HYDROPOWER:
Its noble role in socio-economic development and its promise of sustainability for the future

Second Prof O.D. Thapar endowed lecture
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I feel extremely honoured to be delivering the second Prof O.D. Thapar endowed lecture, for such a globally renowned institute as IIT Roorkee, founded in 1847 making it the oldest scientific and technical institution in the country. I have admired your research work over many years and I have had the pleasure to publish papers from the Institute since the beginning of my career, way back in the 1970s. Of your 22 Departments today, one can see that at least half can be directly associated with the study, planning and development of hydropower. And clearly IIT has always been at the leading edge of hydro, and especially small hydro, research.

My lecture today is probably very different to those which many studying here may be used to: I will not include a single equation.

My aim is to put your research work on specific aspects of renewable energy into the broader context of the global role of hydropower, past, present and future, demonstrating the multiple benefits of hydro for society, and thus to underline the importance of the career pathway you have chosen. I will trace developments in hydropower from its early role in economic development to its crucial role in the coming years, as countries transition towards carbon-free economies. Therefore, this talk will be a journey through all the ups and downs of opinions about hydropower, and its unfaltering role in meeting many needs of society – which underlines its unique characteristics in the energy mix.

1. HYDRO and History

When comparing various forms of energy, and particularly renewable energy, a key feature of hydropower is of course the maturity of its technology. That is not to say the industry is not dynamic today, with plenty of new developments, refinements and efficiency increases, but these new developments are based on very firm foundations. Early hydro schemes date back to the 19th century, and the first large-scale developments linked with industrial development were built in the middle of the 20th century.

India was one of the pioneering countries for hydropower development, along with the UK and USA, and the Sidrapong hydro plant, in the foothills of the Arya tea estate near Darjeeling, was commissioned in November 1897, making it the first hydro plant in Asia. With an original capacity of 130 kW, it was uprated to 1 MW in 1916, and after a repair to landslide damage in the 1980s it was still operating to celebrate its 100th anniversary in 1997.

1.1 Early pioneering hydropower developments

• ***Snowy Mountains, Australia***
This enormous complex was constructed between 1949 and 1974, and was the largest infrastructure scheme in Australia, comprising 16 dams, 9 power stations and two pumping stations. It provided peak power for three states, as well as 2100 Gl of water for use in irrigated agriculture.

• ***Hoover, USA***
Construction of this scheme began in 1931. It was a challenging project, and a large number of workers lost their lives, working in extreme heat, and at times in unventilated tunnels. During the Great Depression in the USA, it provided employment for thousands of workers, as well as supplying irrigation water, hydropower, flood protection, and a water transfer system across several states. It provides electricity to 1.3 million people, and was instrumental in the development of major cities in the southwest USA.

• ***Aswan, Egypt***
Built in the 1960s, Aswan played a pivotal role in Egypt's industrial development, economy and culture. As well as hydropower, the project provided flood control and urgently needed irrigation water supplies. It saved the country from nine consecutive years of drought, and from devastating floods in 1975 and 1988.

• ***Grande Dixence, Switzerland***
Grande Dixence was built between 1951 and 1961 in western Switzerland, with a workforce of around 3000, working at a high-altitude site. It exploits the runoff from 35 glaciers. Still today world's highest gravity dam, Grande Dixence is now is part of a major hydro and pumped-storage complex. Its original purpose was to develop Swiss industry after the second world war. Today the complex supplies about 15 per cent of Swiss electricity.

• ***Bhakra-Beas, India***
This scheme, which went ahead in 1947, and was another early major feat of engineering, with multiple and massive benefits, which brought ringing socio-economic uplift to a large region. Apart from irrigation water for three states, and hydropower, the scheme provided effective flood control over thousands of hectares of land [Sharma, 2021[1]].

2. HYDRO and Socio-Economic Development

A message which really underpins this paper is the fact that hydropower stands out, compared with all other forms of energy, including renewable energy, in that it is the *only* one which can offer such a range of major additional benefits multipurpose benefits.

Hydro schemes can provide water, energy and food security, as well as a number of technical benefits, and indirect social benefits.

