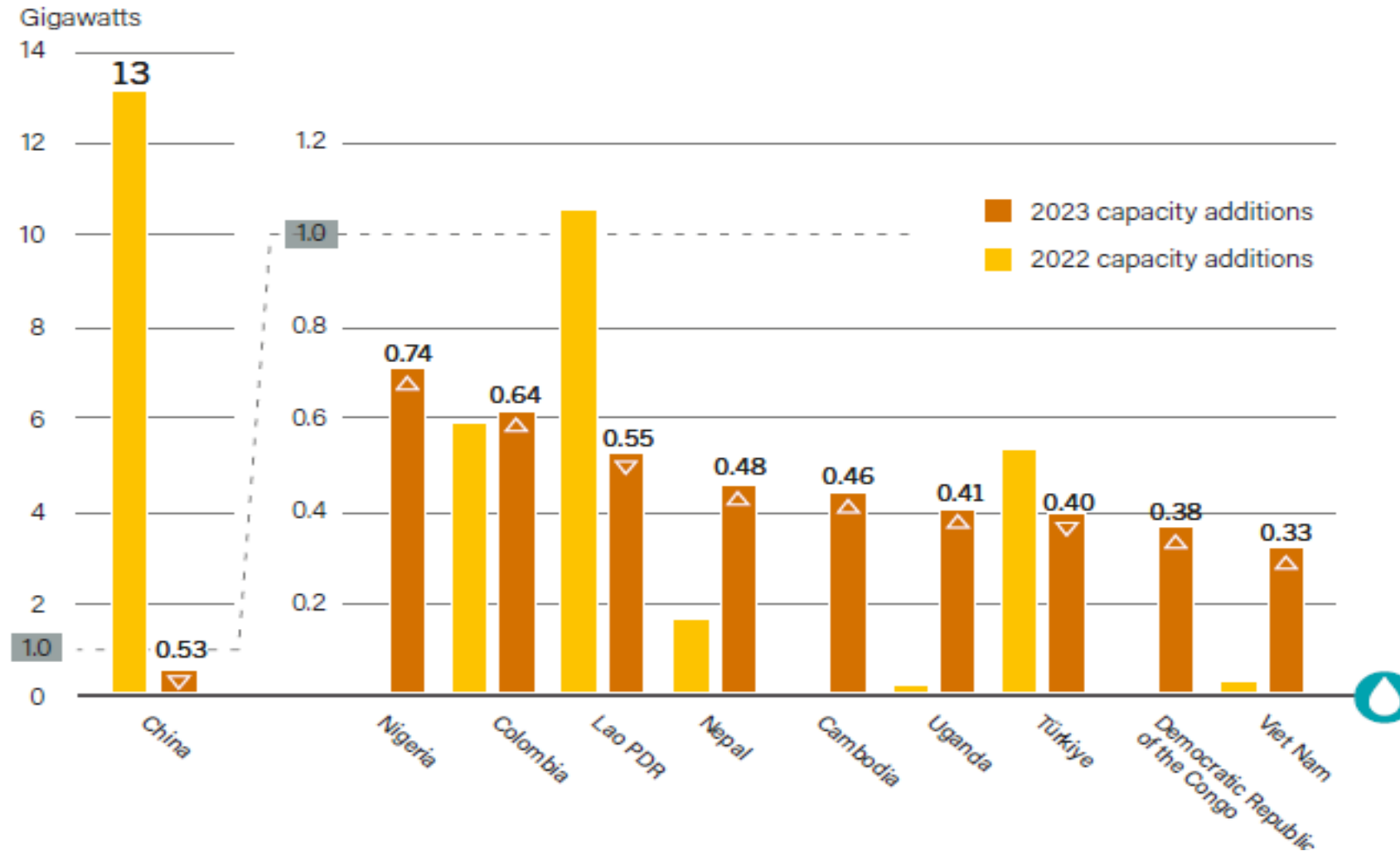
Next 6 countries

Russian Federation	4%
India	4%
Türkiye	3%
Norway	3%
Viet Nam	2%
Japan	2%



Hydropower Capacity Additions - Year 2022 & 2023

Top 10 countries N°1 China

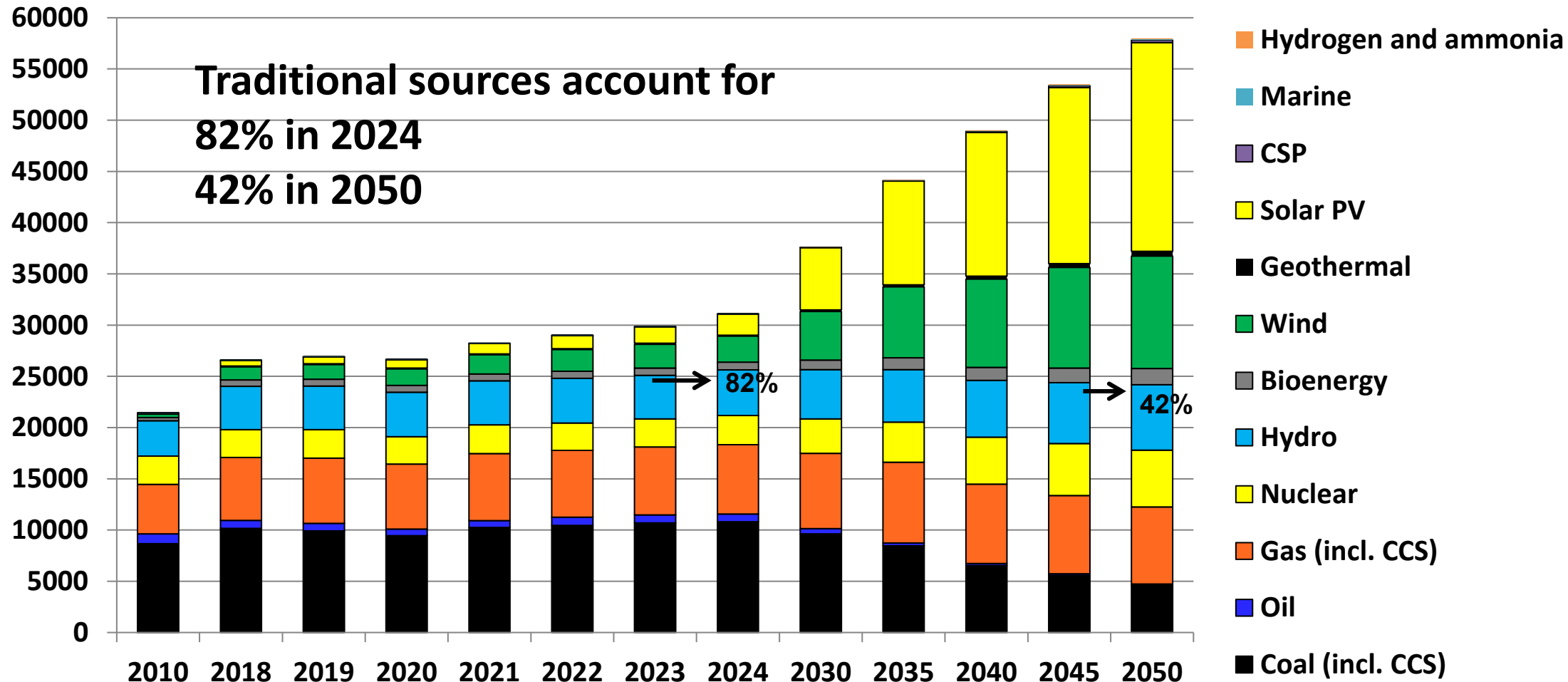


World Electricity Generation by Source

IEA WEO 2025 STEPS

Electricity Generation grows substantially, « traditional » Energy sources are drastically reduced. Wind and Solar PV take the lead

