Hydropower 2050

Identifying the next 850+ GW towards Net Zero

iha
international hydropower association

Contents

Executive Summary

There needs to be a step change in the amount of global installed capacity of sustainable hydropower by 2050 in order to support the clean energy transition away from fossil fuels and to tackle climate change. This is based on an assessment of modelled pathways to Net Zero from independent energy agencies, as well as looking at current and future planned hydropower capacity.

Hydropower is today the largest source of renewable electricity, with over 1,300 GW of installed capacity providing more than 15% of the world's electricity. The twin challenges of development and climate change means that we need to both increase the total amount of electricity generated whilst significantly increasing the contribution of low carbon sources. The transition to clean energy is urgent and vital.

Forecasting future electricity systems is a challenge, but analysis from major international organisations such as the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) is clear, if we are to tackle dangerous climate change we will need far more renewable generation, potentially increasing by a factor of 10.

Although much of this new renewable deployment will be led by wind and solar PV, their variable nature means that there will be a significantly increased demand for sources of flexible low carbon generation. Consequently, the International Energy Agency and the International Renewable Energy Agency both assess that in order to cost effectively keep global warming to below 2°C at least 850 GW of new hydropower capacity is needed. For the more ambitious Net Zero target (limiting temperature rise to below 1.5°C) the numbers are even greater, with at least 2,500 GW of capacity needed (around twice today's installed capacity). Hydropower therefore has a key role in future energy systems as an enabler of variable renewables, as well as a renewable energy source itself.

Substituting new build hydropower for other dispatchable energy sources would be a huge undertaking and most likely impractical in the limited time available. By 2050 hydropower will be the dominant source of system flexibility. No low carbon options are available today that can deploy at the scale needed. If it were replaced by carbon intensive gas, the extra emissions would be around the same as Japan, the world's third largest economy, emits in a year.

The International Hydropower Association (IHA) has undertaken a new analysis of its global hydropower database, which shows that there is at least 500 GW of projects in the pipeline i.e. future hydropower capacity. However, only 156 GW of this is under construction. 165 GW has been regulator approved but awaiting construction, 138 GW is pending approval and 89 GW has been announced. Moving these projects into construction is crucial if we are to cost-effectively tackle climate change.

This original analysis shows clear trends for future hydropower, such as the regional disparities in development and the growth of pumped storage. Breaking down the pipeline by regions demonstrates larger future growth in capacity in East Asia and Pacific, Africa, and South and Central Asia, with 240 GW, 118 GW and 91 GW in the pipeline respectively. It highlights the great potential in regions where hydropower is less developed, as well as the centrality of hydropower for many countries' shifts towards renewable energy and extending electricity access to growing populations.

The analysis also confirms the growing importance of pumped storage hydropower, currently the world's most widespread source of energy storage capacity. Data shows that, if all projects in the pipeline were completed, pumped storage capacity would almost double in future. This will be especially important for future energy systems with a high proportion of variable renewables such as wind and solar PV.

A further analysis of academic research suggests that, even allowing for tight environmental and social restrictions as required of sustainable hydropower, the potential for an additional 850 GW of installed capacity is well within our reach by 2050. If we add off-river pumped storage, we get much closer to the required 1200-1300 GW set out in the IEA and IRENA Net Zero pathways.

Hydropower, like all sources of electricity, has physical restrictions. In the case of conventional (run-of-river and reservoirs) hydropower this means at the very least access to flowing water. As a well-established technology many sites, particularly in Europe and North America, have already been used. Furthermore, many theoretically feasible sites are situated in areas that for a range of practical, economic, social and environmental considerations mean they would not be suitable for hydropower.

There is large regional variation in potential, with hydropower relatively underdeveloped in Africa, Asia, and South America. In Europe and North America, additional capacity could come from modernising existing plants or retrofitting non-powered dams. Currently, outside of China, the pace of development is slow. Moving from understanding the global potential to actual deployment will therefore take huge political will and enabling market mechanisms.

Going forward, there is no excuse for new build hydropower to not be developed sustainably – the IHA is leading the way in establishing a new Hydropower Sustainability Standard. Hydropower developers should take advantage of the Hydropower Sustainability Tools and Hydropower Sustainability Standard to ensure that projects are fit for purpose. This means that new projects will be built in a way that minimises impacts on the local environment and communities.

The IHA recommends a range of policy measures to facilitate at least 850+ GW by 2050. Firstly, governments should use financial mechanisms to incentivise investment in hydropower. In order to secure the deployment of the appropriate technology, investors must be appropriately remunerated for flexibility and storage and need long term reliability of their revenues. Subsidies, grants and capacity markets are some of the mechanisms able to achieve this.

Furthermore, **hydropower is unique amongst electricity generation technologies in providing a wide range of non-energy benefits such as flood and drought control and irrigation.** A truly holistic assessment of its impacts should include these.

Secondly, sustainability and climate resilience must be embedded into the planning and operation of new hydropower. By utilising the Hydropower Sustainability Standard and IHA's Climate Resilience Guide (2019) the industry can provide greater confidence to investors and governments.

Policy makers should facilitate modernisation and retrofitting (brownfield development). Additions to electricity generation capacity can be achieved by refurbishing aging hydropower plants. Furthermore, fitting turbines to non-powered dams is another method to utilise existing infrastructure, offering low impact added capacity.

Finally, regulatory frameworks must be timely and proportionate. Currently, too many projects are stuck in limbo due to extensive delays, slowing down the deployment of essential infrastructure vital for tackling climate change.

Background

Hydropower is today the largest source of renewable electricity globally, generating more electricity than all other renewables combined. However, in order to transition energy systems and limit the global temperature rise to no more than 2°C, the scale of sustainable hydropower construction must increase rapidly. Targets for a 1.5°C limit are even more ambitious. **Hydropower 2050** establishes the key role that it will play in the clean energy transition and consequently for tackling climate change.

The Intergovernmental Panel on Climate Change confirmed in 2020 that energy production accounts for over two-thirds of global greenhouse emissions[1] so a transition to clean, renewable energy will be fundamental for achieving Net Zero by 2050. This means renewable sources will have to form a much larger proportion of the future world energy mix, than in 2019 when they represented only 11.4% of global primary energy.[2] With rapid electrification in all sectors and world population increases, the demand for electricity will ramp up in the coming decades. Hydropower, wind and solar will all have to increase significantly to meet this demand.