If a storage element is involved, then this can provide not only clean power (for industry, domestic use, and to power healthcare and educational facilities), water supply for domestic consumption and industry, irrigation water for agriculture and food security, but it can also play a vital role in grid stability, which is particularly important in view of the increasing use of intermittent renewable energies. And today reservoirs offer great opportunities for hybrid schemes.

In the case of run-of-river schemes, river regulation, flood control and enhancing inland navigation can be major additional benefits.

A number of indirect benefits generally result, for all types of hydro schemes. The following are two examples of multiple benefits and integrated social development, in different parts of the world

2.1 Merowe, Sudan

The multipurpose Merowe scheme in northern Sudan, where a 1250 MW hydropower plant was commissioned in 2010, is an example of a major dam offering a wide range of direct and indirect benefits. As well as more than doubling the country's installed capacity, and allowing for the creation of a new high voltage transmission network linking the project to several major load centres in the country, the project will provide irrigation water for an area of about 400 000 hectares [Bartle, 2009[2]].

Farmers' and water users' associations have been formed, to encourage an exchange of experience on new agricultural techniques. An example is the production of seed potatoes; as a result of the project, these can be cultivated and stored at the correct temperature for the first time. Previously potatoes were imported, but now the whole country can be supplied, and high quality of the potatoes are being exported, boosting revenue for the country.

The resettlement plan has incorporated the construction of new hospitals with modern surgical facilities, clinics, mosques and schools. Some of those resettled from the reservoir are receiving water and electricity for the first time.

One of the first major benefits of the project, during construction, was the creation of road links between the town of Merowe and the capital, Khartoum. Less than 10 years ago, the journey between these towns would have taken up to nine days, by camel, on foot and partly by truck. Naturally this had major implications for sick people, or pregnant women, trying to reach hospitals in Khartoum. Now the journey takes just three hours on asphalt roads.

2.2 GAP project, Southeast Anatolia, Turkey

This is a classic example of integrated regional development, based on the construction of 22 large dams across a wide area, with great emphasis placed on social aspects. Direct benefits of the scheme will eventually be about 7500 MW of hydro capacity and the irrigation of an area of about 17 000 km^2, which, before the project, was a vast arid desert. It now resembles a market garden. Turkey's area of irrigable farmland will have doubled as a result of the GAP project. And there have been major improvements to the quality of life in the region.

New crops have been introduced, and cotton production has vastly increased. Entrepreneur support and guidance centres opened to encourage investors to develop new agricultural practices. Training in animal husbandry was established. Special women's centres were created from the beginning, to help them develop new skills and to develop cottage industries. Previously they would have been confined to housework.

There was some controversy about the project, as a town, which had actually been abandoned and derelict for some time, was to be submerged by the reservoir of one of the first projects.

But international groups of students worked on the restoration of mosaics, frescoes and artefacts from that town, so they could be preserved in a museum; thus, the cultural heritage has been retained of an area which would otherwise have been ignored.

2.3 River regulation and flood control

Hydropower development has led to the taming and controlling of stretches of some of the world's major waterways, making otherwise wild stretches navigable, and hence providing the opportunity to increase waterborne transport and enhance national and regional development. Here are some examples from the Americas, Asia and Europe [Bartle, 2018[3]].

2.3.1 Columbia River, USA

Work began in the 1930s on planning to develop the hydropower and navigation potential of the Columbia river in the USA. Flood control measures, and some water diversion and storage for irrigation were also included. The first two major schemes to go ahead were Grand Coulee and Bonneville dams, both with large hydro plants, and other schemes followed some years later after World War 2.

Power demand in the western USA had tripled by the late 1940s, and the Government prioritized the development of more large hydro schemes on the Columbia river, and in parallel provided modern locks to accommodate the latest large sizes of barge, which were mainly being used to transport wood, and agricultural and petroleum products, downstream.

2.3.2 Jiangxia Shihutang, Gan river, China

China's inland waterway transport network is the largest in the world. Jiangxi, a landlocked province, until recently was considered to be economically underdeveloped, and improving transport on its waterways was identified as a key priority. A major scheme called the Jiangshi Shihutang Navigation and Hydropower Complex was designed to improve use of the Gan river for freight transport, and to have the side benefit of cleaner energy production to meet increasing demand in the region. A huge additional benefit was flood protection for communities in an area vulnerable to intense flooding.