(TWh)

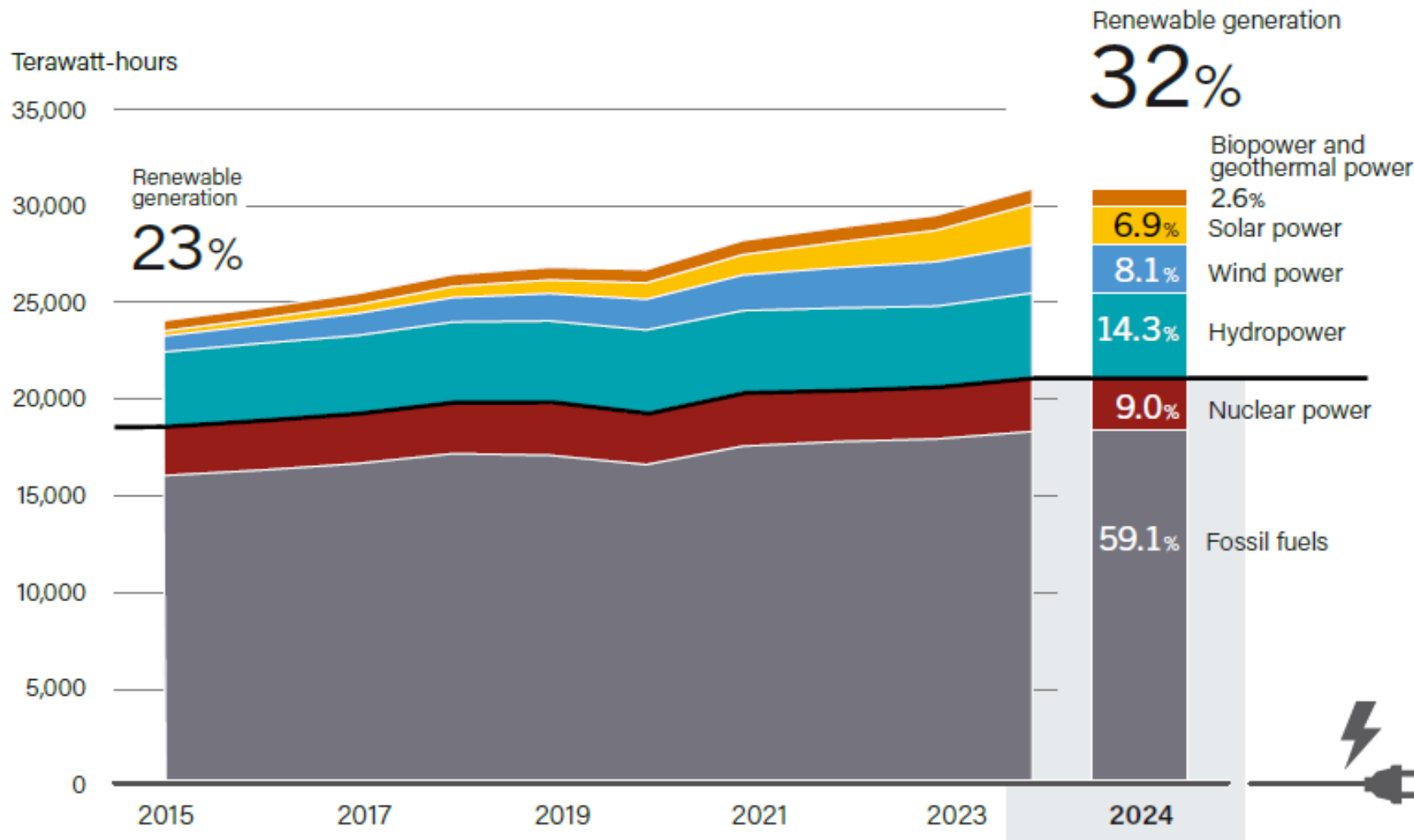


Source: Data from IEA WEO 2025



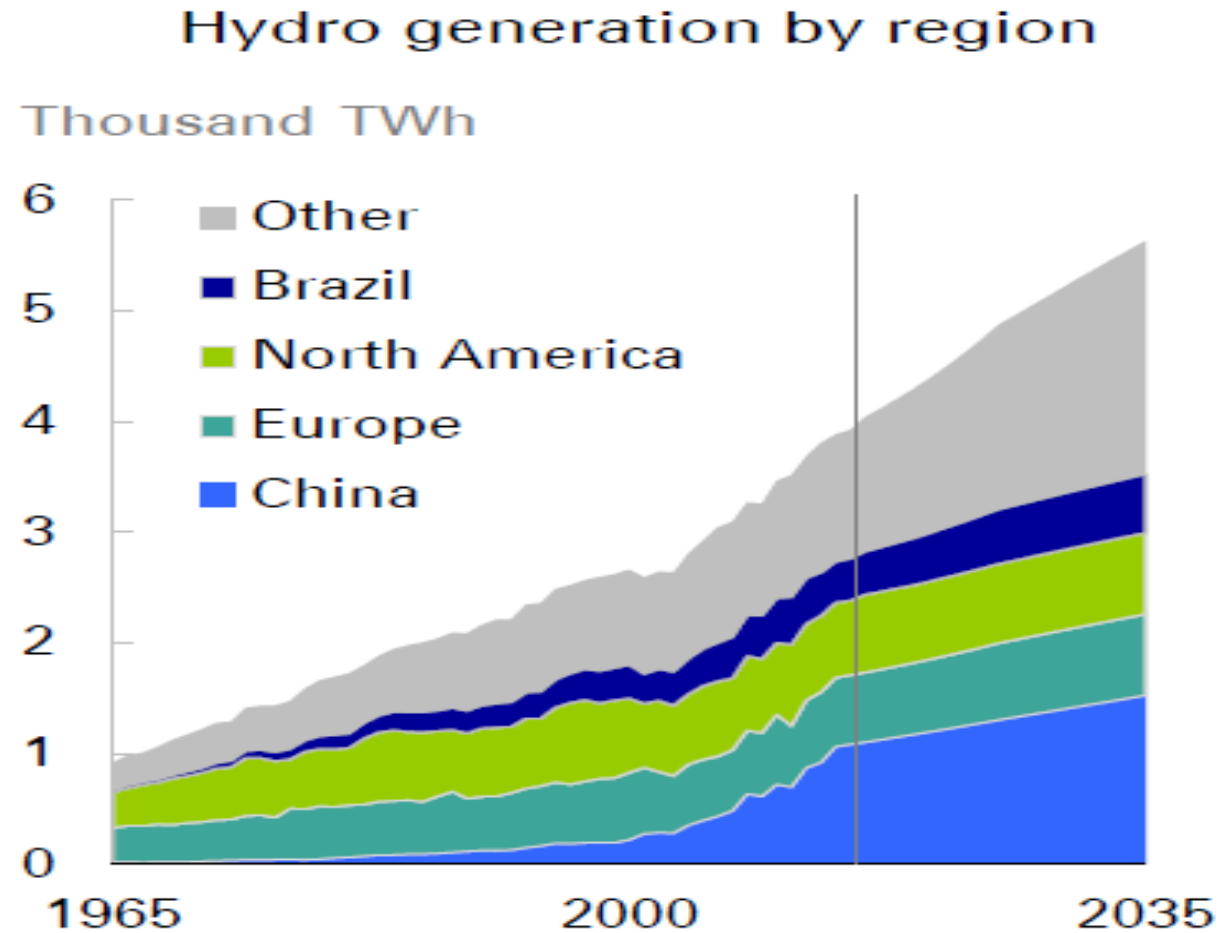
Share of Hydropower in Electricity Generation