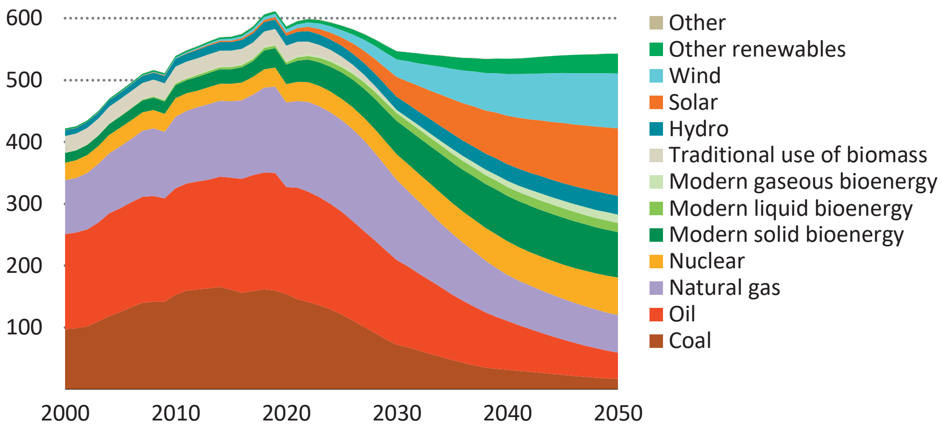
"Energy is at the heart of the climate change emergency and it must be at the heart of its solution. A swift and broad transition to renewable energy will be essential to achieve the emission reduction goals laid down by the Paris Agreement"

Patricia Espinosa, UNFCCC Executive Secretary

In its *Global Renewables Outlook: Energy Transformation 2050*, the International Renewable Energy Agency (IRENA) calls for an additional 850 GW of total hydropower capacity by 2050, including pumped storage hydropower. This is modelled on its 'Transforming Energy Scenario' where temperature rises are below 2°C.[3] Similarly, the International Energy Agency (IEA) requires an additional 843 GW by 2040 in a 'Sustainable Development Scenario', contained in its landmark *World Energy Outlook 2020*.[4]

For limiting temperature rises to no more than 1.5°C, hydropower capacity will need to expand even more. Recent reports set out the case: in 2021 IEA modelled a pathway to Net Zero by 2050 for energy systems, one it describes as the most technically feasible, cost-effective and socially acceptable. In this scenario renewable sources generate 88% of total electricity; wind and solar have a 68% share, and hydropower approximately 10%. With a total installed capacity for renewables of 26,600 GW, hydropower would have at least 2660 GW installed in 2050.[5]

In other words, in the IEA Net Zero scenario **total hydropower capacity would double by 2050**, adding at least 1300 GW. This model reflects the importance of thinking of energy systems holistically – hydropower is a fundamental part of the wider renewables mix, with different energy sources supporting and complementing each other.



Similarly, the International Renewable Energy Agency (IRENA) models a 2050 Net Zero scenario where renewable sources generate 90% of electricity, with total conventional hydropower capacity (excluding pumped storage) at approximately 2500 GW and a further 400GW of pumped storage hydropower.[6]

This report takes the IEA and IRENA targets for an additional 850 GW of hydropower as its starting point. It is an ambitious first step, described as 'a total transformation of the energy systems that underpin our economies'.[7] But it is necessary – an interim report from the UNFCCC in February 2021 showed how currently governments are far from meeting Paris Agreement targets, emphasised as a 'red alert for our planet' by UN Secretary-General António Guterres and an 'urgent Call to Action' by COP26 President Alok Sharma.[8]

The landmark Synthesis Report from the Intergovernmental Panel on Climate Change (IPCC) in August 2021 further confirmed that global warming will have irreversible effects and temperature rises 'of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in carbon dioxide and other greenhouse gas emissions occur in the coming decades'.[9]

The case for immediate, strong action by policy makers is clear. This report will set out the status of hydropower today, where it is being expanded, and where additional capacity may come from. It will conclude with policy recommendations necessary to bridge the gap.

The role of hydropower

Going forward, the only acceptable hydropower is sustainable hydropower

Hydropower projects offer some of the lowest lifecycle GHG emissions per unit of energy generated.[10] For this reason, they will be essential for producing clean energy when compared to more polluting, non-renewable alternatives. A World Bank note on its work in the sector states clearly that 'support for hydropower is mitigating climate change by reducing reliance on fossil fuels' and cites the example of the Tarbela IV Extension project in Pakistan, where adding an additional powerhouse to an existing dam will reduce the country's total emissions by about 1 percent.[11]

Recent publications acknowledge the role sustainable hydropower will play for economic development and access to energy, while also tackling climate change. The World Bank's **Climate Change Action Plan 2021-2025** identifies hydropower as a 'key clean energy source' that it will support for a 'just transition' away from fossil fuels including coal.[12] Strategies emphasise the need for future hydropower development to be sustainable. This includes coherent planning and management so that negative effects on ecosystems are mitigated and projects are 'well suited to local conditions and are resilient to climate change'.[13]

Any new hydropower construction should therefore have sustainability embedded into each stage of its development and operation. The multistakeholder Hydropower Sustainability Council includes representatives of social, community and environmental organisations, governments, commercial and development banks, and the hydropower sector. It governs the Hydropower Sustainability Standard and the Hydropower Sustainability Tools. The Council is supported by the International Hydropower Association's non-profit sustainability division which serves as its secretariat.

> ***'Sustainable hydropower has a major role to play in helping countries to achieve sustainable development, meet renewables targets and address climate change'***
>
> **Ashok Khosla, Chair, Hydropower Sustainability Council**

The Hydropower Sustainability Tools establish a common language for industry, governments, and civil society to evaluate sustainability issues in the hydropower sector. There are three complementary tools that collectively allow us to measure and benchmark projects against basic good practice and proven international best practice:[14]

- **Hydropower Sustainability Guidelines on Good International Industry Practice** (HGIIP) – key document that defines the outcomes that constitute good international practice.
- **Hydropower Sustainability Assessment Protocol** (HSAP) – measures performance compared to defined basic good practice and proven best practice.
- **Hydropower Sustainability ESG Gap Analysis Tool** (HESG) – can be used to check for gaps against good practice on environmental, social and governance topics, and includes a gap management plan.

