HYDRO

THE FUTURE OF HYDROPOWER

FROM A TECHNOLOGY PROVIDER'S VIEW

DIEGO VILANOVA

JULY, 9TH , 2023

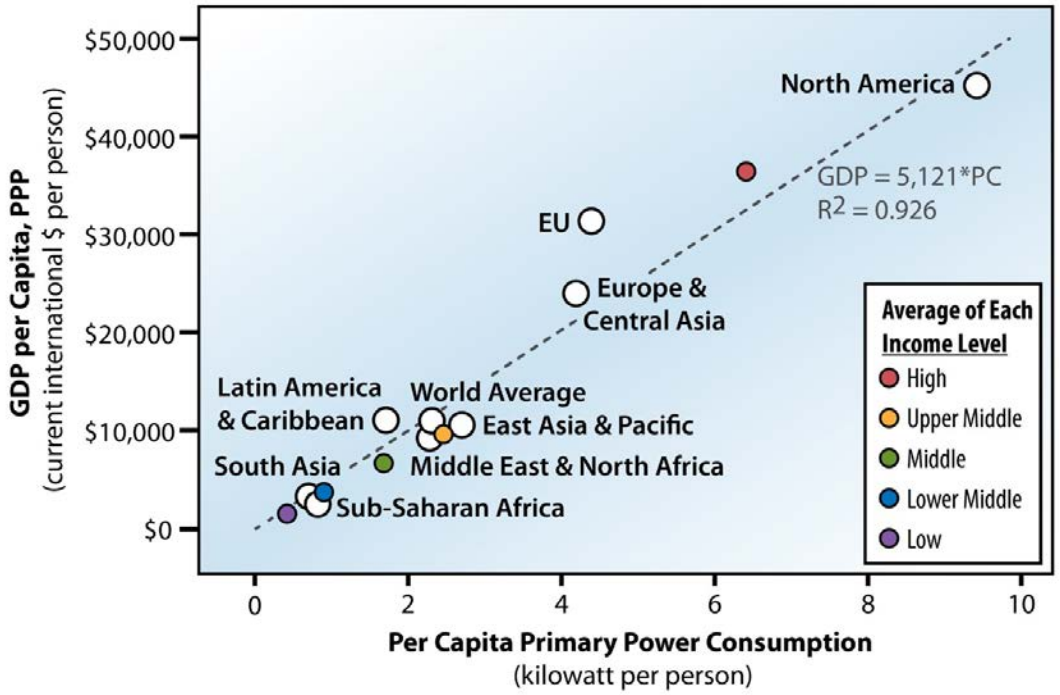
ANDRITZ

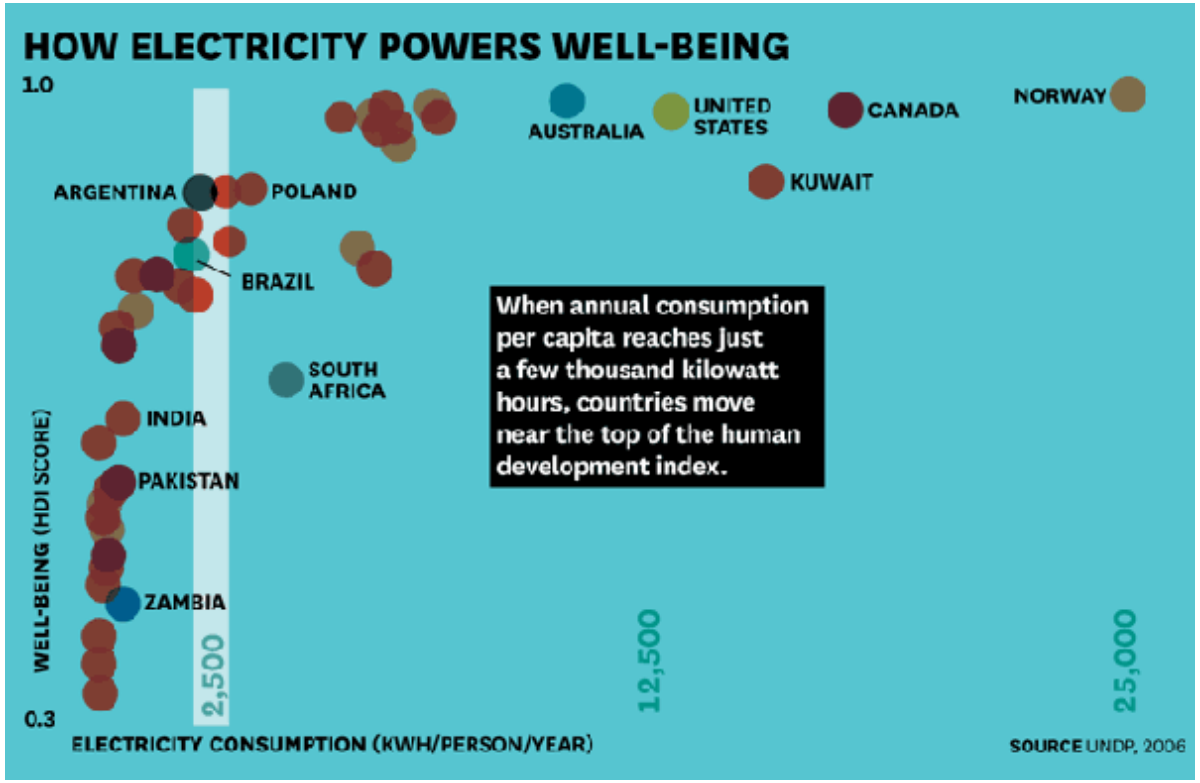
ENGINEERED SUCCESS


IT ALWAYS SEEMS
IMPOSSIBLE
UNTIL IT'S DONE.
-NELSON MANDELA

HUMAN WELL-BEING IS A DIRECT FUNCTION OF POWER CONSUMED

Electricity – blood stream for human development





Source: Dr. Bruce Dale, Michigan State University

AFRICA - TODAY

Hydropower generation

~150,000 GWh/year

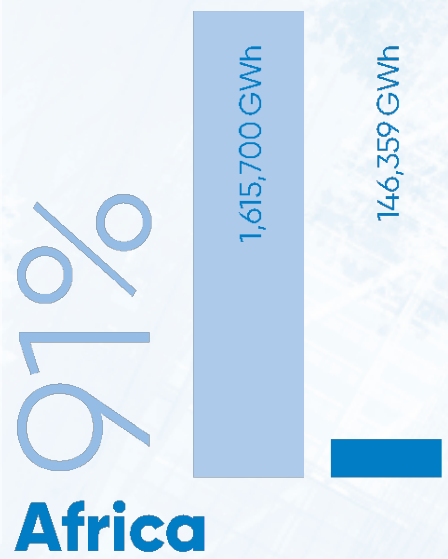
Technically feasible potential

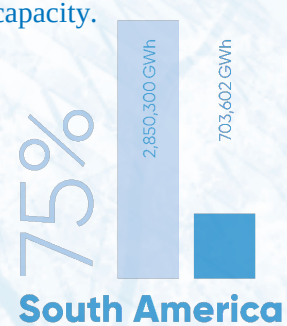
~1,600,000 GWh/year

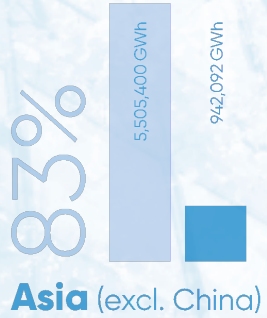
Hydropower demand by 2030 *

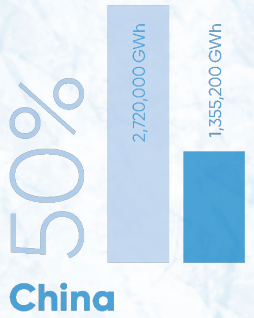
~ +150,000 GWh/year

* Sustainable Africa Scenario (SAS) states that doubling of the current hydro capacity is required by 2030 capacity.