Electricity Generation by Energy Source, 2015-2024



Hydropower Generation by regions

Reminder: A BP vision 2016



Source: BP 2016
Energy Outlook 2035



Hydropower is an important part of Renewable Energies

- Important potential of development in the world, notably Asia and Latin America, China, India and Brazil
- In Asia, China Hydro has a growth of 10% per year.
- Since 2004, China has been the 1st producer of hydro-electricity in the world. Installed capacity end 2024 = 436 GW.
- Hydropower capacities were expected to double over the period 2011 – 2035 in China and India.
- Hydropower development means important environmental and social impacts.
- Hydroelectric capacities can also be working as energy storage system, using pumped-storage hydroelectricity for load balancing: # 190 GW installed capacity worldwide end 2024.



Pump Storage Power Station (PSPS) of REVIN (Ardennes - France)

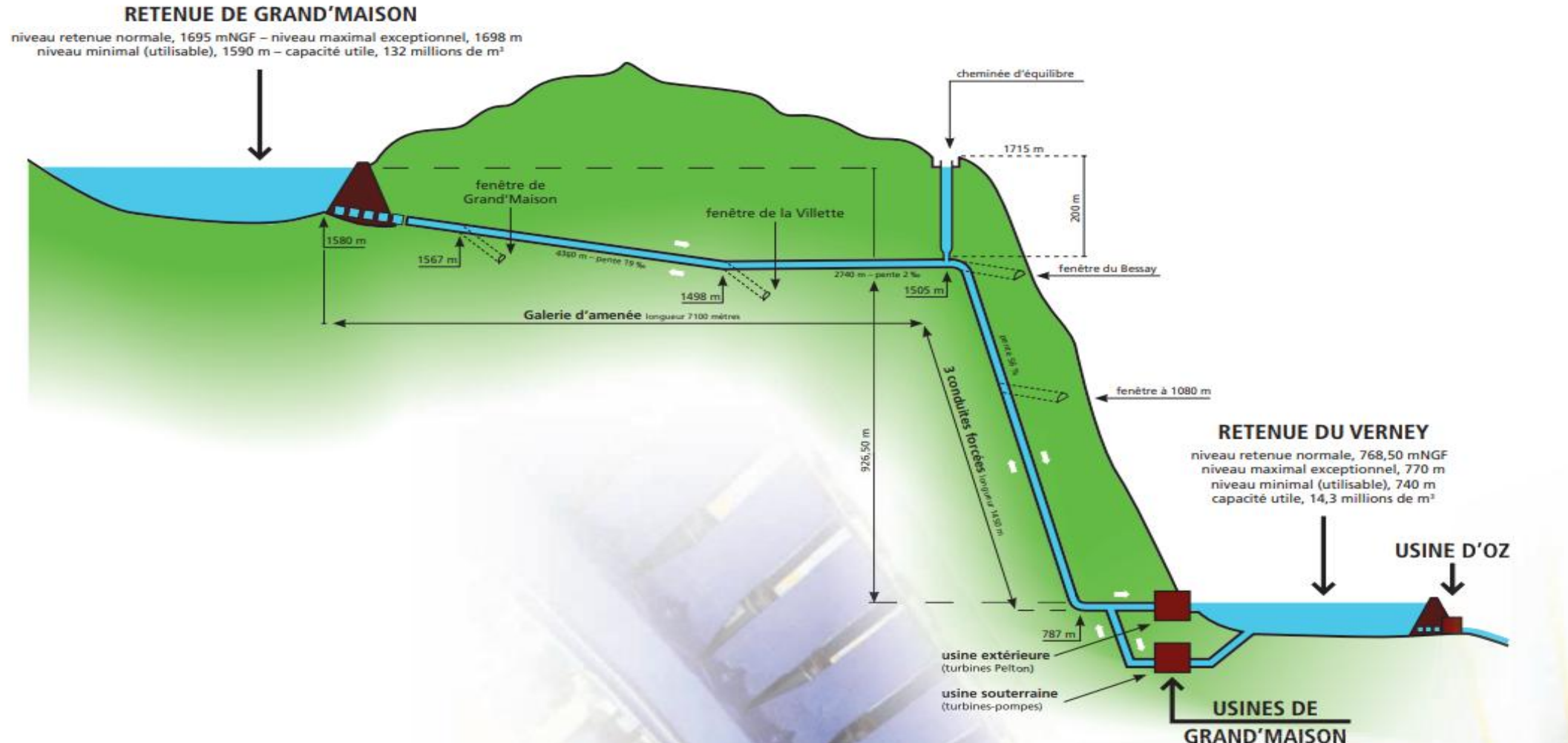


Two 7 millions cubic meters reservoirs, altitude difference 230 m – 800 MW



PSPS of Grand'Maison (Isère – France)

Working principle (from EdF)