Hydropower Sustainability Standard

The Hydropower Sustainability Council governs the Hydropower Sustainability Tools and is leading the way in the renewables sector by launching a sustainability standard for hydropower. Under the Hydropower Sustainability Standard, new hydropower projects will be independently certified against the Hydropower Sustainability Standard for their performance in sustainability. This sets minimum performance expectations for environmental, social and governance (ESG) criteria, and acknowledges projects that go beyond the standard's minimum requirements with silver and gold recognitions.

The Hydropower Sustainability Standard[15] calls for a world where hydropower projects enable:

- Healthy ecosystems – projects manage impacts to ecosystems and protect critical habitats
- Prosperous communities – projects share their benefits with affected communities
- Resilient infrastructure – projects take into account regional water needs and availability
- Good governance – projects implement ethical and transparent policies and practices

By supporting the development of the Hydropower Sustainability Standard, the International Hydropower Association is working towards a future where hydropower plays its part in meeting future energy demands while mitigating impacts to communities and the environment.

Hydropower enables variable renewable energy

Hydropower will play a role in future energy systems not only as a renewable source of energy itself, but as a vital *enabler* of other renewables. All Net Zero 2050 modelled scenarios indicate a huge increase in solar PV and wind capacity. For example, the IEA pathway necessitates wind and solar PV increasing from 9% of electricity generation to 68%, which will require average *annual* additions of 340 GW for wind and 600 GW for solar PV from 2030 to 2050.[16]

Wind and solar capacity has grown rapidly in recent years due to falling costs and will continue to grow. As they are variable renewables, it will be crucial to establish security and flexibility in future electricity generation. Reservoirs and pumped storage hydropower plants already play a large part in global electricity flexibility, with a 30% share of flexible supply capacity (similar to the shares of coal and natural gas).[17] Many plants are able to increase or decrease generation rapidly and so can meet changing demand, or in the case of wind and solar, a rise or fall in electricity generation. In this way investing in new hydropower capacity will be a catalyst and complement to wind and solar, providing a more reliable back-up in the case of changing weather conditions.[18]

The necessity for dispatchable energy sources, combined with the global commitment to reduce fossil fuel use, means 850+ GW of new hydropower capacity will support and enable the energy systems of the future.

Case study:

Hydro-Québec

"We all recognise that climate change is real, and that sustainable hydropower is part of the solution

Hydro-Québec is happy to contribute to developing and operating hydropower sustainably. We have played an active role in the development of the Sustainability Standard and will use this programme to certify our Eastmain generation complex."

David Murray, Chief Innovation Officer and Executive Vice President – Generation, Health, Safety and Environment at Hydro-Québec

What if we didn't build any new hydropower?

The IEA and IRENA modelling builds the lowest cost feasible scenarios. Of course, it is possible to substitute one source of electricity for another. But when we consider the implications of excluding even the most conservative estimate – 850 GW - for new hydropower, it is clear that tackling climate change will be extraordinarily challenging without hydropower's low carbon, flexible generation.

If hydropower were to be replaced by burning coal or gas the additional annual carbon emissions would be huge, at around 2.6 billion tonnes (approximately equivalent to India's total annual emissions today) and 1.3 billion tonnes (more than e.g. Japan's annual emissions) respectively. Such emissions would clearly be incompatible with stopping climate change.

Substituting for solar PV or wind would pose a very different challenge. Hydropower has a higher 'capacity' factor (amount of generation per installed unit) than either wind or solar. To take IRENA's capacity[19] factors as an illustration, replacing 850 GW of hydropower with solar would require over 2,250 GW of new solar just to generate the same amount of electricity - more than 3 times the total global installed capacity of solar PV in 2020. This is on top of the large amounts of new solar already called for by IEA and IRENA.

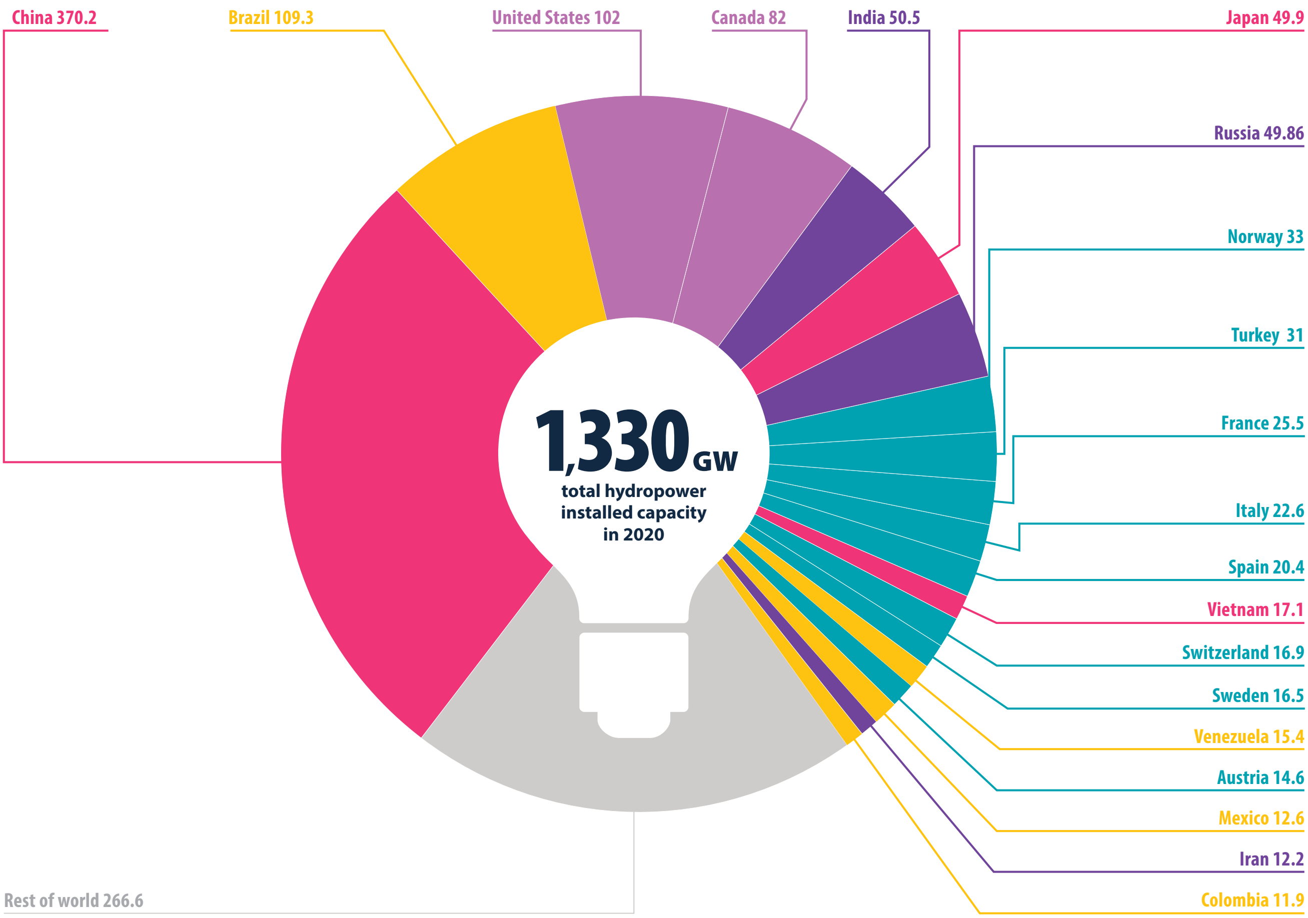
However, both wind and solar are also highly variable - they do not necessarily generate in sync with demand. This means that they would need to be complemented with some form of storage to meet demand. Today pumped storage hydropower is the dominant form (90%+) of grid-scale storage deployed today. But excluding pumped storage would mean that we need to turn to technologies readily available today - such as lithium-ion batteries, which are suitable for short duration (less than 4 hours) but rapidly lose cost effectiveness over longer periods - or technologies that are not yet deployed.