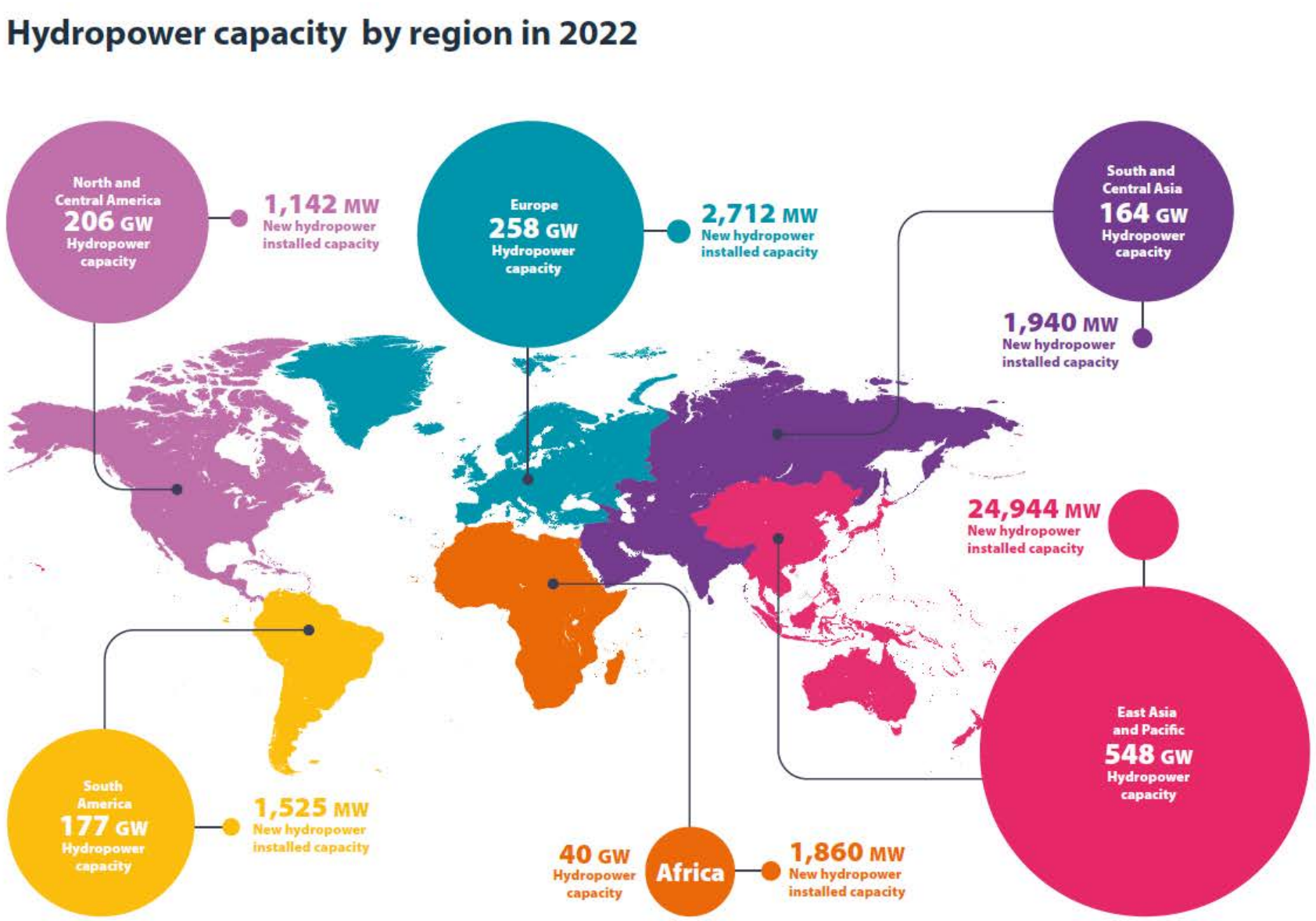


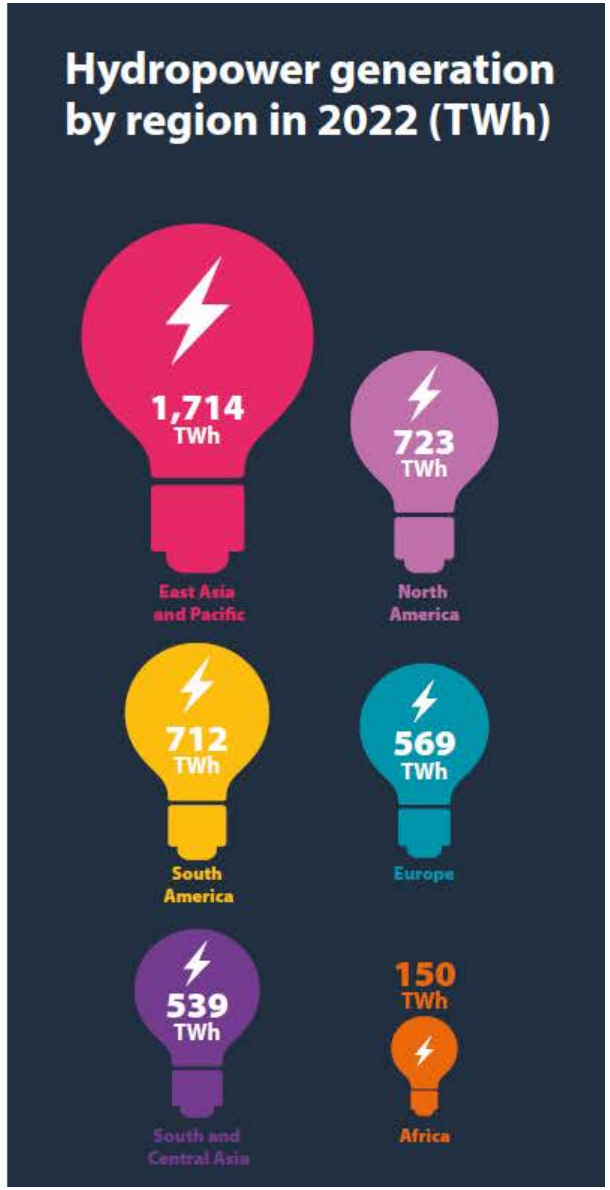
Technically feasible hydropower potential (GWh/year)

Power generation from hydropower (GWh/year)

Source: Hydropower & Dams World Atlas 2022

AFRICA - TODAY





Source: IHA, 2023 World Hydropower Outlook

AFRICA - TODAY

Hydropower remains the continent's primary renewable resource at over 40 GW of installed capacity

Ranking by total installed hydropower capacity

Rank	Country/Territory	Installed capacity (MW)*
1	Ethiopia	4,824
2	Angola	3,836
3	South Africa	3,600
4	Zambia	3,153
5	Egypt	2,876
6	Democratic Republic of the Congo	2,760
7	Mozambique	2,216
8	Nigeria	2,111
9	Sudan	1,923
10	Morocco	1,770
11	Ghana	1,584
12	Guinea	1,156
13	Uganda	1,095
14	Zimbabwe	1,081
15	Cote D'Ivoire	879
16	Kenya	837
17	Cameroon	822
18	Tanzania	562
19	Malawi	391
20	Mali	360
21	Namibia	347
22	Gabon	331
23	Algeria	269
24	Congo	218
25	Madagascar	214
26	Reunion	134
27	Equatorial Guinea	128
28	Rwanda	117
29	Liberia	93
30	Senegal	81
31	Lesotho	73
32	Burundi	72
33	Tunisia	66
34	Sierra Leone	64
35	Mauritius	61
36	Eswatini	61
37	Togo	49
38	Mauritania	48
39	Burkina Faso	34
40	Benin	33
41	Central African Republic	19
42	Sao Tome And Principe	2
43	Comoros	1

*including pumped storage

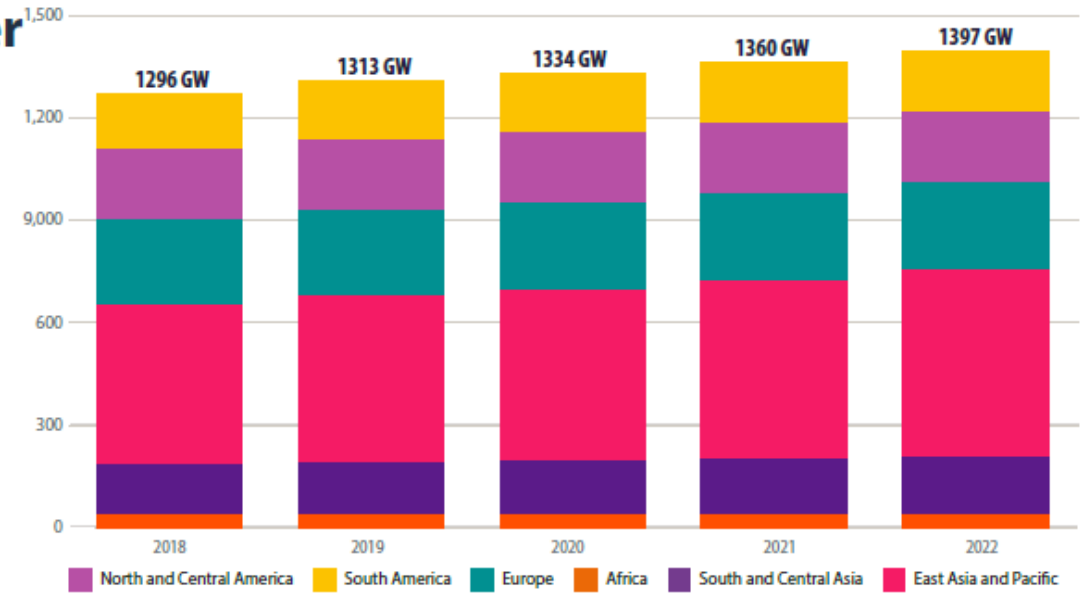
Top 5 countries by capacity added in 2022