The scheme was completed in 2014, and now a 38 km stretch of river has been upgraded to allow for 1000 t vessels to use the waterway for 95 per cent of the time, compared with 27 per cent formerly. Hydro generation avoids an estimated 220 000 tons of CO_2 emissions. More than 4000 ha of farmland is protected from flooding, and a road across the dam crest has shortened the travel distance between two important cities by 12 km.

2.3.3 Douro River, Spain/Portugal

A total of 15 dams and hydro plants have been built on the 900 km-long Douro, which flows through Spain and Portugal on the Iberian Peninsula. The purposes were to regulate flow, calm various turbulent stretches of the river, generate hydropower and allow for navigation along what are now calm waters, through locks. Five dams are within Spain, five are on the border with Portugal, and the other five are within Portugal.

Vessels up to 83 m long can now pass through the locks, and the highest lock, at Carrapatelo dam in Portugal, has a maximum lift of 35 m.

The Douro is especially important for the transport of agricultural produce, and of course the famous Port wine, but also for tourist boats.

2.3.4 Danube River, Romania and Serbia

The Djerdap 1 and 2 (also known as Iron Gates) Hydro Power and Navigation System is one of the largest such schemes in Europe. It was developed to exploit the significant hydropower potential available, and to improve the conditions for navigation in what was formerly a very dangerous stretch of the Danube, on the border of Romania and Serbia.

It is acknowledged today that the project has completely fulfilled its intended purpose. The average hydropower production is 13 TWh/year, and this covers an important share of power demand in Serbia and Romania.

2.3.5 Rio Madeira, Brazil and Bolivia

A major on-going scheme, as part of the Initiative for the Integration of the Regional Infrastructure of South America (IIRSA), is the Rio Madeira development; the Madeira river is a tributary of the Amazon. The aim of IIRSA is to integrate highway networks, rivers, hydroelectric dams and telecommunications throughout the continent, to allow for greater trade, and ultimately a South American community of nations.

The Rio Madeira scheme involves two major dams and hydro plants in Brazil, one on the border with Bolivia, and a further one within Bolivia.

The scheme is the cornerstone of the Brazil-Bolivia-Peru hub of the IIRSA initiative, and is opening up a 4200 km-long industrial waterway for the passage of barges, which will allow for the transport of soya beans, timber and minerals to Atlantic and Pacific ports.

3. HYDRO and Public Opinion

Public awareness about dams, and public acceptance of them, have fluctuated in several waves over the past decades. The situation has improved enormously over the past 15 years or so, but it has been a rough journey at times. Experience has clearly demonstrated that good communications, as well as a concerted effort to learn from unsatisfactory cases in the past, have provided the keys to progress.

In many parts of the world, large dams and hydroelectric plants were built between the 1930s and 1960s, as a basis for industrial development. And while they certainly did provide clean renewable energy, boost national economies, help develop industry and create employment in the post-war years, far less was really known or appreciated in those days about potential negative impacts. Also sometimes not enough was done to ensure that the livelihoods of local communities were improved by the projects, for which they had made some sacrifices.

There were cases when power from large developments was transmitted to large load centres some distance away, and villagers close by, who had sometimes experienced the most disruption, waited years for basic power and water supplies. In reality there was a clear turning point in the 1980s, when developers began to invest more heavily, and consultants began to learn much more, about mitigating or avoiding negative social and environmental impacts. The resettlement of local people was (and in some cases still is) a major controversial issue. Again, many lessons have been learnt to ensure that not only are people compensated fairly, but more importantly that they directly gain from the project with improved living standards.

3.1 Opposition and the WCD Report

The situation in the 1990s included some strong demonstrations and campaigns by well organized political NGOs who seemed better at communicating than dam engineers. They often took historic examples and claimed that dams in general (regardless of scale, or how they were designed) were ineffective, damaging or unsafe. This put immense pressure on politicians, financing organizations and developers to halt or vastly scale down badly needed projects in the less developed countries.