Other technologies in development include carbon capture utilisation and storage (CCUS) and the use of green hydrogen. However, CCUS is still in its infancy and is yet to be deployed at scale. Green hydrogen will play a major role in decarbonisation, but the priority for its deployment will be in hard to abate sectors such as heat and heavy transport.

Other sources of low carbon power include nuclear. But, like other existing sources of low carbon electricity the world nuclear fleet is already forecast to grow significantly by 2050 (near doubling according to the IEA).[20] Therefore, any replacement of hydropower with nuclear would need to be in addition to the already sizeable contribution of new nuclear capacity.

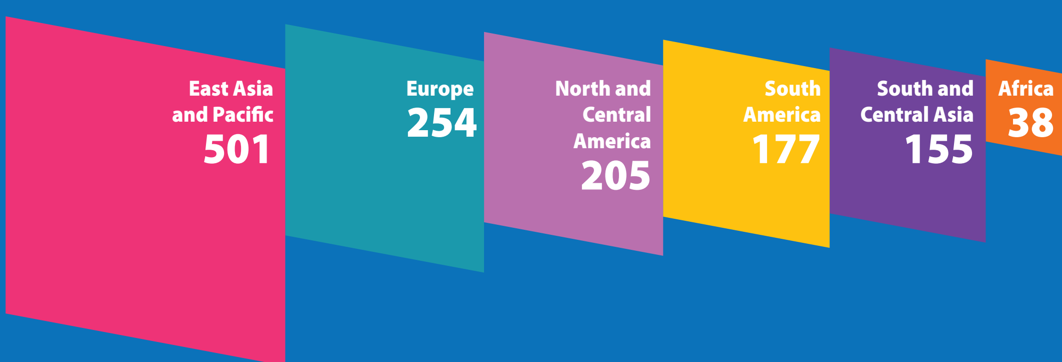
It is clear that when we think of future energy systems holistically, and how to balance different low carbon energy sources, hydropower will need to expand and be a key part of the energy mix.

Hydropower today[21]



Hydropower installed capacity (GW) of top 20 hydropower producers and the rest of the world, including pumped storage (2020)

Hydropower capacity by region in 2020 (GW)



Assessing the current status of hydropower demonstrates its importance for the world's energy supply. It also indicates trends that are set to continue as the sector builds towards 850+ GW by 2050.

In 2020, global hydropower installed capacity reached **1,330 GW**. The sector generated a record of 4,370 TWh of electricity in 2020, approximately equivalent to the annual electricity consumption of the United States.

Hydropower accounts for around 17% of global electricity generation today.[22]

During 2020, 21 GW of capacity was added (1.6% year-on-year growth). This is higher than additions in 2019 (17 GW) but still lower than the rate of additions required in order to achieve a clean energy transition and reach Net Zero. This scenario would need a capacity growth rate of at least 2% year-on-year.

Table 1: Top 5 countries by hydropower capacity

Country	Installed capacity (GW)
China	370
Brazil	109
USA	102
Canada	82
India	50

Notable trends:

- China leads global hydropower growth – the current installed capacity of over 300 GW is 2.57x that of 2005, showing the rapid increase in construction.[23]
- On average, hydropower plants in Europe and North America are older. This means they will require modernisation (refurbishment to improve efficiency) to maintain or increase capacity
- Since the 1970s, hydropower growth has been led by emerging economies in Asia and Latin America, reflecting the greater undeveloped potential[24]

Pipeline – projected capacity growth

This section provides a long-term forecast of growth in global hydropower capacity in the coming decades. Capacity will increase as hydropower will continue to provide renewable electricity generation and play a major part in the world's energy system. However, the forecast also shows that much more capacity is required in order to meet the 850+ GW target and achieve Net Zero. This will require a change in prioritisation across industry, the public sector and financial institutions.

Methodology

This analysis draws upon the International Hydropower Association's database, a comprehensive data set comprising of over 13,000 stations in over 150 countries. The database is updated with information gathered from (1) official statistics from governments and regulation agencies; (2) scientific articles and reports; (3) daily news reports of hydropower development, declarations of contracts and equipment deals; and (4) direct consultation with operators and industry sources.

The pipeline is thus defined as hydropower stations in this database currently with one of the following statuses:

- Under Construction;
- Regulator Approved;
- Pending Regulator Approval;
- Announced

This captures a totality of hydropower stations at different stages of development:

- For the two categories of 'Under Construction' and 'Regulator Approved' we can be most confident in the completion of the stations.
- 'Pending Regulator Approval' includes stations that have conducted feasibility studies and have submitted documentation to be approved by energy regulators.
- 'Announced' includes proposed stations at the earliest stage of development.

It is by no means certain that all stations in the pipeline will be built. Local contexts may change and a number of proposed stations may not be approved by regulators. Nonetheless, the pipeline data is useful for showing how capacity is increasing and for helping us to understand the scale of the challenge to reach 850+ GW by 2050.