- 1st Ethiopia 750 MW
- 2nd Guinea 450 MW
- 2nd Zambia 450 MW
- 3rd Mali 140 MW
- 4th Madagascar 28 MW

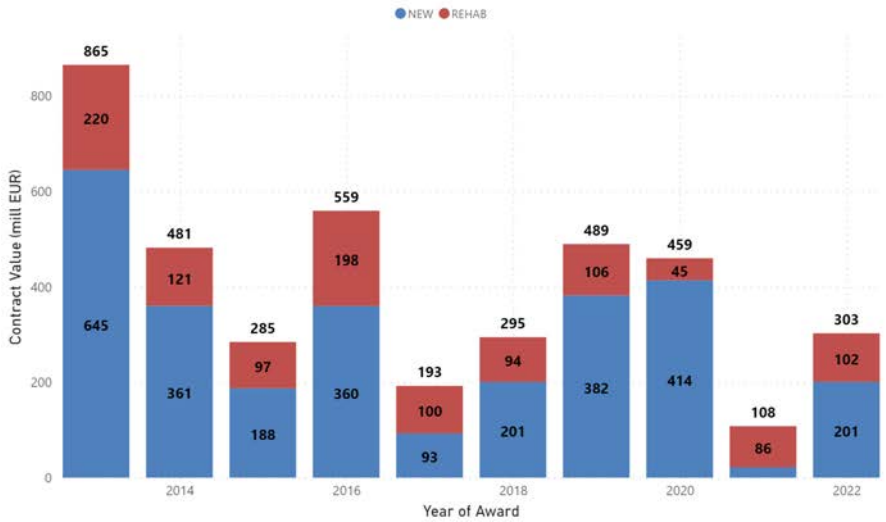
Source: IHA, 2023 World Hydropower Outlook

AFRICA - TODAY

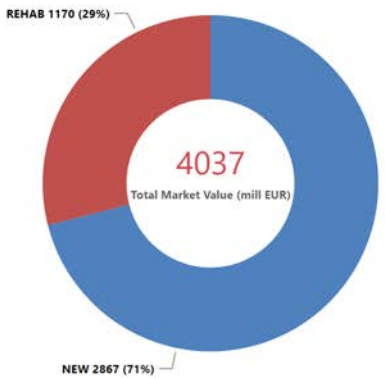
Hydropower installed capacity growth, 2018-2022



Market Development Greenfield / Brownfield



Market Value Greenfield / Brownfield



Source: Andritz

"Considering Africa's high potential for hydropower development and a need to rapidly increase electricity to meet demand, accelerating access to financing and sustainable construction is crucial for the region."

Source: IHA, 2023 World Hydropower Outlook

HYDROPOWER SYSTEM ADVANTAGES

Large range of low-carbon capacity available

- From kW to GW in a single project
- Option to export electricity in regional grids

Operational flexibility and efficiency

- Fast start-up and shut-down
- Highly efficient and adjustable output

Storage and back-up

- Rapid availability, and ancillary services
- Option to absorb surplus (pumped storage)

Multiple freshwater services

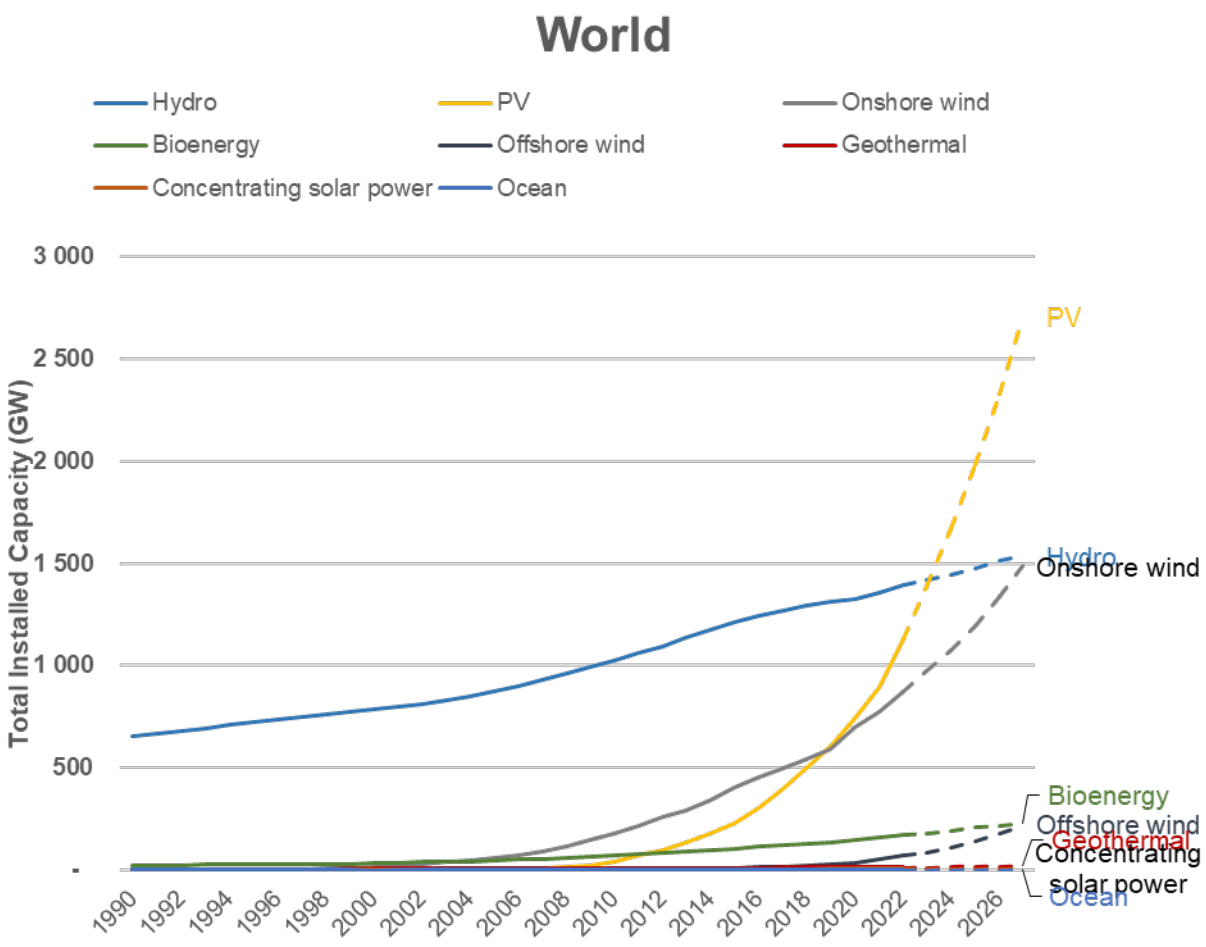
- Water supply, irrigation, navigation, tourism
- Climate-change adaptation (flood and drought mitigation)