There were some ironies, in that the most active organizations, speaking with the loudest voices to condemn developments were from relatively comfortable parts of the world, like Switzerland, the UK and the USA; they had heating in the winter, refrigeration for food and medicines in summer, and of course clean drinking water supplies. They offered no feasible alternatives for water and energy supplies to the developing world.

There were some cases when it became clear that protestors were mobilizing local people to protest against their will, as they could foresee the benefits, and the possibilities for compensation and employment. This era culminated, at the turn of the last century, with a report issued by the World Commission on Dams [WCD, 2000[4]] which was generally critical about on dams, and quoted a few major cases from the distant past implying that no progress had been made since then. Again, no alternatives were offered to supply billions in the developing world with clean water and energy.

3.2 Turn around in opinion

The situation began to change at the turn of the century. The World Bank, at this time, re-examined its perspective on water infrastructure, and in 2002 launched its Water Resources Sector Strategy, which clearly endorsed the development of large water infrastructure; then in 2003, Directions in Hydropower was published by the Bank [World Bank, 2002[5] and 2003[6]], re-affirming its commitment to supporting hydropower and dams. Professional associations such as ICOLD, IEA, IHA, ICID and the technical media played a role, as well as the UN, and many Governments. Efforts were made to present balanced information about the role of water infrastructure and hydro plants

4. HYDRO and Society

A number of factors have helped to increase public acceptance of water infrastructure and hydropower plants.

4.1 Enhanced communications

Delivery of clear information to the public, through dialogue, explanations, and where possible offering involvement in decision making made a big difference. Involving local people in making decisions does not have to be more expensive. Allowing displaced people to choose the layout of their resettlement towns, villages or hamlets can be helpful, as well as choosing the design of places of worship, sports centres, and other public buildings. Such involvement leads to a sense of co-ownership of the development.

Improved dialogue can also lead to a better assessment of local needs, so that assumptions are not made on behalf of others.

4.2 Livelihood improvements

Providing side-benefits specifically for locals so they are not 'left behind' is also vital. While large cities and industries may be deriving obvious benefits from a scheme, it is just as important for local people to gain substantial benefit. And it is usually the case today that project budgets will cover added facilities for communities, or scope to develop agriculture, fisheries, health centres, etc, as well as new housing for those who need to relocate.

4.3 Avoidance of pollution and mitigation of climate impacts

Support for clean renewable energy was further strengthened by concerns about climate, and about particulate emissions from fossil-fuel powered plants, and it was also clear that waterways could be better controlled from extreme floods (now becoming common) by water infrastructure.

4.4 Recreation facilities

More attention is also paid today to improving the aesthetics of around dams and powerplants (flora, bird sanctuaries, etc) as well as the architecture of the schemes themselves. Recreation and tourism can also be encouraged, so the public can be encouraged to enjoy the man-made water bodies for boating, fishing, trekking, birdwatching or just relaxing. In addition to relaxation, Swiss people have been known to ski down dam faces, or bungee jump into reservoirs!

5. HYDRO and the Sustainable Development Goals

It can be noted that hydropower plays a direct role in fulfilling *eight* of the United Nations Sustainable Development Goals, which were launch in 2015 [UN, 2015[7]].

SDG 1: End poverty in all its forms everywhere
Hydro potential is available in most of the less developed countries, and can offer electricity for industry, job creation, educational tools, etc…

SDG 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture
Multipurpose reservoirs which include irrigation water supply can help fulfil this aim.

SDG 3: Ensure healthy lives and promote well-being for all at all ages
Clean water, electricity to improve healthcare, food refrigeration, etc, are the key to achieving this goal

SDG 6: Ensure access to clean water and sanitation for all
Multipurpose reservoirs provide this.

SDG 7: Ensure access to affordable, reliable, sustainable and modern energy for all
What could be better than a non-polluting source of energy; the fuel is free.

SDG 9: Build resilient infrastructure, promote sustainable industrialization and foster innovation
Resilient water infrastructure is being constructed to withstand natural disasters and harsh conditions, and dams in remote areas are bringing industry to areas which would otherwise remain underdeveloped. Cases range from the freezing Far East part of Russian, to the humid jungle of Sarawak.