Capacity of pumped storage hydropower in 2021, by leading country (GW) by IHA

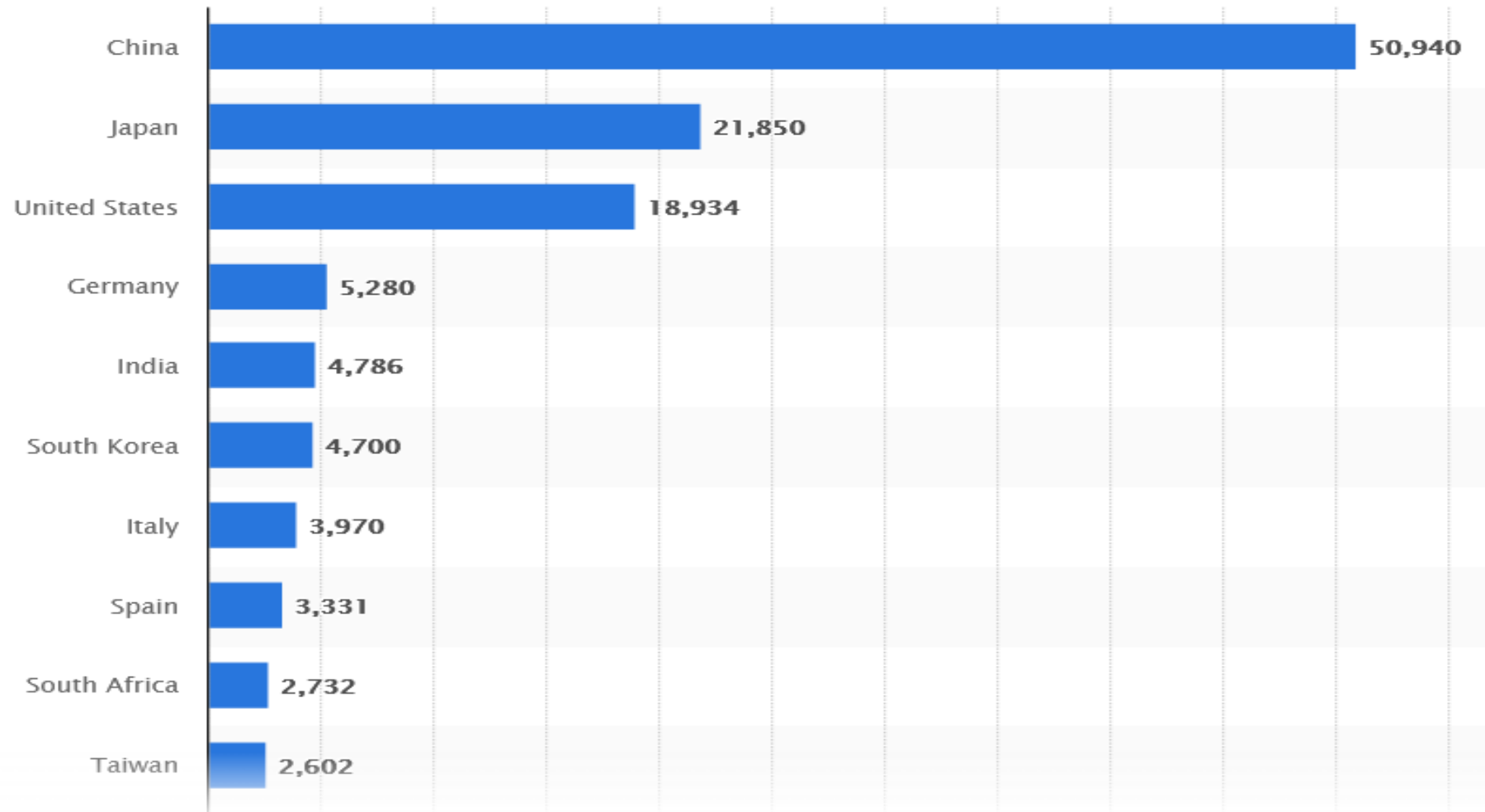


Pumped storage hydropower capacity (182 GW in 2023) represents over 94 % of installed global energy storage capacities well ahead of lithium-ion and other battery types.

Source: International Hydropower Association (IHA) – 2022 report
Nota: Figures differ according to sources



Capacity of pumped storage hydropower in 2024 by leading country (GW) by Statista

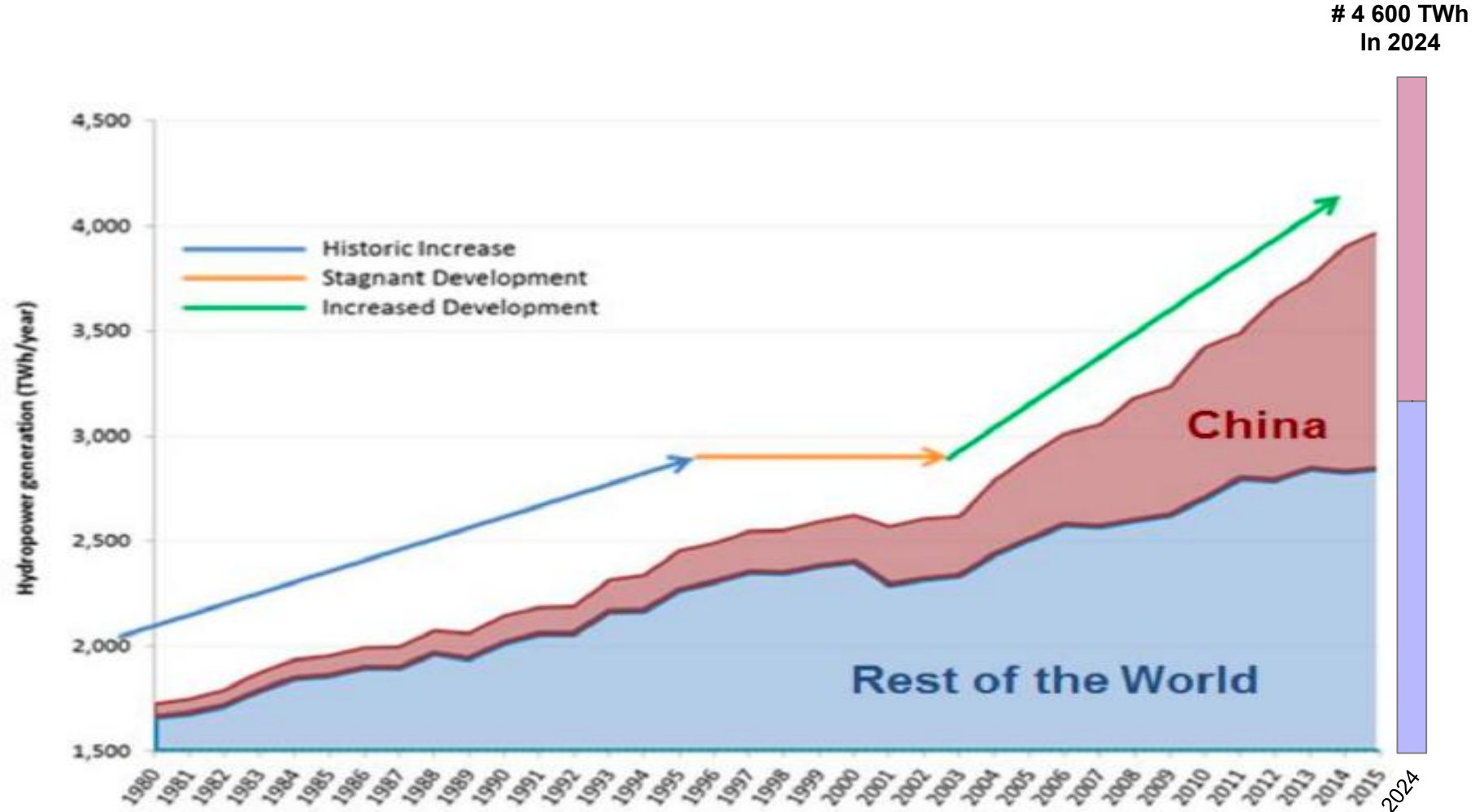


Source: Statista 2025

Nota: Figures differ according to sources



Hydropower Generation Evolution - the Weight of China



Source: IHA, EIA

Source: IHA (International Hydroelectricity Association) & EIA (US Energy Information Administration)/IRENA 2022/IHA 2025