Source: IHA, International Hydropower Association, R. Taylor

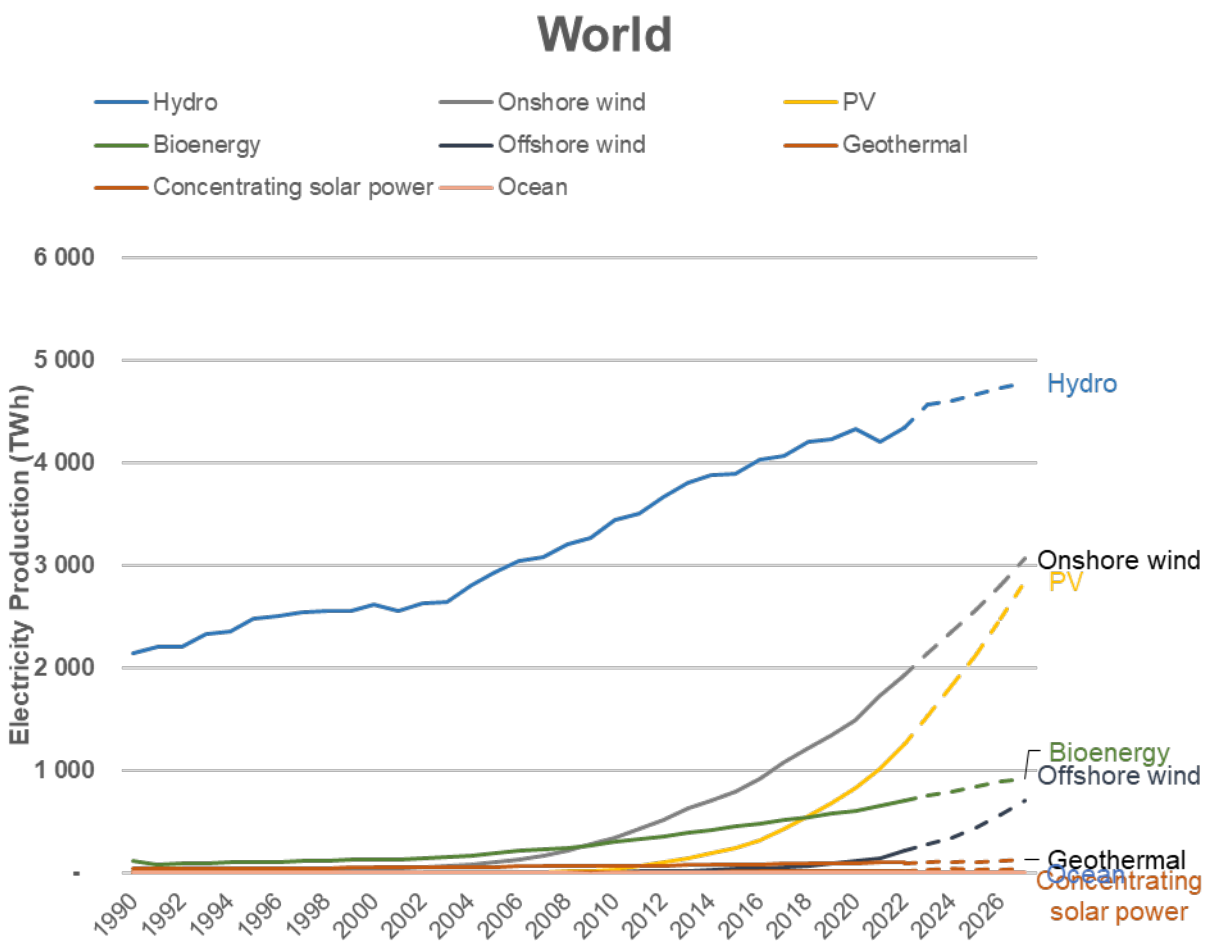
RENEWABLES DEVELOPMENT

All figures show the IEA main case

Capacities (GW)



Generation (TWh)