SDG 13: Take urgent action to combat climate change and its impacts
Reduce emissions by developing clean, renewable hydropower – replacing fossil fuel generation, to the maximum possible extent.

SDG 17: revitalizing of partnerships for sustainable development.
(See next section)

6. HYDRO: Enhancing International Partnerships

6.1 Joint development of international waterways

Organizations like the Mekong River Commission, the New Partnership for African Development, and many other regional bodies, encourage the sharing of data, joint studies and planning, and bring together experts from the riparian countries to focus together on issues such as environmental protection.

Cross-border collaboration on the development of shared waterways can enhance goodwill and harmony between nations. Where conflicts could arise, then regional organizations can work together on treaties between the riparian countries.

There are many examples of countries working together on joint developments on major international waterways – like the Senegal river in West Africa, where a number of schemes have been developed jointly by Mali, Senegal, Guinea and Mauritania, with the capacity shared between the countries, under the auspices of the Organization for the development of the Senegal River (OMVS).

The regional power pools of Africa are also playing an important role.

The Mekong/Lancang river is another example, where the riparian countries pool their expertise and data, and conduct joint studies, and seek mutual agreement before hydro developments are planned. The Mekong River Commission and the Lancang-Mekong Water Resources Cooperation Centre play important roles in facilitating this [Tian, 2020[8]].

The sharing of data and studies become all the more critical in view of climate change impacts, in terms of data collection, hydrological modelling, risk assessments relating to natural hazards. Protection and mitigation measures should be carried out jointly, as naturally waterways and landslides will not recognize national borders.

6.2 Power trading

Another kind of partnerships relates to power trading, and one of the best examples is India's long-standing agreements with Bhutan, and more recently with Nepal, to import power from these countries which have vast hydro potential.

The mutual benefits are perfect, with India meeting increased demand for power, and the economies of the neighbouring countries being greatly boosted by the arrangement, facilitating further social development.

Another example is Thailand, importing power from Laos, Cambodia, and Vietnam. These are not the only cases, and there is scope for many more such arrangements.

7. HYDRO and the Environment

In my lifetime working in this profession, I have seen massive changes over the years: increasing knowledge and experience of environmental issues, which in many cases have varying significance and impact in different parts of the world.

I recall a time when there was not a great conversation about the environment, but today there is probably no engineering company without experts, or a whole department, focusing on ecological and environmental impact management.

Protocols and guidelines exist, and the international financial institutions have played a big role in developing and ensuring they are applied to developers seeking project funding.

Over the past 20 years, there have been progressive developments and refinements in environmental impact assessment tools, and much has been published. ICOLD created a Technical Committee on Environment during the 1990s, and has published Technical Bulletins on the Subject. At our own annual hydropower conferences, E&S always features high on the agenda.

Technical developments have emerged at the same time; we can see much R&D in the field of fish-friendly turbines, oil-free bearings and so on, just to name two examples.

8. HYDRO and its role today

8.1 Global statistics and trends

The following data have been taken from the latest edition of our *H&D World Atlas and Industry Guide* [Aqua-Media, 2020[9]] in which a world survey is researched and updated each year, based on data from national utilities, ministries and regional organizations (and covering about 170 countries). Totals are rounded, and necessarily approximate where some data could not be obtained.

- World hydro capacity in operation: 1230 GW
- Hydropower capacity under construction totals: 125 GW
- Hydropower production in 2020: 4313 TWh.

Hydroelectric plants are in operation today in at least 162 countries; more than 50 per cent of these operate as part of multipurpose developments.

Below are figures to show the growth in hydropower over the past 15 years, by region. Notable statistics are the tremendous pace of development in Africa, in terms of capacity and production; and, the enormous and continuing achievements in Asia.