Reminder - Key data and figures for Hydropower Technology by IRENA 2015 (Economic figures evolve upon time)

Technical Performance	Typical current International values and ranges		
Energy input	Hydro power		
Output	Electricity		
Technologies	Very small hydro power (VSHP, up to 1 MW _e)	Small hydro power (SHP, 1–10 MW _e)	Large hydro power (LHP, >10 MW _e)
Efficiency (turbine, Cp max), %	Up to 92	Up to 92	Up to 92
Construction time, months	6–10	10–18	18–96
Technical lifetime, yr.	Up to 100		
Load (capacity) factor, %	40–60 (50)	34–56 (45)	34–56 (45)
Max. (plant) availability, %	98	98	98
Typical (capacity) size, MW _e	0.5	5	50
(Existing) capacity, GW _e	75		925
Environmental Impact			
CO ₂ and other GHG emissions, kg/MWh	Negligible		under investigation ¹
Costs (USD 2010)			
Investment cost, USD/kW	3 400–10 000 or more	1 000–4 000	1 050–7 650
O&M cost USD/kW/yr.	45–250 or more	40–50	45 (average)
Economic lifetime, yr.	30		
Interest rate, %	10		
Production cost, USD/MWh	270 or more	20–100	20 – 190



PART 3

HYDROPOWER IN FRANCE



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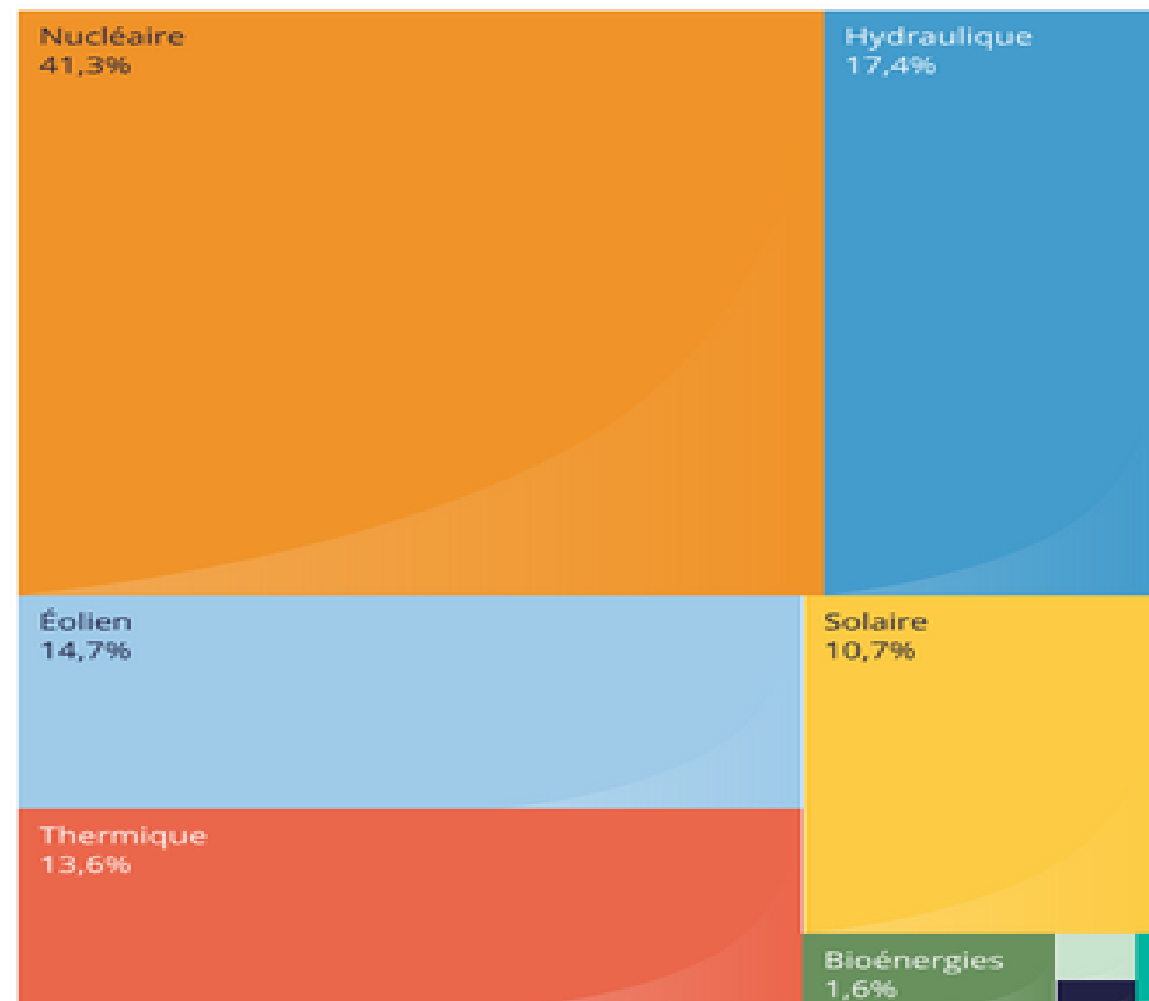


Hydropower is an important part of Renewable Energies in France

Composition du parc de production et de stockage électrique (Juin 2024)

- Nucléaire : 41,3 %
- **Hydraulique : 17,4 %**
- Éolien : 14,7 %
- Thermique : 13,6%
- Solaire : 10,7 %
- Bioénergies 1,6 %
- Autre : 0,2 %
- Stockage non hydraulique : 0,2 %
- Géothermie : < 0,1%
- Energies marines : < 0,1 %