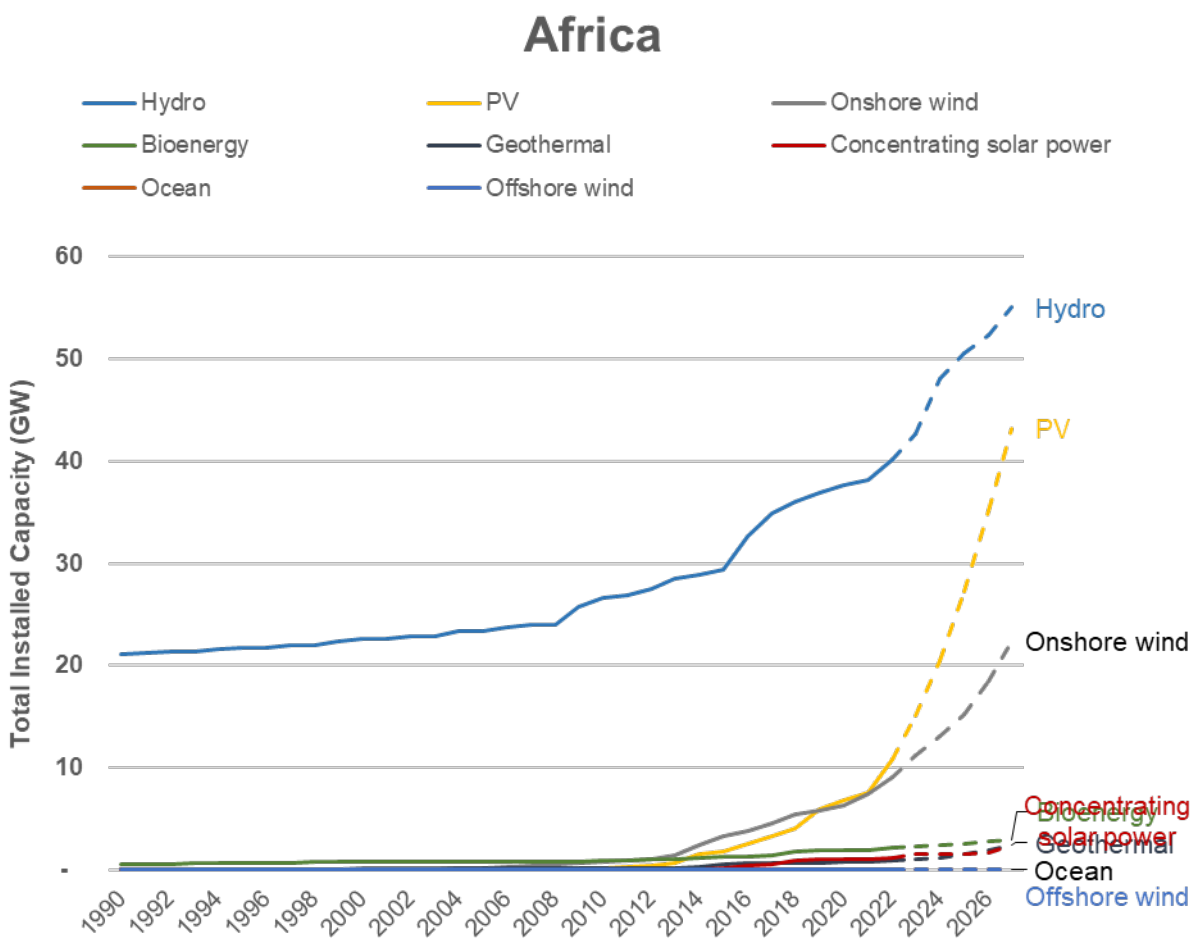


Source: IEA, Renewables 2022 - Analysis and forecast to 2027

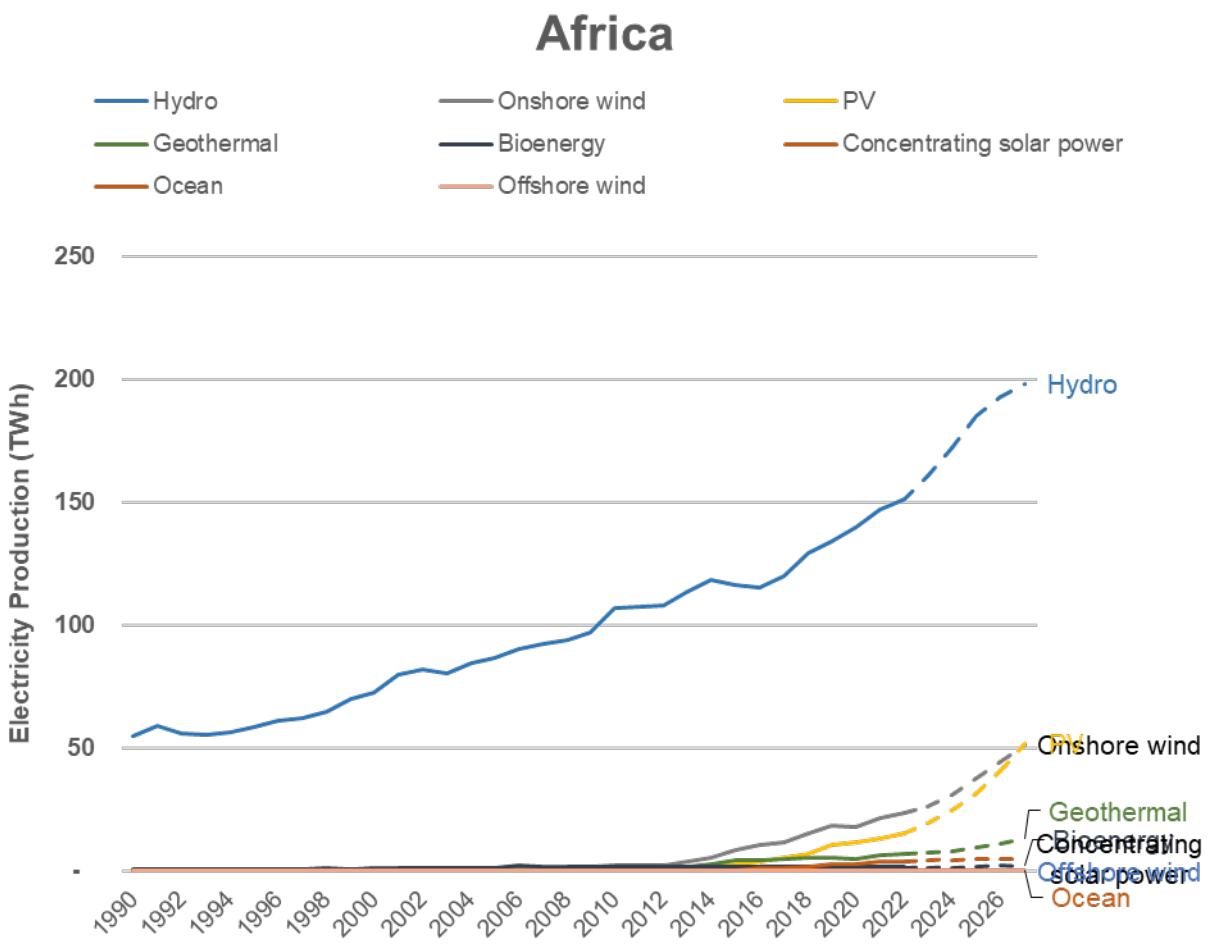
RENEWABLES DEVELOPMENT

All figures show the IEA accelerated case

Capacities (GW)



Generation (TWh)



Source: IEA, Renewables 2022 - Analysis and forecast to 2027

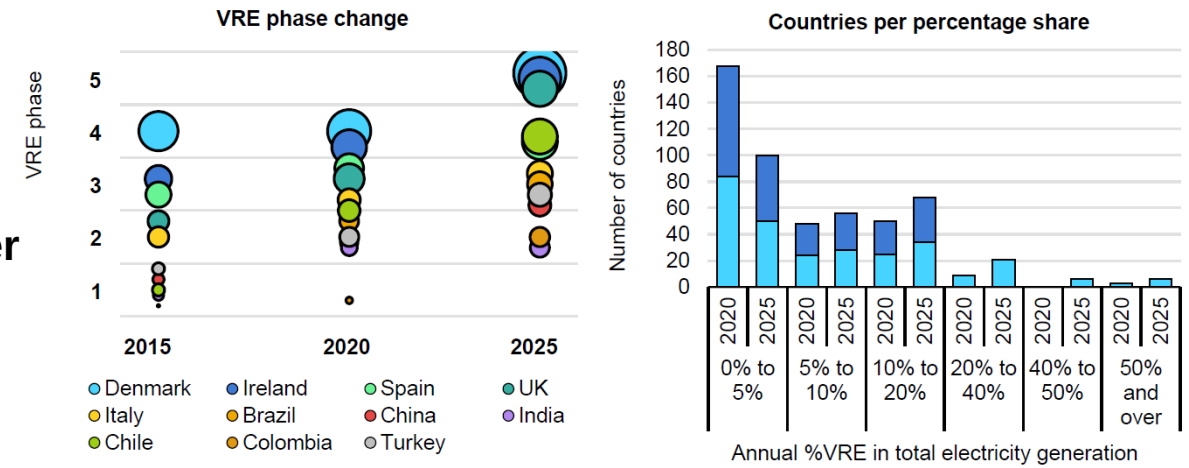
FLEXIBILITY NEEDS ARE INCREASING

IEA categorizes the integration of VRE into a "*phase assessment framework*" of six different phases

IEA VRE integration phases

- **Phase 1: No noticeable impact from VRE** at the system level
  - 2020:, 84 countries at phase 1, whereas it is expected that by 2025, only 50 will remain
- **Phase 2: 5-10% VRE share**
  - Integration challenges begin to emerge
  - Differences between load and net load become noticeable
  - but **VRE still have a minor impact on the system as a whole**
- **Phase 3: ~15-30% VRE share (annually) and beyond**
  - **VRE determine the operating pattern of the whole power system**
  - **and additional flexibility options are needed**
- **Phase 4: periods where VRE make up almost all or all generation**
  - currently only 6 countries
- **Phase 5: growing amounts of VRE surplus or deficit compared to total electricity demand**
  - for days to weeks
- **Phase 6: growing amounts of VRE surplus or deficit compared to total electricity demand**
  - **for days to weeks**
  - **and seasonal or inter-annual imbalances**

Evolution of countries' VRE integration phases



Note: Bubble size reflects the share of VRE in total electricity generation.

VRE.....Variable Renewable Energy

Source: IEA, June 2021, Hydropower Special Market Report

THE KEY DRIVERS

Hydropower is facing opportunities and challenges

- **Growing electricity demand**
  - Emerging Countries (both residential and industry)
  - Decarbonization > Electrification of industries
  - Decarbonization / sector coupling > Powering green hydrogen production

- **Flexibility and storage for integrating wind & solar PV**
  - Flexible and firm capacity as a backup
  - Growing demand for reservoir and pumped storage > the “water battery”
  - Hybrids and integrated systems

- **Ageing hydropower fleet / optimization of O&M**
  - Rehabilitation, Upgrade, Digitalization

- **Climate Change Resilience and Adaptation**
  - Change of flow regimes, extreme weather events, ..
  - Resilience of Equipment and Infrastructures
  - Prevention from floods and droughts, freshwater management

- **Impact on nature and local communities**
  - Water quality, river connectivity and other environmental impacts
  - net-positive benefits on society

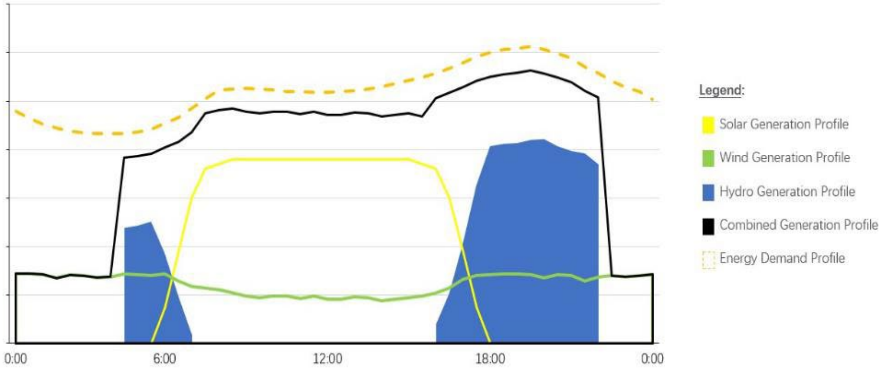
HYDROPOWER – INTEGRATED POWER PLANTS

KIDSTON RENEWABLE ENERGY HUB - AUSTRALIA

The World’s first dispatchable renewable energy plant

New energy concepts based on hybrid solutions balancing the energy before stressing the grid

- combination of a solar and wind power station with a pumped storage plant



Kidston / Australia
2 x 125 MW reversible pump turbines
Main focus: supply balanced energy into the grid!

„FLEXI“- HYBRIDS

Hydropower + X

Hydropower – Battery Hybrids
- Improve fast and dynamic frequency response by coupling hydropower and batteries
- Significantly reduce turbine wear and tear

PSP – Wind – PV Hybrids
- Balancing the energy before stressing the grid

Hydropower – floating Solar PV Hybrids
- Co-locating with existing hydro sites can double power output while reducing variability and utilizing existing transmission infrastructure
- Huge potential (“*Floating solar panels on 1% of reservoirs ‘could double’ Africa’s hydropower capacity*”)
- Europe’s largest floating PV plant; EDP / Alqueva reservoir / 5MWp / online in mid 2022
- Recently announced: Endesa / Alto do Rabagao dam / 42MWp / online 2026

FLEXIBILITY AND GRID STABILITY

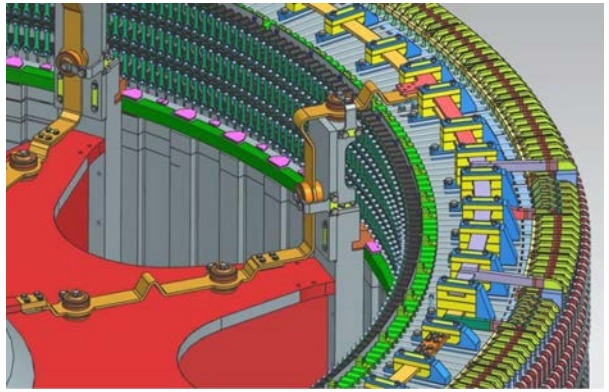
New Generator Technologies

Why Variable Speed?

