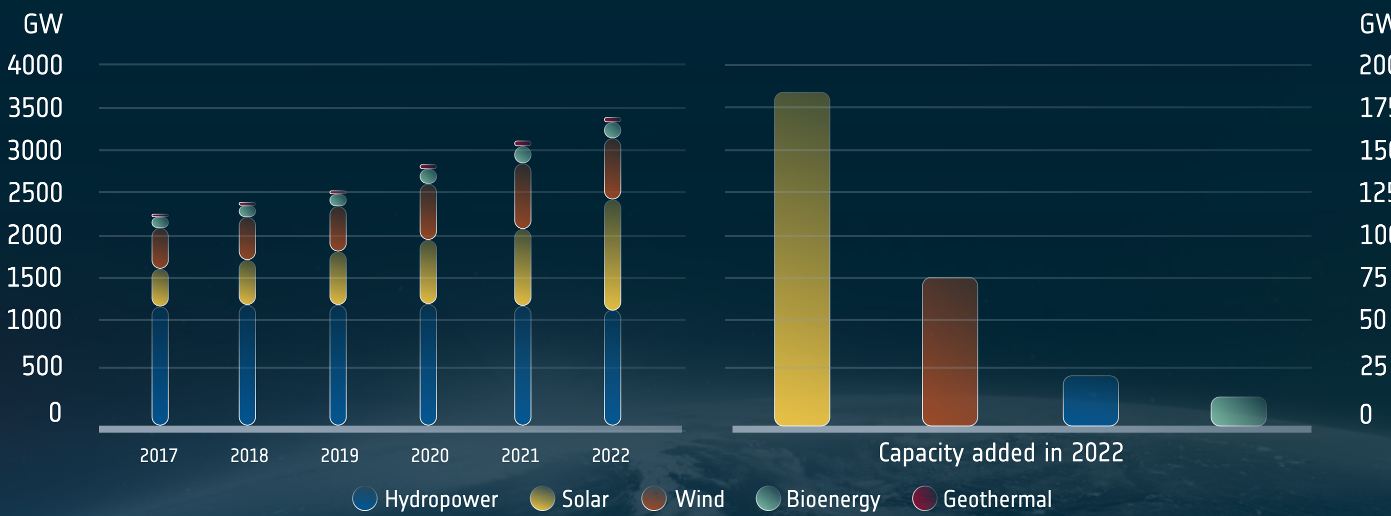
SPACE MEETS HYDRO ENERGY: USE CASES AND MARKET OPPORTUNITIES

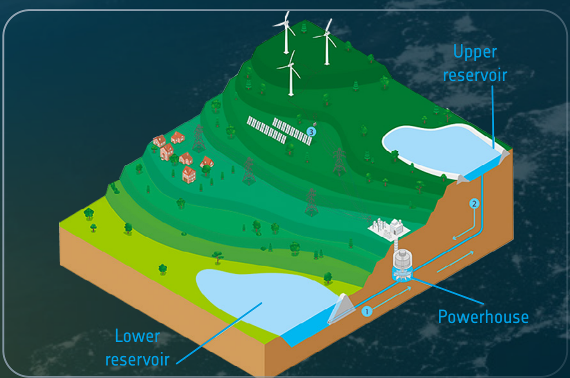
Introduction to hydro energy

Humanity's oldest source of renewable energy currently plays a pivotal role in the energy supply of over 160 countries worldwide. **With 4,252 TWh generated in 2021**, hydropower makes the largest contribution to total renewable electricity generation (37%), coming right after coal and natural gas[1]. Nonetheless, its growth rate has been relatively slow in comparison to solar and wind energy largely due to environmental and social impacts, complex permit acquisition processes and long construction times.

To reach carbon neutrality by 2050, hydro energy has a major role to play. It offers three distinct advantages when it comes to clean energy generation. Firstly, hydropower is one of the most **cost-effective** ways of generating electricity. Secondly, dams can provide **multiple benefits** as their infrastructure can be used to supply clean water for homes and agriculture, for instance, or to mitigate the impact of increasingly frequent extreme weather events, such as floods and drought.