AFRICA	***Increase over the past 15 years***
34 227 MW of hydro in operation	+61%
138 625 GWh/year of hydro production	+60%
ASIA	
623 505 MW of hydro in operation	+149%
2 165 181 GWh/year	+153%
SOUTH AMERICA	
177 858 MW of hydro in operation	+48%
700 246 GWh/year of hydro production	+26%
EUROPE	
200 001 MW of hydro in operation	+12%
550 217 GWh/year of hydro production	+4%
WORLD	
1 230 412 MW of hydro in operation	+66%
4 312 582 GWh/year of hydro production	+56%

8.2 Regional progress and priorities

AFRICA

- The installed hydro capacity is about 34,300 MW
- Hydro under construction totals 18,640 MW
- Only about 8.5 per cent of hydro potential is developed
- More than 50,000 MW is currently planned in about 50 countries
- Africa is beginning with floating solar PV in several countries; it is predicted that if floating solar panels were to be installed on 1 per cent of African reservoirs, this could double electricity production
- Many large-scale regional schemes are under way and planned, especially in eastern (Tanzania), western (Guinea, Senegal, Mali, Mauritania), central (Rwanda, Burundi, DRC) and southern (Zambia, Zimbabwe) Africa.
- The estimated small hydro potential is around 10,250 MW

Leading countries for hydropower development include: Ethiopia, Cameroon, Uganda, Angola, Tanzania

ASIA

- The installed hydro capacity is about 623,500 MW
- Hydro capacity under construction totals 88,625 MW
- Only about 27 per cent of hydro potential is developed
- More than 175,400 MW is currently planned in about 37 countries
- The countries leading with the development of floating solar PV plants are China, Japan, India, Indonesia, Vietnam. Omkareshwar in India will be the largest when commissioned.
- There are important cross-border schemes in SE Asia and Indian Sub-continent
- A vast small hydro potential exists, > 138,000 MW.

The leading countries for hydropower development include: India, China, Pakistan, Laos, Vietnam, Indonesia

LATIN AMERICA

- The installed hydro capacity is about 117,900 MW
- Hydro capacity under construction totals 8167 MW
- About 25 per cent of hydro potential is developed
- More than 28,000 MW is currently planned in nine countries
- Several large bi-national developments are in operation or under construction (eg, Itaipú – Brazil/Paraguay, the Rio Madeira complex – Brazil and Bolivia; schemes now planned for Argentina and Paraguay).
- Floating solar PV exists on some large Brazilian reservoirs (eg, Sobradinho)
- Estimated small hydro potential is around 28,000 MW

The leading countries for hydropower development include: Argentina, Bolivia, Chile, Colombia and Peru

EUROPE

- The installed hydro capacity is nearly 200,000 MW
- Hydro under construction totals 3590 MW
- About 50 per cent of hydro potential is developed
- About 8000 MW is currently planned in 37 countries
- There are floating solar PV installations in Germany, Portugal, Switzerland, UK and others
- Pumped storage upgrades are a priority, and Estonia plans a UPH scheme
- Estimated small hydro potential is around 37,550 MW

The leading countries for hydropower and pumped-storage development, and upgrading, include: Norway, Switzerland, Germany and Portugal.

AUSTRALASIA

- The installed hydro capacity is about 14,000 MW
- Hydro and pumped storage under construction is around 2070 MW (mainly Australian pumped storage)
- About 22 per cent of hydro potential has been developed
- Up to 3000 MW is currently planned in 10 countries (large scale schemes in Australia and mini hydro elsewhere)
- Floating solar PV is being developed in Australia
- A major scheme is Snowy 2.0 pumped storage, Australia
- Estimated small hydro potential is around 1210 MW

Leading country for hydro (pumped-storage) development is Australia, with at least three more schemes planned after Snowy 2.0; small hydro is under way in Fiji, PNG, New Caledonia and the Solomon Islands

8.3 The special importance of small hydro

The global importance of hydropower in general has been highlighted so far, mainly in terms of large-scale schemes, and a special mention should now certainly be made to acknowledge the huge role played by small-scale hydropower. So many of the developing countries, with largely rural populations, are in desperate need of more electricity for rural electrification.

It is predicted that global installed SHP capacity will soon reach >100 GW. China alone has at least 45,000 small hydro schemes in operation. The precise number in the world is not easy to calculate, as records may not exist for a large number of very small plants, and countries have different definitions of 'small'.