- Regulation of pump input power
- Speed adjustment for optimum operation (efficiency, stability)
- Needed for large head variation and special grid services

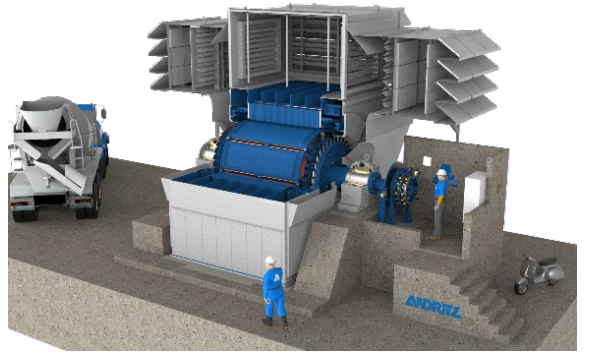
- **Variable Speed DFIM (Double Fed Induction Machine):** approx. +/- 7 % speed range
- **Variable Speed (full size converters)**: ≈ 50% speed range, other base frequency
- **Synchronous Condenser:** Providing reactive power and inertia to the grid, new customers

Variable Speed DFIM:



Kühtai II: 2 x 95 MVA, full size converter fed synchronous generator

Synchronous Condensers:
Brazil, Australia, USA

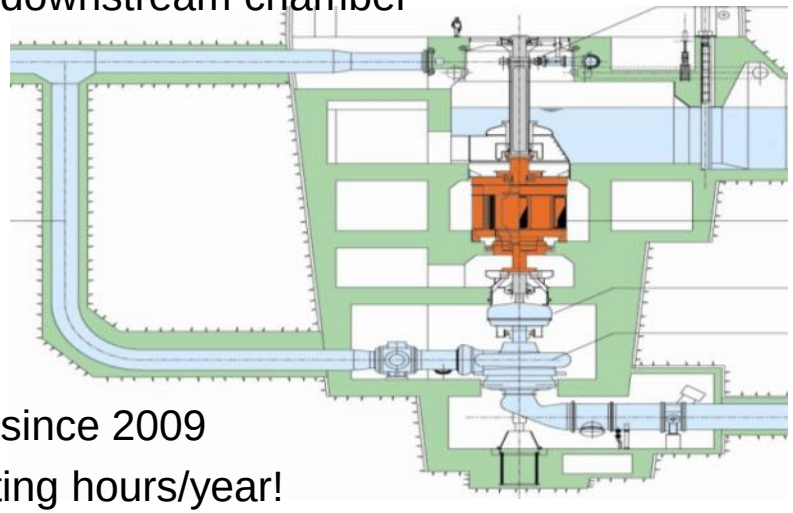


FAST REACTION TO GRID INSTABILITIES

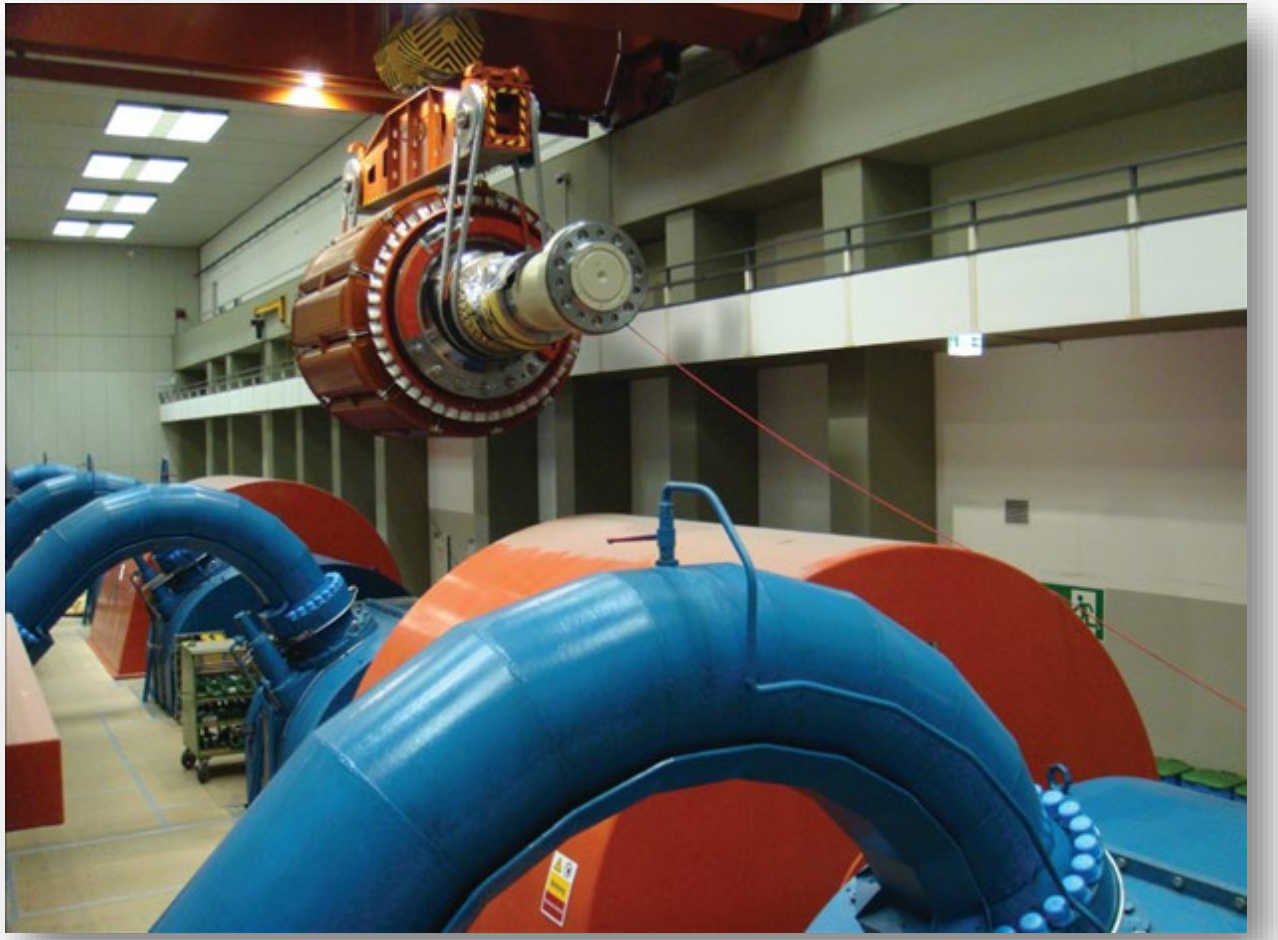
+/- 500 MW WITHIN 20-30 SECONDS

KOPS II / Austria

- 3 x 180 MW (Tu) - 150 MW (Pu)
- Full load: 20-30 s (Tu and Pu mode)
- Head: 826 m
- Unique Ternary concept
- Pressurized downstream chamber



- In operation since 2009
  8,000 operating hours/year!