The Pipeline

The analysis provides a **headline figure of 548 GW** of additional hydropower capacity in the pipeline for coming years, across the four categories mentioned above. The following top-level figures are rounded to the nearest gigawatt (GW) for the station capacity.

Table 2: Hydropower 'pipeline' by operational status, IHA database

Operational Status	Total capacity (GW)
Under Construction	156
Regulator Approved	165
Pending Approval	138
Announced	89
Total	548

Adding this to the existing capacity of 1330 GW gives a future total of 1878 GW - if these projects were all built, it would represent around two-thirds of the 850 GW capacity needed to help limit climate change to 2°C. However, this level of projected growth represents less than half of what is needed to meet Net Zero.

The message is clear - there is a clear gap between what is needed to tackle climate change and what is actually being built.

Regional variation

Table 3: Hydropower 'pipeline' by region, IHA database

Region	Capacity (GW)	Percentage (%)
East Asia and Pacific	240	43.8
Africa	118	21.5
South and Central Asia	91	16.6
South America	48	8.8
North and Central America	28	5.1
Europe	23	4.2
Total	548	100

Assessing the hydropower pipeline by region emphasises the large discrepancies in growth across different areas. As previously noted, since the 1970s added capacity has been greater in emerging economies in Asia and Latin America. In the last fifteen years, 85% of new stations have been constructed in emerging and developing economies.[25] This analysis indicates this trend will continue, with a large proportion of development occurring in East Asia, Africa, and South and Central Asia. This reflects the fact that in Europe and North America the hydropower market is more mature, with a greater proportion of the potential already developed. Even in more mature markets there might be considerable potential for off-river pumped storage, retrofitting non-powered dams, and modernising existing plants.

China's contribution to previous and projected growth in capacity is particularly noteworthy. In the fifteen years from 2005-2020 it accounted for 50% of global gross capacity expansion.[26] The pipeline shows that China will continue to play a large role in future hydropower growth – analysis estimates approximately 156 GW of future capacity in China across the four categories above.

In June 2021 the first two turbines (1 GW each) at the 16 GW capacity Baihetan station began generating electricity, with full completion expected in July 2022.[27] Hydropower is set to be particularly important for China's long-term energy planning and transition away from fossil fuels; the government has committed to CO2 emissions peaking in 2030 and achieving carbon neutrality by 2060. This ambitious target will require an 'undisputable growth trajectory for non-fossil fuels' according to the Institute for Climate Change and Sustainable Development at Tsinghua University.[28]

However, as the data shows, the majority of capacity in the pipeline will come from other regions. This demonstrates the importance of hydropower as a global energy source, as well as its growth in regions where it is currently under-utilised. Country-level energy plans provide more information on how hydropower is set to expand in different regions.

For example, Nationally Determined Contributions (NDCs) are part of the Paris Agreement. They are high-level plans for how each signatory country will meet the targets of the Agreement and reduce emissions. A new analysis of all NDCs shows the centrality of hydropower for a number of countries. In the medium-term, Nepal plans to add around 8 GW, Bhutan 7 GW and Laos 8.5 GW. Other NDCs note the potential for expansion, such as Congo estimating 14 GW total potential or India with over 100 GW (about half currently developed).[29]

Away from the NDCs, countries have set out detailed energy system plans that demonstrate how hydropower could further expand. In Pakistan, the 'Indicative Generation Capacity Expansion Plan 2021-30' uses statistical models to calculate scenarios on how the energy mix could change based on future demand. In all modelled scenarios, hydropower has an installed capacity of 23 GW by 2030, significantly up from the current 10 GW capacity.[30]

Case Study:

Bhutan Sustainable Hydropower Development Policy 2021

This policy document from the government of Bhutan notes how hydropower 'is today the backbone and driver of the nation's economy' that 'has spurred Bhutan's high economic growth rates over the last couple of decades'.

In future the focus will change on the type of hydropower; a shift will occur from run-of-river to **pumped storage** combined with 'other alternative renewable energy resources' to ensure energy security.

The policy emphasises social and environmental considerations for future development. It makes provisions for people impacted by new hydropower plants and highlights the need for there to be a robust Rehabilitation, Resettlement and Local Development Plan as well as an Environment Impact Assessment for new hydropower.

In this way Bhutan will be able to develop its significant hydropower potential while mitigating societal and environmental impacts.[31]

Growth in pumped storage

Three main types of hydropower plants are run-of-river, storage (dams) and pumped storage.

Table 4: Hydropower 'pipeline' by hydropower type, IHA database[32]

Hydropower type	Capacity (GW)
Run-of-river	59.6
Pumped Storage	157.2
Storage	235.4

Compared to the current installed capacity of pumped storage (161 GW) it is notable that the data shows an almost doubling of global capacity in future. It is also worth noting that it is the most prominent hydropower type in the 'Announced' category of the IHA database, showing how it is becoming more popular and so growth will increase in the longer term.

Pumped storage hydropower plants will play a key role in system flexibility by providing longer term energy storage. The principle of these plants is simple – at times of low demand (low electricity price) water is pumped from a lower to an upper reservoir and released at times of high demand (and high prices) to drive a turbine and generate electricity.[33]