Renewable power capacity growth[2]



Closed loop PSH illustration from IHA[3]

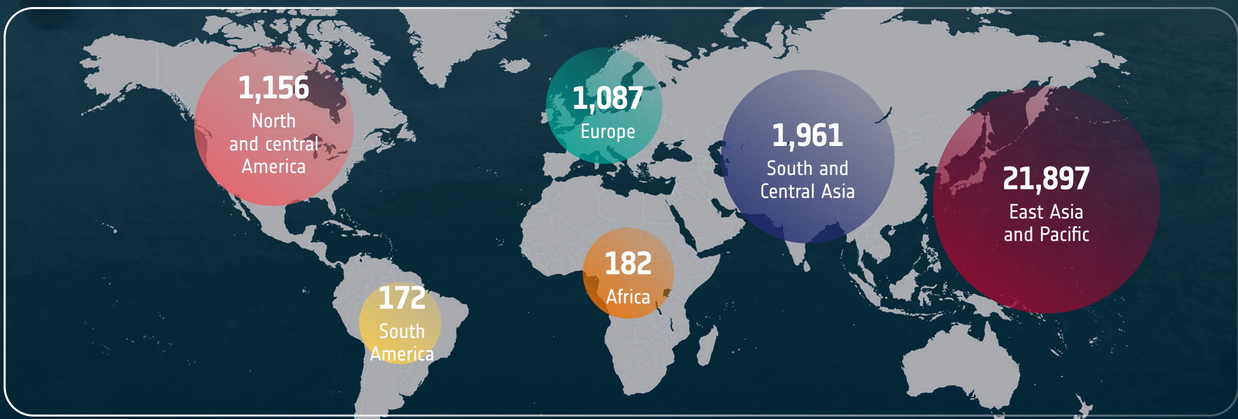
Lastly, it **provides flexibility and can be stored**. No back-up is required and on account of its reliability, hydropower can adapt to the daily and seasonal fluctuations of the next two largest renewable sources (solar and wind). Pumped hydropower storage (PHS) especially offers major potential in supporting the rapid growth of solar and wind energy as it absorbs and releases energy on demand.

The East Asia and Pacific region is the fastest-growing hydro energy market on account of the major investments that have been made there.

1. HYDROPOWERSTATUS REPORTSECTOR TRENDS AND INSIGHTS...
2. RENEWABLE CAPACITY HIGHLIGHTS...
3. LET'S GET FLEXIBLE – PUMPED STORAGE...

In 2021, the countries with the greatest installed hydropower capacity were China (29%), Brazil (8%), the United States (7%), Canada (6%), Russia/India/Japan (4%) and Norway (2%). Developing countries currently have most of the world's untapped potential for hydropower and remote rural areas in these countries could, for instance, be served by off-grid and mini-grid hydro systems.

International and multi-stakeholder cooperation is playing a significant role in preparing the future of hydro energy by fostering collaboration, financing and sustainability compliance. Examples of this cooperation include the International Renewable Energy Agency (IRENA) or the International Hydropower Association (IHA).



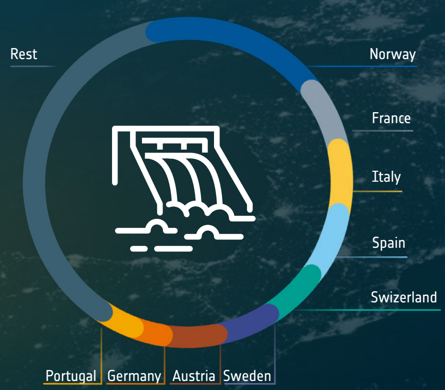
New hydropower installed capacity by region in 2021 (mW)

Overview of the European hydropower market

Owing to its technologically developed and mature hydro energy industry, Europe is a leading force in the development, innovation and export of hydropower. In 2021, hydropower installed capacity amounted to 255 GW, representing around **one-fifth of the world's hydro capacity**, and 44 GW of this total consisted of PHS[4]. Hydropower also accounted for 32% of the European Union's renewable electricity production and provided 12% of the EU's electricity[4].

In absolute terms, Norway is Europe's largest hydro electricity supplier (99% of its own electricity comes from hydropower)[5], mainly through Statkraft, a state-owned utility that is also one of Europe's leading hydropower companies. France comes a close second (main provider EDF), followed by Italy (Enel SpA) and Spain (home to Cortes, Europe's largest PHS plant).

In relative terms, Switzerland owes a very substantial portion of its renewable energy generation to hydropower (80% capacity in 2021, including marine), as for Romania (59%), Croatia (64%), Austria (66%) and Latvia (86%)[6].



Hydropower installed capacity by country in Europe[4]

Since 2000, new large-scale hydropower developments have been few and far between in Europe, with 40% of European hydro infrastructure now more than 40 years old. Given that major refurbishment is needed after 45–60 years on average, a **large share of the hydro infrastructure will urgently need to be refurbished** in the coming years.