ENVIRONMENTAL PERFORMANCE

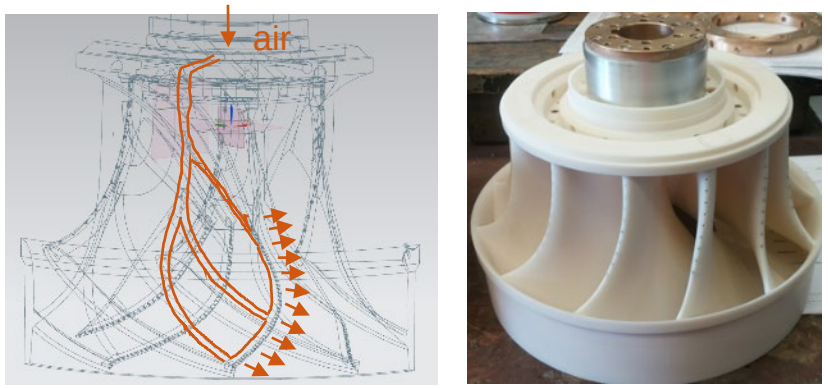
Oil-free design / Fish friendliness / Dissolved Oxygen

TARGET

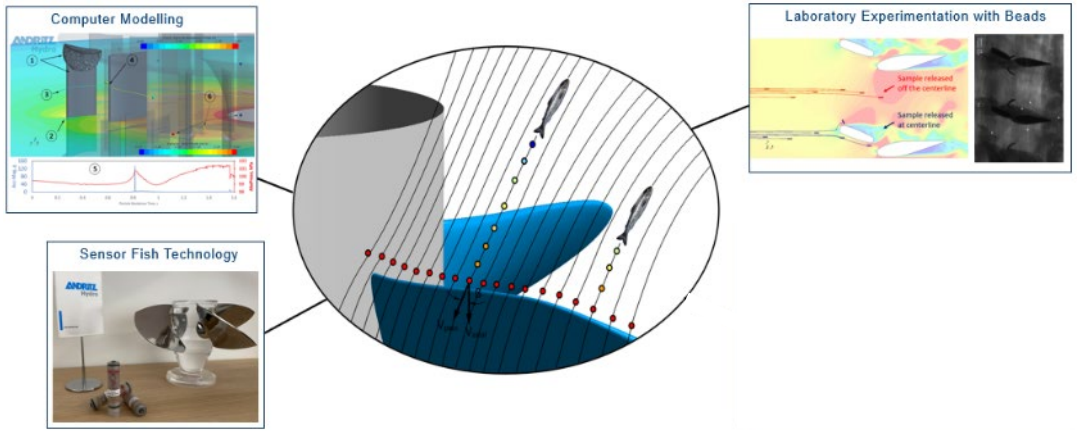
- **Continue R&D efforts in environmental questions**

MARKET POTENTIAL FOR PRODUCTS AND RELATED SERVICES

- **Oil-free design**
- **Fish friendliness**
- **Dissolved Oxygen via Runner –** downstream oxygen content will be raised to the ecologically favorable range via turbine operation



Aerated runner blade



Methods to assess fish mortality properties

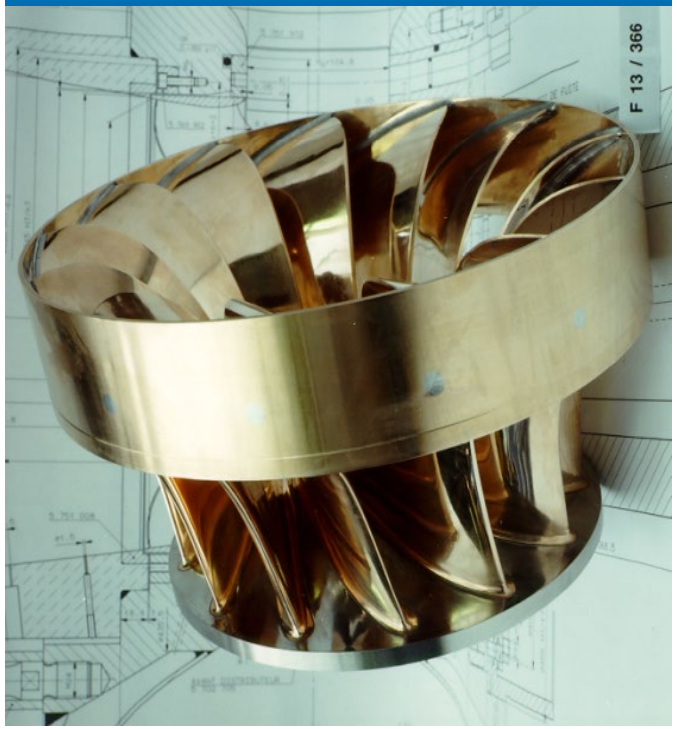
MAKING MOST OF THE EXISTING

REFURBISHMENT, UPGRADE, DIGITALIZATION, CYBER SECURITY

Diagnosis

Analysis

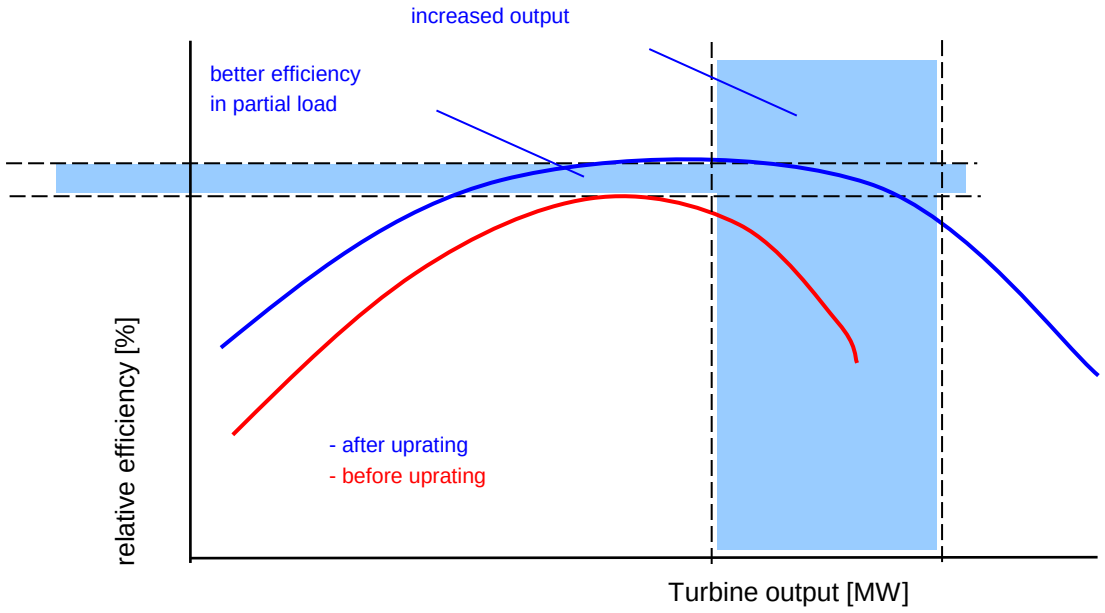
Therapy

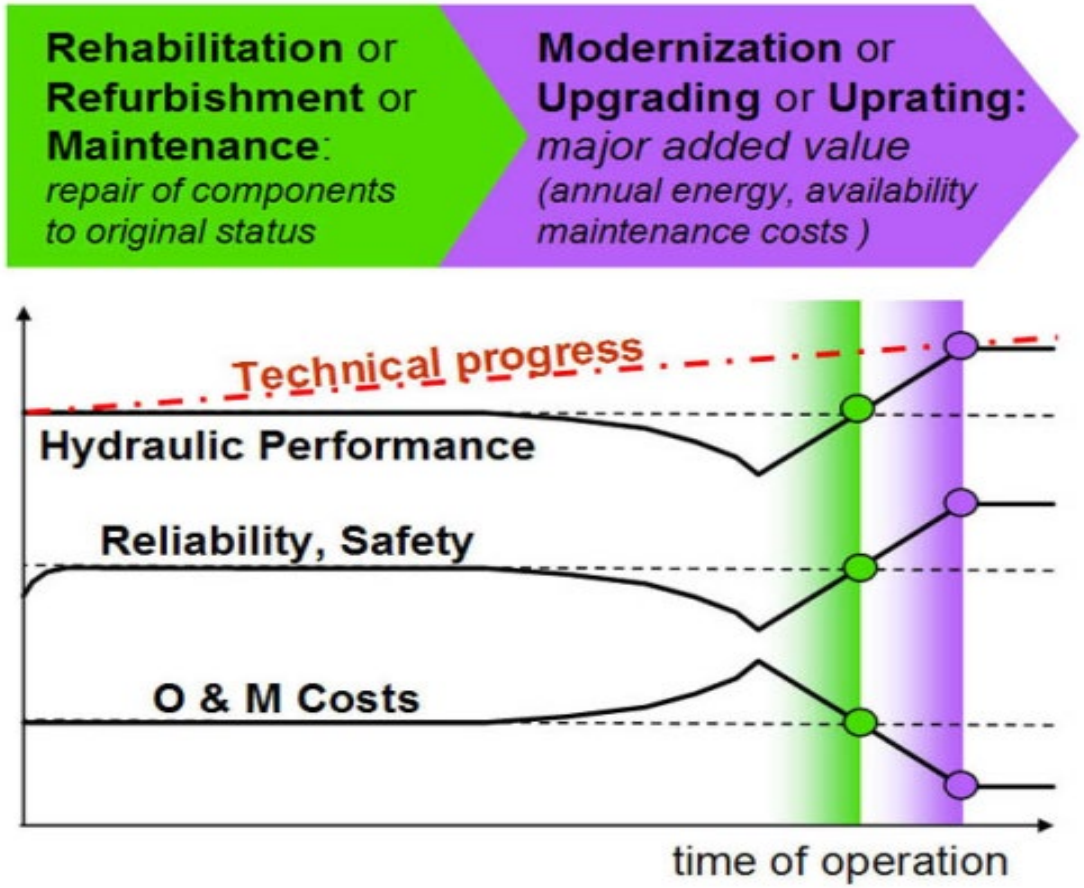


FIT FOR THE NEXT 50 YEARS

Additional renewable energy

- For each 30 GW upgraded per year and for each 5% of increase of performance, rehabilitation programs will create 1.500 MW of renewable and predictable energy