A vast potential remains in almost all parts of the world.

Specific attributes of small schemes can be summarized as follows:

• Projects can be simple and low cost, and adapt easily to rural communities
(more than 1 billion rural people lack an electricity supply).

• Small hydro equipment can be retrofitted at existing civil works; advantage is taken to install small hydro on irrigation canals, in cooling water systems, at existing dams built for other purposes, etc. This represents a low-cost way to gain additional capacity.
More and more innovation can be seen in this respect, in terms of civil works and machinery. The development of ultra-low head turbines is a contributing factor.

• 66 per cent of world small hydro potential is untapped, according to the latest global overview report of UNIDO and ICSHP [UNIDO & ICSHP, 2019[10]].

• Global installed small hydro capacity is around 78 000 MW, more than 60 000 MW in Asia, which represents less than 40 per cent of Asia's SHP potential.

• Huge SHP potential remains in: India, Bhutan, Nepal, Indonesia, Vietnam, China, Kazakhstan, Japan… as well as throughout Africa, Latin America and Europe.

9. HYDRO: Into the Future

9.1 Some of the challenges to be addressed

Some of the current challenges can be summarized briefly as follows

• *Tackling more challenging and remote sites:* Examples are the Himalayas, Far East of Russia, parts of central Asia, etc. There is an associated need to deal with extreme climates and natural hazards. But promising new developments in automation/artificial intelligence enable some processes to be carried out remotely.

• *Difficult terrain and geological challenges*: careful advance studies are required to avoid unexpected incidents, which can cause project delays.

• *Logistics of bringing equipment to remote sites.*

• *The need to manage/limit sedimentation in reservoirs*: this includes designing civil works to avoid problems; efficient removal systems; machinery resistance to silt damage.

• *Cyber security*: A relatively recent man-made hazard, cyber risks also affect the energy sector. Research needs to continue constantly, and expertise is increasing in counter-measures, with many companies today specializing in this. There is a need to share experience.

• *Succession planning*: Those studying at IIT will ensure that research and technical developments are in good hands. Those of you who are studying at this world-renowned institute will be stepping into the shoes of eminent and experienced experts in the various interrelated disciplines associated with hydropower development.

9.2 Examples of emerging trends

9.2.1 Floating solar PV panels on hydro reservoirs

It is well known that hydropower serves to facilitate the development of intermittent renewables. Hydropower and solar PV make excellent partners, and floating solar PV installations offer some unique advantages. They have been emerging in the past seven or eight years, but now developments are accelerating. There are reported to be installations in some 60 countries.

India was one of the early developers, and when the Omkareshwar scheme is commissioned, it will be the world's largest floating solar PV park, with a total capacity of 600 MW.

Apart from the obvious advantage of the synergy between solar power and hydropower, these schemes offer additional benefits, for example:

• The saving on land use, meaning they can be installed to larger sizes, or in countries with a high population density.
• The panels help to reduce evaporation in the reservoirs.
• On a large water body, there will be less shade on the panels (compared with panels on land which could be shadowed by buildings).

9.2.2 Increase in pumped storage

The increasing importance of pumped storage has become very evident, and there are many examples worldwide where countries are planning to upgrade their portfolio of pumped storage plants, add pumped storage at existing plants, or are embarking on pumped storage schemes for the first time.

The largest pumped-storage plants in operation and under development are in China, Korea, Japan, India, and the USA. Ongoing programmes of pumped-storage development and upgrading are going on in Ukraine, Russian, Austria, France, Switzerland, Portugal, Germany and Iran. New schemes in the last few years have gone ahead in Israel and The Philippines. Kenya is considering its first pumped-storage scheme.

The USA, Australia, Scotland (UK), have new schemes planned for implementation soon, and the first underground pumped-hydro scheme, with a planned capacity of 500 MW, is moving ahead for development in Estonia, and was reported in the last issue of my journal

[Burdett, 2021[11]]. This is a concept which has been researched and discussed over several decades, as a solution for countries without the appropriate topography and other conditions required for conventional pumped storage. Now the 500 MW scheme is moving ahead.