At the same time, small-scale and hybrid hydropower solutions are emerging, and are expected to grow in Europe in the future. **Hybrid plants combining solar and wind energy** generation offer controllable and flexible electricity generation, reduce transmission interconnection costs and can lower upfront costs related to permits, site acquisition and engineering[7]. **Small-scale plants** help to reduce the negative social and environmental impacts of large projects. The reservoirs of large plants lead to methane emissions, the displacement of people, sedimentation and disrupted stream dynamics[8]. Small plants, however, have no such reservoirs, and therefore have a minimal impact. Finally, other technologies such as closed-loop schemes or fish-friendly turbines are being considered to achieve compatibility with environmental restrictions expected by the EU.

4. 2022 HYDROPOWER STATUS REPORT...
5. HYDROPOWER IRENA...
6. IRENA OVERVIEW...
7. HOW HYBRID PV TECHNOLOGIES CAN CONTRIBUTE TO...
8. HYDROPOWER (SMALL-SCALE)...

Hydro energy needs: harnessing the potential of space technologies

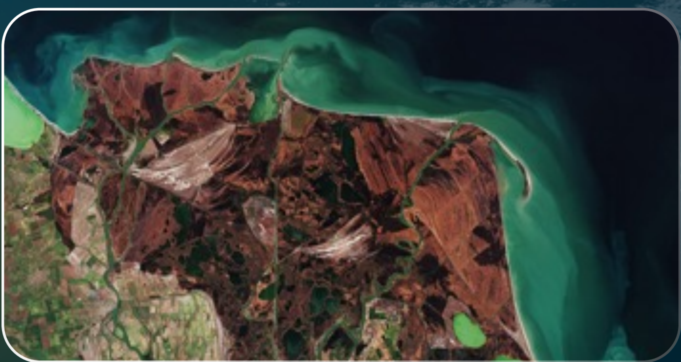
Today in Europe, the need to reconsider established systems and processes in the hydro energy market is more urgent than ever before. Refurbishment options that can maximise the potential for efficiency while supporting small-scale and hybrid projects as well as addressing environmental aspects are very much in the spotlight. With these needs, fresh potential is emerging for space-based solutions in Europe as well as in the rest of the world.

LOCATION-SCOUTING FOR NEW AND DIFFERENT TYPES OF HYDROPOWER PLANT

Optimal locations for new large and small-scale plants must be identified to support the growth targets for hydro energy. Satellite images can permit water resource assessments and thus help find locations with high energy generation potential where the environmental impacts caused by rerouting or damming the water flow would be minimal[9]. Hybrid plant locations could also be found by combining solar, wind and hydro Earth observation technologies.

IMPROVEMENT OF ELECTRICITY GENERATION FORECASTING

Flexibility is a key advantage of hydroelectric plants, and can be maximised through improved prediction. Earth observation (EO)-based forecasts offer considerable potential for the provision of hydrological and hydrometeorological modelling through a data assimilation scheme. EO-derived parameters include runoff estimates, precipitation and evaporation, soil moisture, river discharge and snow-related insights. Snow strongly influences management decisions as many plants are situated in mountainous regions. Currently, snow water equivalent (SWE) data is obtained through measurement campaigns that are expensive and involve safety issues due to avalanche risks.



Danube Delta viewed by Copernicus Sentinel-2 images

Another advantage of satellites is that they enable long-term data collection, which can help identify trends and patterns. These can be coupled with machine learning or data assimilation to improve prediction still further.

BANKABILITY

New plants require long-tenor loans and their construction typically poses higher risks, making them less attractive for private investors who prefer a rapid and secure ROI[10]. Accurate forecasting could help improve the bankability of planned new projects, leading to an overall increase in investment in hydro energy through public-private partnerships.

CLIMATE CHANGE AND INFRASTRUCTURE MONITORING

Real-time data on the structural health of dams to detect potential issues in their infrastructure can increase a site's safety and make it possible to take prompt action. EO data collection is suited to being performed more frequently and is cheaper in comparison to in-field measurements. Both methods can, however, be used simultaneously for optimal results, as seen, for instance in Enel Green Power's GPS Hydro project, which is based on the precision satellite positioning provided by the Global Navigation Satellite System (GNSS)[14]. Drones can also work in tandem with satellite images for closer inspection, providing a faster, safer, cheaper and more versatile alternative to traditional techniques such as scaffolding.