DIGITAL O&M AND ASSET MANAGEMENT

CUSTOMER CENTRIC **O&M** SUPPORTED BY **DIGITAL SOLUTIONS**

Operation & Maintenance

Predictive Maintenance

Metris DiOMera digital platform

ISO 55001:2014

THE OPPORTUNITY

Green hydrogen production to **grow** from 0.7 Mt/a in 2020 to 300 Mt/a in 2050

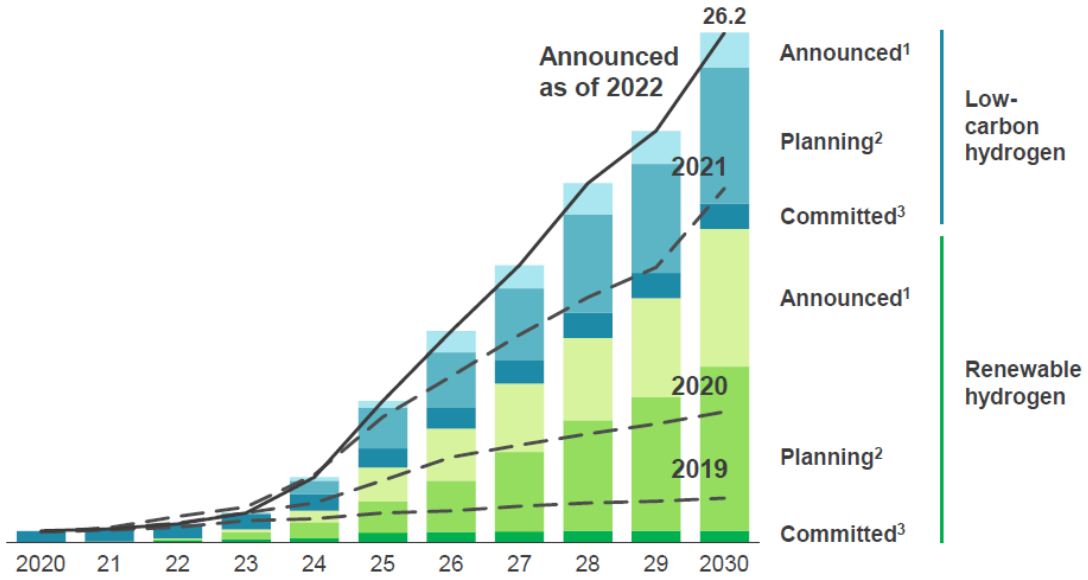
Main drivers for green hydrogen scale up:

1. Decarbonization of industries (refineries, chemicals, steel), transportation and energy storage, e.g. EU Green Deal
2. Reducing price of renewable energy (down to < 20 €/MWh)
3. Money in the market (funding and investors) for sustainable investments

Info:
1 Mt/a Hydrogen = 12 GW installed
Today's costs for Green H2 is between 3 to 6 €/kg. The aim would be to reach 2€/kg
And you need 9 liter water per kg H_2

Exhibit 5 – Announced clean hydrogen production volume by pathway

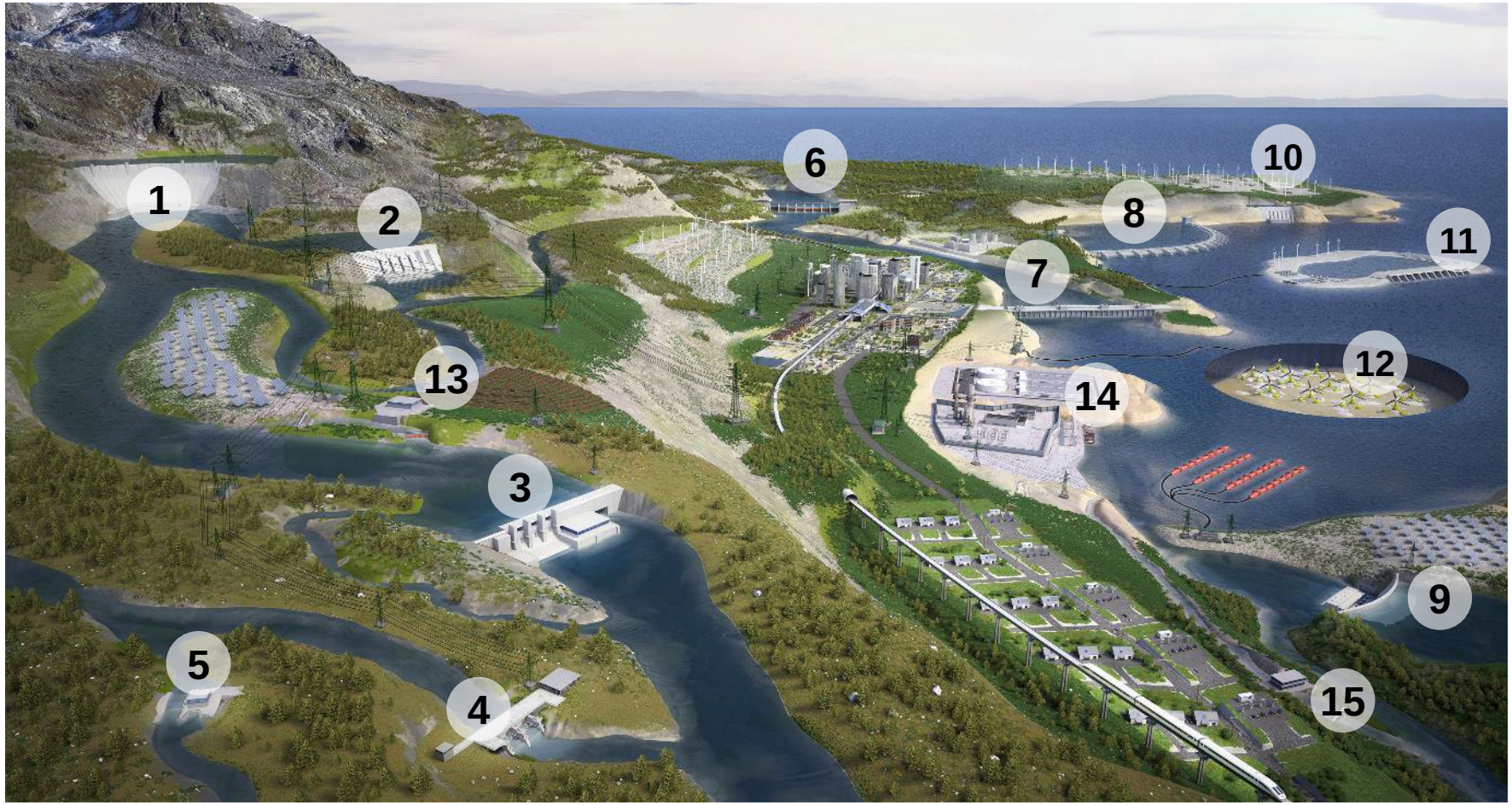
Cumulative production capacity, MT p.a.
As of May 8, 2022



¹ Preliminary studies or at press announcement stage
² Feasibility study or front-end engineering and design stage
³ Final investment decision has been taken, under construction, commissioned or operational

Source: Hydrogen Council, Hydrogen Insights 2022

POWER GENERATION FROM HYDROPOWER IN THE FUTURE - SCENARIO 2050



1) Annual storage reservoir
2) Short-term storage reservoir
3) Conventional river power plant
4) Small hydropower plant
5) Ecological Flow
6) Urban river power plant
7) Low head hydropower plant
8) Tidal power plant
9) Pumped storage power plant (fresh water); energy storage for solar power plant
10) Pumped storage power plant (salt water); energy storage for wind park
11) Energy island; off-shore pumped storage power plant for wind/solar/tidal
12) Tidal stream power array
13) Irrigation system
14) Desalination plant
15) Flood control pump station

The future depends on what we do in the present

Mahatma Gandhi