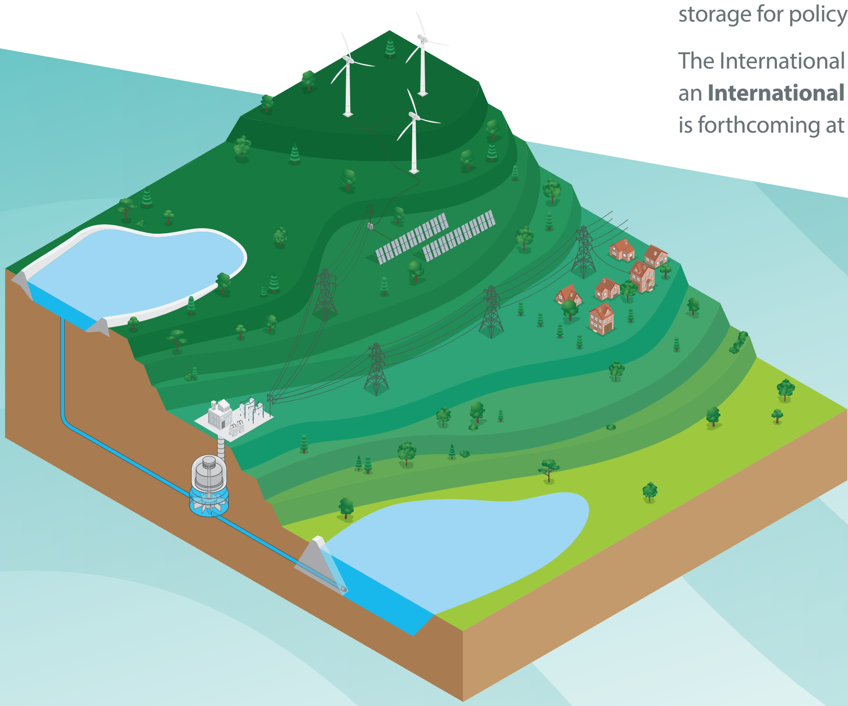
As well as compensating for periods of low electricity supply, pumped storage can help to avoid curtailment (wasting energy) by absorbing excess supply. Recent extreme weather events show the necessity for flexible electricity grids. For example, winter storms in February 2021 caused major blackouts in Texas, with the Public Utility Commission of Texas (PUC) calling for an overhaul of the state's electricity market.[34]

In 2018 pumped storage hydropower plants accounted for over 94% of global energy storage capacity, approximately 161 GW installed.[35] The IEA estimates that pumped storage will account for 30% of hydropower capacity growth from 2021-30.[36] Integrating electricity storage with generation could enhance grid stability. For example, in India the Solar Energy Corporation has awarded a tender for the 1,200MW Pinnapuram Integrated Renewable Energy Project, which will couple a 1,200MW pumped storage system with a 2,000MW solar PV plant and a 400MW wind farm together at a single substation.

It is an energy resource that is set to grow globally, even in regions like Europe where hydropower capacity is more developed. For example, the Gouvães pumped storage plant in Portugal is set to begin operation in 2021 and will have a capacity of 880MW, adding flexibility to Portugal's energy grid.[37]

The National Energy Administration in China is reportedly seeking comments on long-term plans for a massive expansion in pumped storage capacity to 680 GW.[38] Though not captured in the pipeline figures above, and by no means a certainty that it would be built, it nonetheless shows the importance of energy storage for policy makers.

The International Hydropower Association is currently convening an **International Pumped Storage Forum** and a detailed report is forthcoming at **pumped-storage-forum.hydropower.org**.



Potential

This section confirms that there is more than enough potential hydropower capacity to achieve 850+ GW by 2050.

Analysing global hydropower potential provides insight into *how* the sector could have a feasible route to the additional 850+ GW that is required. Comparing existing installed capacity to the potential will illustrate regions where more investment could be made. Of course, any assessment of potential must take into account social and environmental factors.

Various studies have estimated the potential electricity generation of hydropower by analysing runoff and stream flow data. At the highest level this gives a figure for gross theoretical potential, which is the energy generation if all natural runoff at all locations could be harnessed for hydropower. Of course, this would never be practical, so studies further break it down into technical, economic and exploitable potential. Zhou et al[39] gives the following definitions:

- Technical potential – annual energy that could be developed under current technology, regardless of economic and other restrictions
- Economic potential – annual energy that could be developed at costs competitive with other energy sources
- Exploitable potential – competitive annual energy with the consideration of environmental and other special restrictions

It is difficult to compare studies because they use different methodologies and assumptions. Nonetheless, this section of the report reviews key studies and takes an average figure to calculate indicative potential GW capacity for hydropower in different regions. These figures should not be taken literally but instead provide an indication of regions of the world where hydropower is relatively underdeveloped.

TO NOTE – these figures for potential do not include the potential for pumped storage. In 2019, The Australian National University released a study that showed the potential for hundreds of thousands of pumped storage sites worldwide.[40] These sites require an upper and lower reservoir joined together and can be built off-river (closed loop). Because they do not always rely on the same run-of-river characteristics as other forms of hydropower, there is great potential to increase pumped storage globally. Of course, it is not accurate to predict hundreds of thousands of sites, and any new construction must be sustainable, but this study does indicate the scale of potential growth.

Methodology

Many studies estimate technical potential at a global level. However, for this section we look at those that provide a regional break down. We take data from:

- Zhou et al 2015 – exploitable potential by region (definition above)
- Gernaat et al 2017[41] - full economic potential. The authors define this as potential available at a cost below US$0.10/KWh and full deployment on all rivers across the globe
- Hoes et al 2017[42] - gross potential multiplied by a factor of 0.13, as the study notes that Zhou et al 2015 found the ratio between gross and exploitable potential to be approximately 13%

These calculations give estimates for energy generation in TWh/year for each region.

The next step is to take an average per region from the three studies. Again, this average should not be taken as an exact figure for regional potential since the studies have used different methods. Instead, it provides an estimate in the middle of the wide range. Furthermore, the studies use different regional categorisation when compared to the regions used by IHA. The averages are shown in the table below.

Table 5: estimated potential generation by region based on Zhou et al, Gernaat et al, Hoes et al

Region	Estimated feasible potential (TWh/year)
Africa	2302
East Asia and Pacific**	2777
Europe*	537
North and Central America	2036
South America	1991
South and Central Asia**	2777

* the figure for Europe is an underestimate since Gernaat et al excluded Norway, Sweden, Iceland and Finland. An alternative GW capacity for Europe is provided at the end of this analysis.

** Because these studies calculate based on 'Asia' as a region, whereas the IHA distinguishes between East Asia and Pacific, and South and Central Asia, a more accurate figure is provided at the end of this analysis. In this table the estimates are from dividing the 'Asia' data by two, which is a simplification

We calculate indicative potential in installed GW capacity following a similar method to an IPCC *Special Report on Renewable Energy and Climate Change Mitigation*[43]; here we go from generation in TWh/year to GW capacity by using current regional capacity factors for hydropower. Please see Annex A for a detailed breakdown of each step of this methodology.

This gives a final view of indicative total potential (which includes existing capacity) below, rounding to the nearest 10 GW.