COMPOSITION DU PARC INSTALLÉ France



Source: France HydroElectricité 2025

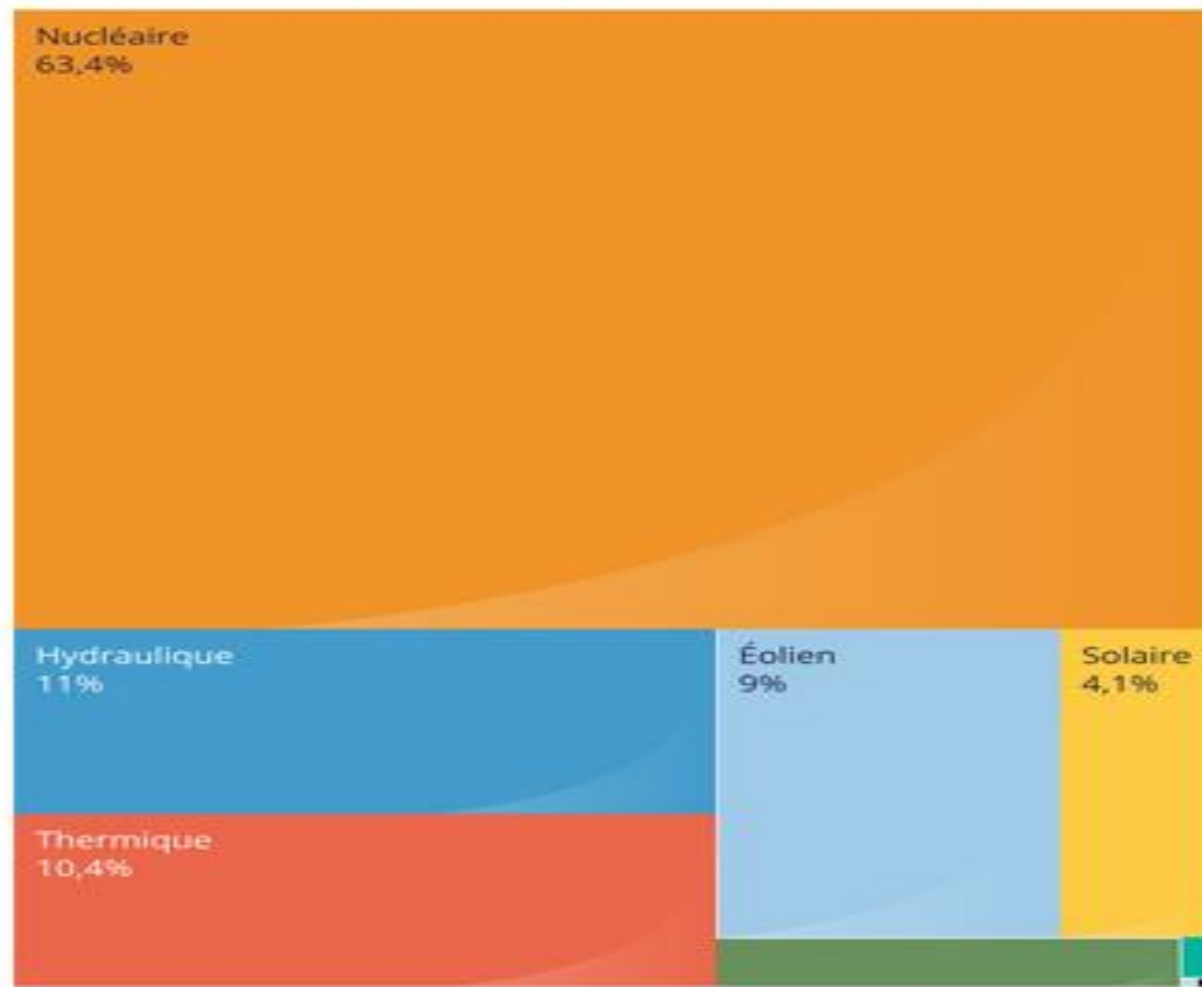


Hydropower is an important part of Renewable Energies in France

Origine de l'électricité produite (Juin 2024)

- Nucléaire : 63,4 %
- **Hydraulique : 11 %**
- Eolien : 9 %
- Thermique : 10,4 %
- Solaire : 4,1 %
- Bioénergies: 1,9 %
- Autre : < 0,1 %
- Stockage non hydraulique : < 0,1 %
- Géothermie : < 0,1 %
- Energies marines : < 0,1 %