Space technology can also be used to map exposed and vulnerable assets for risks of hydrometeorological hazards (e.g.floods) or geo-hazards (e.g. landslides, terrain deformation) through synthetic aperture radar (SAR) data from Sentinel-1 or optical images from Sentinel-2[11] Due to climate change, these risks are increasing rapidly.

Researchers have underlined the importance of sediment levels when it comes to hydropower. Sediment limits the capacity of a reservoir's annual storage volume by an estimated 0.6% approximately and damages the dam[12], leading to revenue loss and an increased risk of flooding. A rising number of researchers and companies in various countries have been analysing hydropower plant sedimentation using satellite data from various sources such as Landsat, Sentinels or the China-Brazil Earth Resources Satellite (CBERS)[13].

9. SATELLITE DATA APPLICATIONS FOR SUSTAINABLE..
10. THE CHANGING ROLE OF HYDRO POWER...
11. SECURITY THAT COMES FROM SPACE...
12. → EO4SD – EARTH OBSERVATION FOR SUSTAINABLE...
13. RIVER SEDIMENTATION CHALLENGES FOR HYDROPOWER...
14. FURTHER DEVELOPMENT OF SMALL HYDROPOWER...

MONITORING AND REGULATING ENVIRONMENTAL AND SOCIAL IMPACT

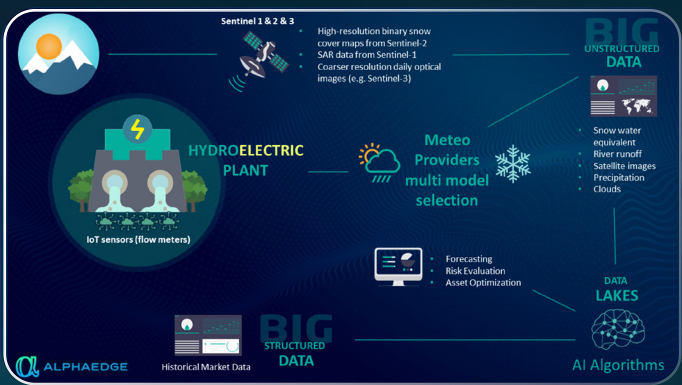
The World Wildlife Fund (WWF) has raised the alarm about the destructive impact of hydropower plants on biodiversity and rivers. More than 150 NGOs have already signed a manifesto calling on the EU to redirect its subsidies and public financing from building new hydropower plants towards refurbishing existing ones, for instance[15]. Potential negative environmental impacts must therefore be **monitored**. Research must be conducted on the processes by which organic material builds up behind dams, decomposes and removes oxygen from the water, thereby killing plants and animals, and methane emissions from submerged vegetation must also be analysed. Finally, strict and transparent **sustainability criteria must be set**. The International Hydropower Association (IHA) launched the Hydropower Sustainability Standard in 2021 to rate and certify projects based on their sustainability compliance, which could potentially be monitored by EO. Negative social impacts such as population displacement or livelihood changes are of major importance, but are barely researched. A better understanding of these impacts could help mitigate them through new approaches and strategies. Satellite imagery offers significant potential in terms of analysing these phenomena.

The role of the space sector in Europe today

Space assets, especially EO, play an important role in the economic and environmental prospects of hydropower plants. ESA supports projects that aim to tackle existing and emerging needs, including forecasting and bankability, as well as climate change, infrastructure and environmental monitoring.

COMPLETE SOLUTIONS FOR HYDROPOWER COMPANIES

Alphaedge, supported by ESA BIC Austria, aims to provide real-time **forecasting, risk evaluation and asset optimisation** for hydropower plants[16]. It uses artificial intelligence on unstructured big data from EO images collected by Sentinel-1, -2 and -3 (e.g. of snow water equivalent, river runoff, satellite images, precipitation, clouds) coupled with Internet of Things (IoT) sensors and structured historical data.