10. HYDRO and its promising future

The COVID-19 pandemic has encouraged organizations influencing power policy to look ahead to the post-pandemic recovery period, and there has been strong consensus on the role of renewables, and the crucial role of hydropower, not only in its own right, but also to work in synergy with other renewables.

As renewables avoid both fuel costs and CO_2 emissions, they obviously have a strong future when economies are weak, and as concerns about climate change continue.

In April 2020, the African Union Commission and the International Renewable Energy Agency pledged to work together to accelerate the development of renewable energy, and hydropower has been highlighted particularly.

• AU Commissioner Dr Amani Abu-Zeid has called for more rapid and extensive development of the enormous renewable energy resources of the African continent, as a key strategy in recovering from the pandemics.

• IRENA's Energy Transformation to 2050 report [IRENA, 20209[12]] points out that hydro capacity would need to increase by around 60 per cent by 2050, and pumped storage would need almost to triple, to help create a sustainable energy future. Its 'Transforming Energy Scenario', aimed at keeping global temperature rises well below 2ºC during this century, predicts that 73 per cent of capacity and more than 60 per cent of generation is likely to come from intermittent renewables, and so hydropower will bring important synergies to the operation of power systems.

• The International Energy Agency launched its World Energy Outlook for 2020 [IEA, 2020[13]], predicting that by 2030, a combination of hydropower, wind, solar, geothermal bioenergy and marine power could provide nearly 40 per cent of electricity supply

11. Conclusion

Current global uncertainties have made everyone stop and think more about the future of our planet: about not taking things for granted, and being more pro-active in determining best practice for a sustainable future. Hydropower and pumped-storage, often working in synergy with other renewable sources of energy, will have a great role to play.

Finally, in an age when it is possible to store 16 TB of data on a small gadget, measure seismic activity on Mars, and achieve amazing things throughout industry with artificial intelligence, still 1.1 billion on our plant are without a reliable electricity supply. In some rural areas of Africa and Asia, children are still forced to do their homework by candle light or under street lights.

So much work lies ahead, and to help undertake that, you at the Indian Institute of Technology who are studying in the field of hydropower and renewable energy have chosen an excellent and rewarding career pathway. I commend your work and wish you all the best.

References

1. **Sharma, D.K.,** "The role of storage dams in regional development: a case study of the Bhakra and Beas dams", *Hydropower & Dams*, Issue 2, 2021.
2. **Bartle, A.,** "Startup at Merowe: a major boost for socio-economic development in Sudan", *Hydropower & Dams*, Issue 3, 2009.
3. **Bartle, A.,** "The benefits of combining hydropower with inland navigation schemes", UNECE Conference 'Connecting by Inland Navigation', Wroclaw, Poland; 2018.
4. **WCD**, "Dams and Development", World Commission on Dams, Cape Town, South Africa; 2000.
5. **World Bank**, "Water Resources Sector Strategy", The World Bank, Washington DC, USA; 2002.
6. **World Bank**, "New Directions in Hydropower", The World Bank, Washington DC, USA; 2003.
7. **United Nations**, "Sustainable Development Goals", United Nations, New York, USA; 2015.
8. **Tian, Fuqiang *et al***, "Drought characteristics of the Lancang-Mekong basin and the role of reservoir regulation", Tsinghua University, China; Issue 5, *Hydropower & Dams*, and HYDRO 2020 On-Line; 2020.
9. **Aqua-Media,** "*Hydropower & Dams World Atlas & Industry Guide 2020*; Aqua-Media International Ltd, UK; 2020.
10. **UNIDO and ICSHP,** "World Small Hydro Development Report 2019", UNIDO, Paris, France; and ICSHP, Hangzhou, China; 2019.
11. **Burdett, M.,** "Pioneering 500 MW pumped-storage scheme advances in Estonia", *Hydropower & Dams***,** Issue 2, 2021.
12. **IRENA**, "Global Renewables Outlook: Energy Transformation 2050"; International Renewable Energy Agency, Abu Dhabi, UAE; 2020.
13. **IEA**, "World Energy Outlook", International Energy Agency, Paris, France; October 2020.