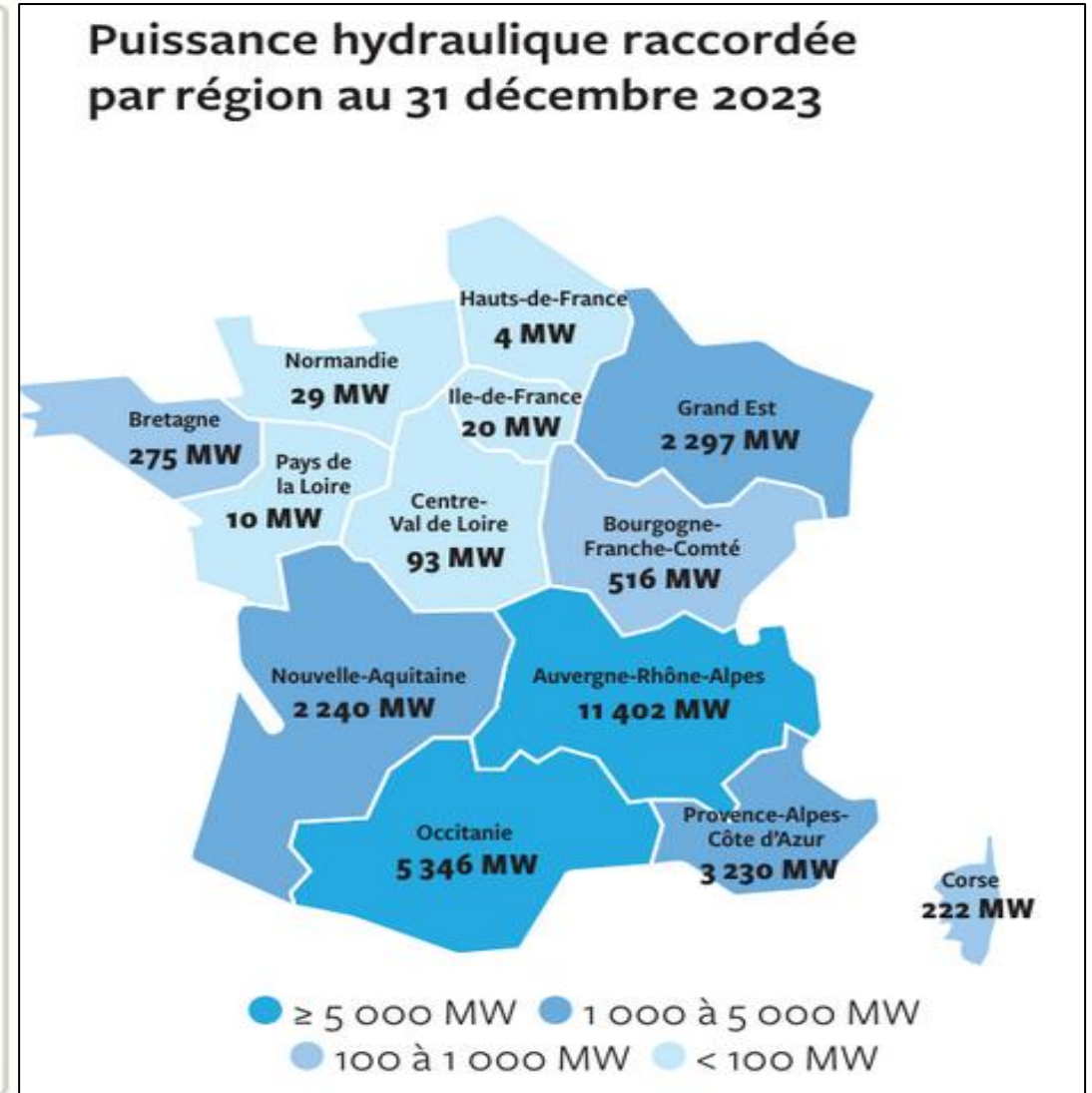
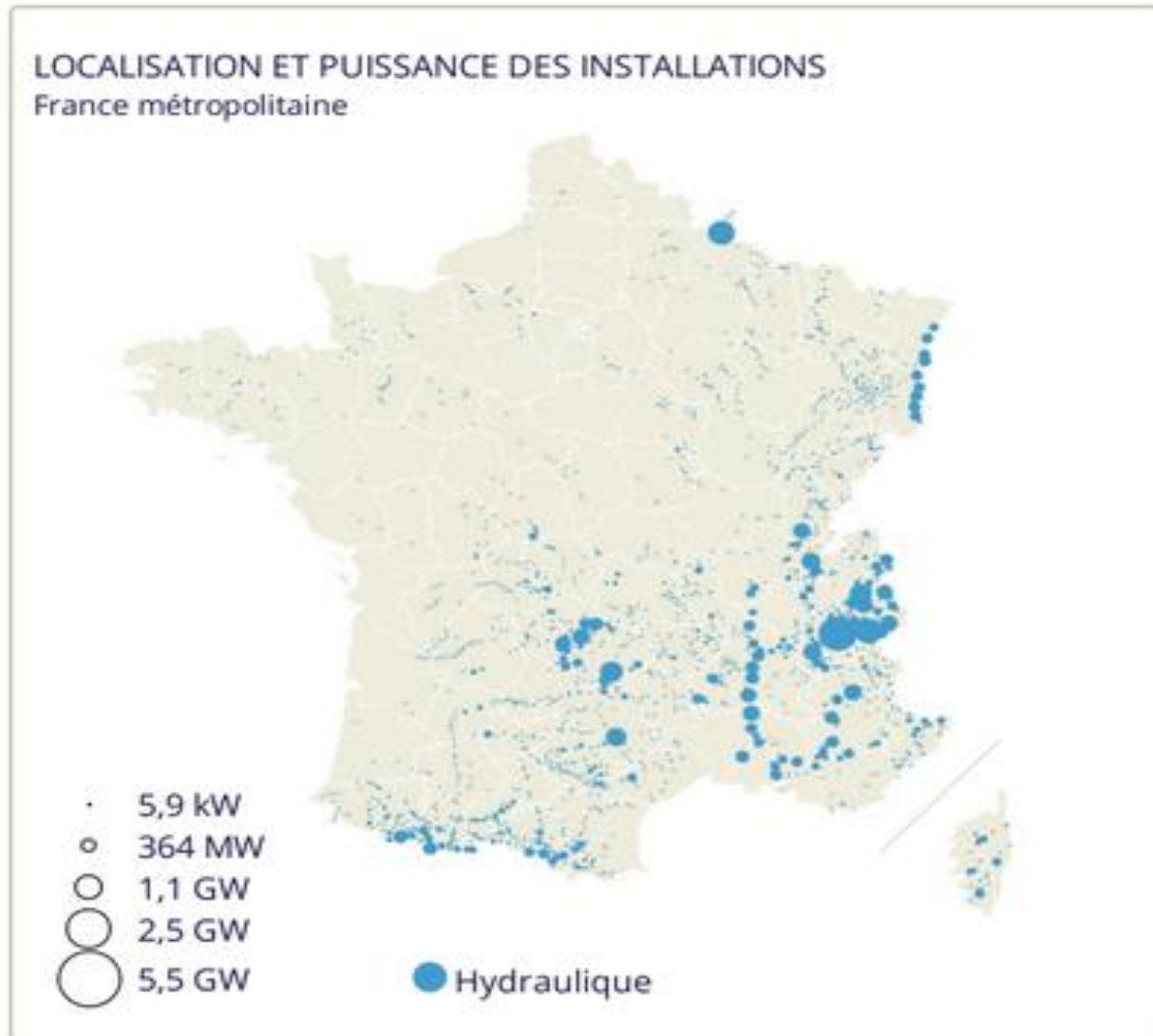
COMPOSITION DU PARC INSTALLÉ France