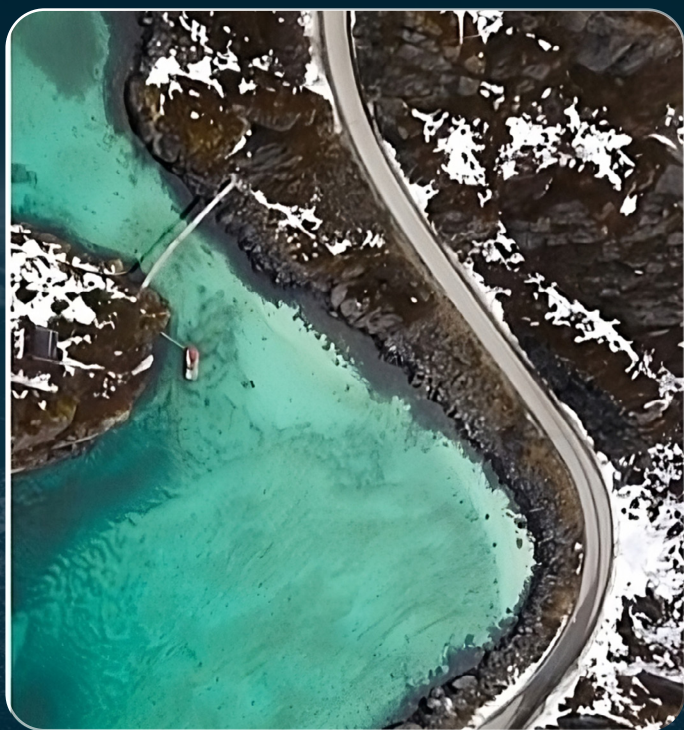


Together with ESA's Business Applications Programme, the Norwegian start-up EDInsights can **map and monitor the surface water and volume of large to medium-sized reservoirs and lakes**[17]. The approach combines radar and optical satellite data from Sentinel and Radarsat satellites with machine learning and cloud processing. EDInsights is also the prime contractor for the WaterInfo project which uses radar images from the Sentinel-1a/b satellites and measurements from the Sentinel-2a/b satellites to monitor changes in the water resources of individual lakes and reservoirs. It aims to **optimise hydropower production planning while improving price predictions and market analysis**.

Finally, the DeFROST project by WeGaw uses Sentinel-2 data to provide hydro energy companies with more accurate snow-based forecasts to improve their planning[18].

NEW RESEARCH RELATED TO HYDROPOWER PLANTS

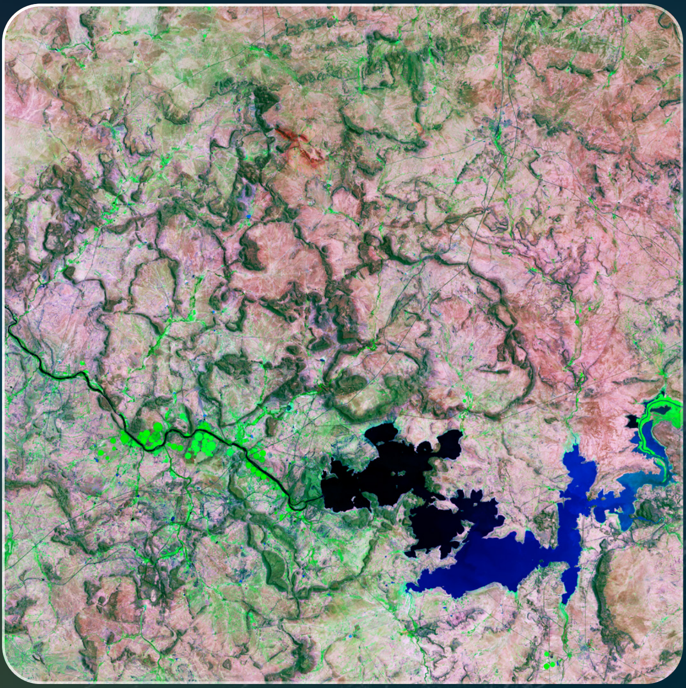
ESA is funding research activities such as Fluvisat to investigate the potential use of satellite-collected video imagery to provide accurate and timely quantification of **water movements and river flows**[19]. Similarly, RIDESAT aims to develop a satellite-based river discharge product for small to large rivers through a novel synergistic utilisation approach of three special sensors (altimeter, optical, and thermal).



15 HYDROPOWER IS DESTROYING EUROPE'S RIVERS...
16. BIG UNSTRUCTURED DATA AND SPACE...
17. SPACEBORNE ANALYTICS FOR HYDROPOWER...
18. WE HELP YOU OPTIMIZE ...
19. EO SCIENCE FOR SOCIETY...