Table 6: Indicative potential conventional hydropower capacity by region

Region	Indicative Potential Hydropower Capacity (GW)	Installed capacity 2020 (GW)[44]
Africa	630	38
East Asia and Pacific	1100	501
Europe	350	254
North and Central America	620	205
South America	500	177
South and Central Asia	600	154

Analysis

These results are not exact but provide an indication of where the potential for further development is and so should be interpreted as an order of magnitude:

- Capacity factors depend on hydrological conditions, status of the plant's equipment, and how hydropower is used. They will change in future, especially if hydropower is used more as a flexible resource, dispatching when necessary
- When we take into account varying environmental and social factors, true potential for development will be lower. Going forward, new hydropower capacity should embed the sustainability principles outlined in previous chapters

Allowing for these caveats and a generous margin of error in the quoted studies, it is still clear that there is more than enough feasible potential to deliver the large capacity increases needed to contribute towards Net Zero.

Regional variation

Assessing potential by region is illustrative. It is notable that there is great potential in regions where electricity access is less widespread - a World Bank note comments how 'only a fraction of the hydropower potential of the developing world has been tapped'.[45] So hydropower will widen electricity access and support economic growth in areas where the relative energy demand will increase substantially.

For example, Africa has a high potential capacity especially compared with current installed hydropower (38 GW). The African Development Bank Group's **Water Strategy 2021-2025: Towards a Water Secure Africa** contains a Strategic Pillar of 'Water for Energy' where the objective is 'an overall outcome of increased hydropower capacity' as currently 'realised sustainable hydropower generation remains low'.[46] The Nile Basin Initiative is an intergovernmental organisation of 10 countries, established to develop water resources in the Nile Basin in a sustainable and equitable way. In 2018 it observed 'huge resource potential yet untapped' including estimated hydropower generation of 450TWh/year 'of which only a small proportion has been developed'. At the same time it notes less access to clean drinking water in rural areas, low electricity coverage and malnourishment in Nile Basin countries.[47]

These examples emphasise the scope and necessity for sustainable hydropower development in a continent where electricity demand would more than double by 2040.[48]

Modernisation and retrofitting

Not all capacity additions will come from greenfield projects i.e. building on new sites. Older hydropower plants, such as those in North America and Europe, can add energy generation capacity through refurbishments, either 'like-for-like' equipment changes or upgrades. This is what we refer to as modernisation.

Life extension of a hydropower plant is when equipment is replaced 'like-for-like' without an effort to increase the overall capacity. Such investment can significantly increase output - the IEA notes that output can increase by some 5-10%.[49] With over 475 GW of the global fleet more than 40 years old, gains equivalent to an extra 25GW-50 GW of new capacity appear achievable, without the challenges of new build. With more significant upgrades (capacity increase and greater efficiency as part of modernisation) the generating capacity can increase by between 10-30%.[50]

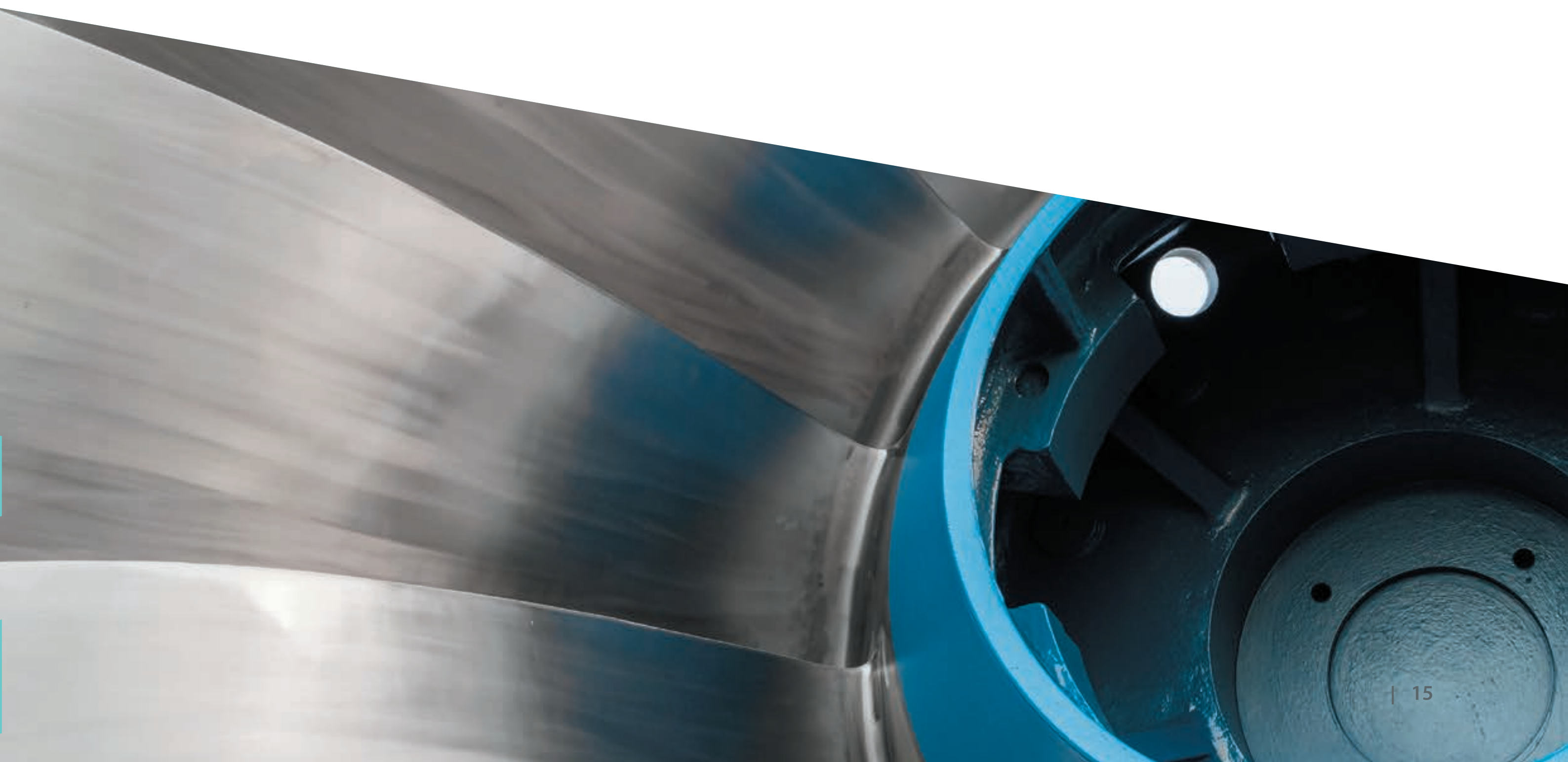
Modernisation is perhaps more important in regions where there is limited scope for greenfield development. Up to 2030, IEA estimates that modernisation will account for nearly 90% of total investment in hydropower in North America and Europe.[51] An example can be found in Mexico, where the government has committed to upgrading 18 existing hydropower plants by 2030.[52] Elsewhere, the Brazilian Energy Research Office estimates that updating existing plants could add 3 to 11 GW of capacity on top of the 109 GW of existing capacity.[53]