Source: France HydroElectricité 2025

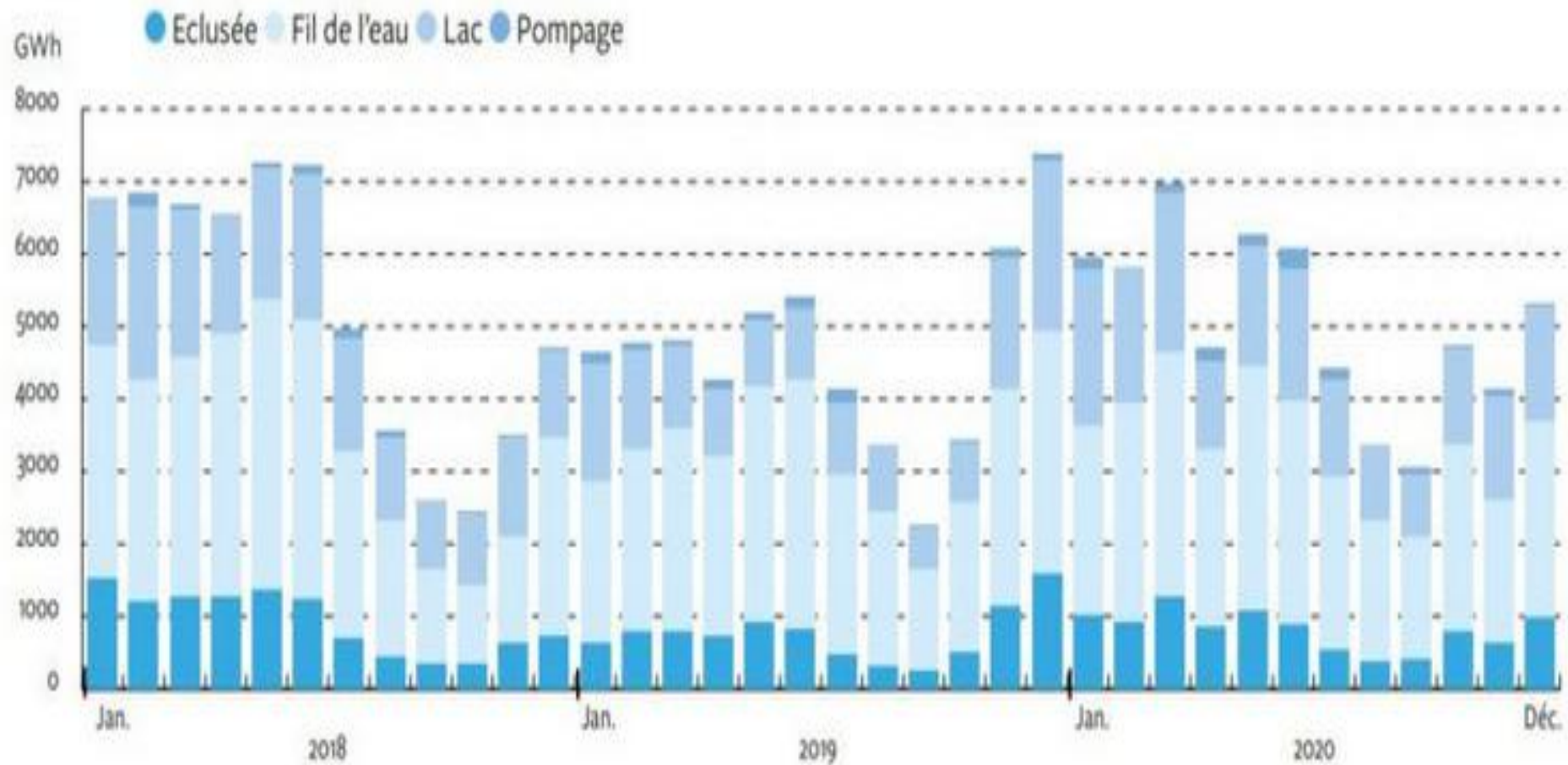


Hydropower is an important part of Renewable Energies in France



An example: Monthly Hydraulic Production

Production hydraulique mensuelle



Source: France HydroElectricité 2025

Hydropower is an important part of Renewable Energies in France

- In France, hydropower is the 2nd source of energy after nuclear energy and 1st source of Renewable Energy for electricity generation (in 2026, 26 GW installed, 60 TWh generation, 12% of electricity consumed in 2026)
- 2 500 installations, out of which more than 90% run of the river.
- The State owns 100% of the hydroelectric dams. The exploitation is attributed to operators like EDF (80%) and Engie (ex. GDF Suez) (17%)
- Nuclear power represents the base load. Hydropower plays the role of swing producer.
- Projects of « small hydroelectricity » (<10 MW) are also being developed.
- The liberalization process for access to hydroelectricity in France generates an important debate. Hydroelectricity, a part of the EU Green Deal.



Small Hydroelectricity (<10 MW)



Small Hydroelectricity (<10 MW)

Environ 2 300
petites centrales
sur 250 000 km
de cours d'eau



**6 TWh / an
de production**

=
Soit l'équivalent
de la consommation de
1 300 000 foyers

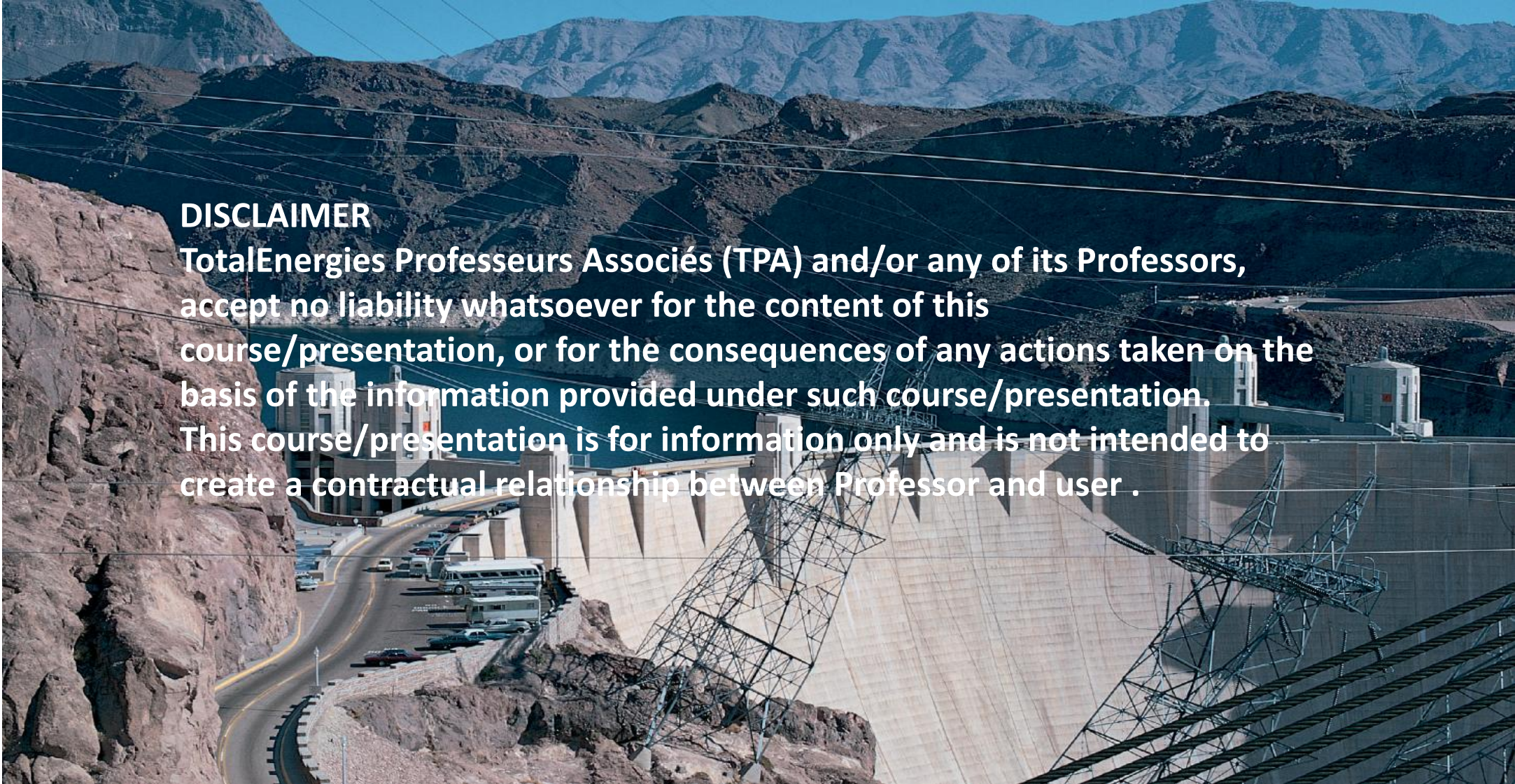
10 % de la
production
hydroélectrique
globale

2 460 MW
de puissance
installée

4 000 heures / an
de fonctionnement
en moyenne

Potentiel global
de développement
de 2,7 à 3,7 TWh





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