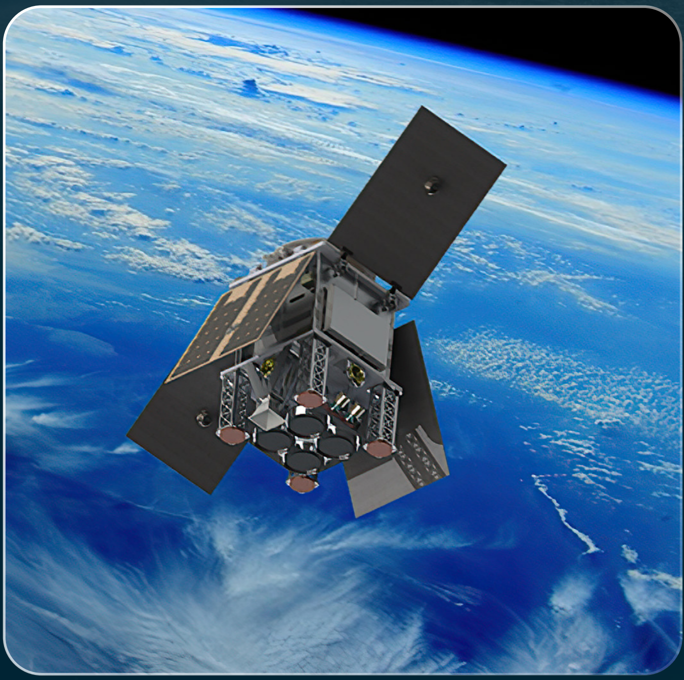
STREAM has investigated river runoff trends. More recently, RIDESAT and STREAM were merged into STREAMRIDE to improve river discharge estimates further[20]. Finally, ESA's large-scale Soil Moisture and Ocean Salinity (SMOS) mission could help increase the accuracy of hydropower forecasting models by improving our understanding of specific parameters they use, such as soil moisture, which is driven by evaporation, infiltration and runoffs.

As stated previously, snow studies are important for the sector's planning capabilities, and new initiatives to monitor **SWE** have emerged. The eo4alps snow project uses high-resolution optical and radar EO from Sentinel-2, SAR data from Sentinel-1 and coarser-resolution daily optical images from Sentinel-3[21]. EOMAP[22] together with Snowcap[23] and the Finnish meteorological institute, combine Sentinel-1 SAR data with snow models based on meteorological data to derive SWE estimates. These will provide highly accurate power generation forecasts for hydropower plants. While the companies are currently preparing for the demonstration study starting this September, potential customers such as Enel have already demonstrated their interests for such innovations. Alongside SWE, EO-based Fractional Snow Cover (FSC) mapping demonstrates strong result for hydrological modelling. The Norwegian Computing Center under the project NVE Copernicus 2, using Sentinel 3, has tested and is now developing an operational solution using deep learning AI technic to map FSC. PRODEX projects Snow Model for Sentinel is also using Sentinel 2 and 3 optical observations to develop a radiate-transfer-model (RTM) which can be used to derive snow properties such as grain size, impurities, surface temperature. These are valuable inputs for advanced distributed hydrological models to predict run-off more accurately.



Sediment analysis: Copernicus Sentinel-2 images of Gariep Dam sediment analysis[24]

The impact of sediment on the storage capacity, lifetime and operating costs of reservoirs has triggered the emergence of new projects. The EU-funded HYPOS project[25] uses optical sensors from Sentinel-1, Landsat and Planet to evaluate new hydropower sites or manage existing ones by focusing on sediment-related parameters. Similarly, EOMAP uses high-frequency PlanetScope data provided by ESA to analyse sediment levels triggered by flushing events[26].



HydroGNSS satellite

In addition, new satellite data sources are being developed, including ESA's HydroGNSS mission. The mission comprises **two identical satellites** to halve the time it takes to revisit the same place on Earth's surface and re-measure various direct and indirect variables of the hydropower sector, such as soil moisture, climate monitoring, drought and floods.

Hydro energy has a key role to play in achieving carbon neutrality, and space technologies have the potential to support the sector further. ESA can support European companies eager to work towards this goal across the whole product development cycle: from science-oriented projects (Future EO[27]) to start-ups via the ESA BIC Network[28], or with co-funding via BASS[29] or Incubed[30].

20. SATELLITE DATA GIVE UNEXPECTED...
21. WATER JADE...
22. EOMAP...
23 SNOWCAP...
24. GARIEP DAM COMPARISON...
25. HYPOS...
26. MAPPIMG AND MONITORING...
27. FUTURE EO...
28. ESA BIC...
29. BASS...
30. INCUBED...