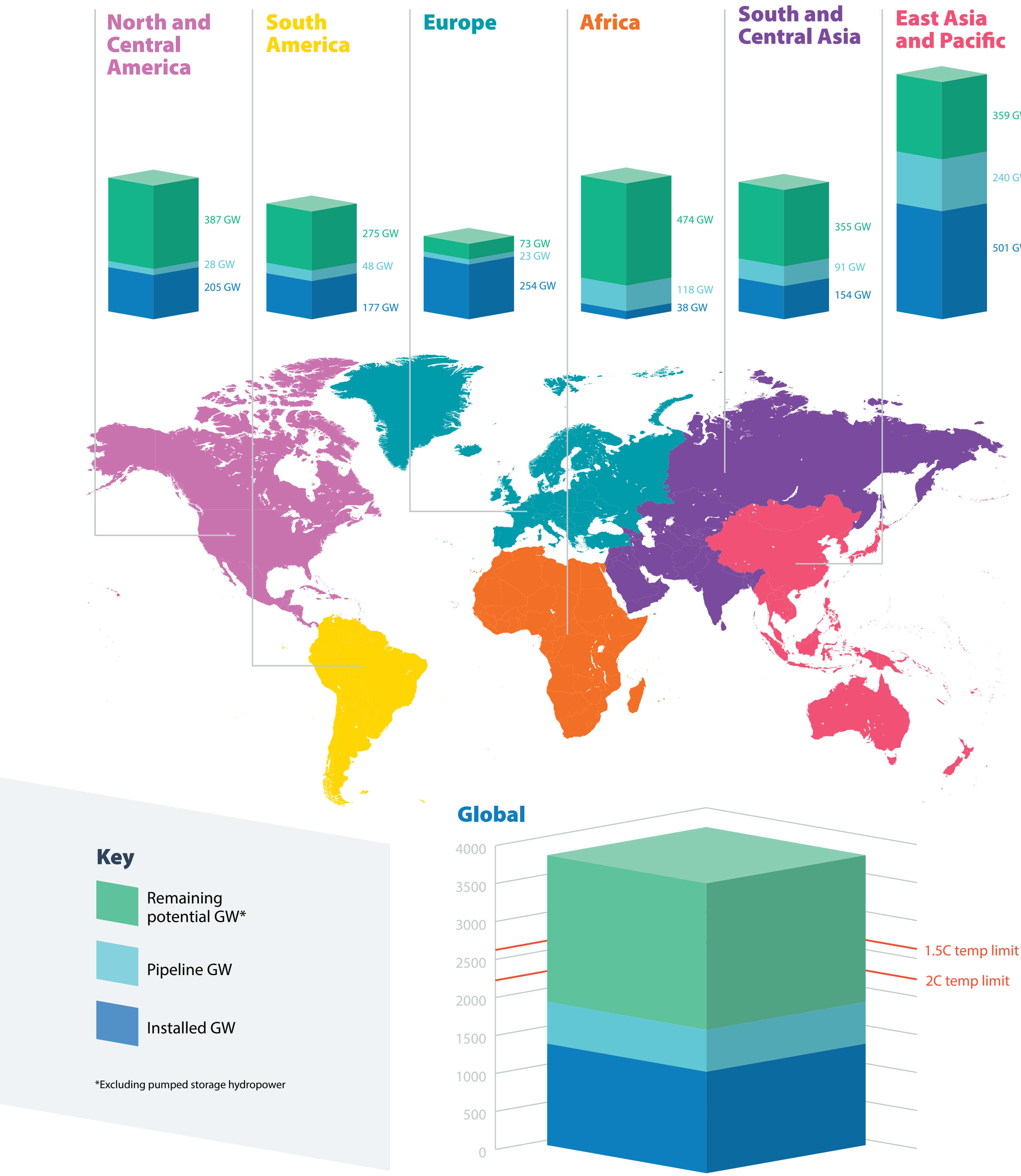
Retrofitting refers to installing energy generating turbines on dams that were not built for hydropower and are currently non-powered. This is another way of creating additional renewable energy capacity without building on a new site. As such, it can lessen the impact of new build infrastructure. In the US, 36 dams have been retrofitted to generate hydropower since 2000, representing over 500MW of capacity.[54]

The global potential could be huge, with some estimates that only a third of large dams are used for hydropower production and in Africa and Asia it could be as a low as 10-15%.[55] Retrofitting allows us to expand electricity generation capacity without the environmental or social costs of building on a new greenfield site.

Scale of the challenge

The following infographic puts together current installed capacity, projected growth (pipeline) and indicative potential. This shows the scale of the challenge ahead and the urgency of change. It is not intended to be prescriptive, and this report is not stating where hydropower should be built. Rather, the graphic shows future possibilities for hydropower to tackle climate change.




North and Central America
387 GW
28 GW
205 GW
South America
275 GW
48 GW
177 GW
Europe
73 GW
23 GW
254 GW
Africa
474 GW
118 GW
38 GW
South and Central Asia
355 GW
91 GW
154 GW
East Asia and Pacific
359 GW
240 GW
501 GW
Global
4000
3500
3000
2500
2000
1500
1000
500
0
1.5C temp limit
2C temp limit
Key
Remaining potential GW*
Pipeline GW
Installed GW
*Excluding pumped storage hydropower

Policy recommendations

Bridging the gap between the amount of hydropower being developed and what is required to tackle climate change will need changes in public policy as well as industry. This final section offers some key recommendations, by no means a comprehensive list but a starter in the direction of achieving 850+ GW.

Plan for a low carbon future now

Policy makers must start planning the electricity systems of the future now. In most countries these will be dominated by variable sources of electricity like wind and solar. Without system flexibility there is a risk that electricity supply does not match demand or that grids rely on high carbon sources such as gas and coal. The long lead times associated with building the most cost effective means of providing low carbon system flexibility and resilience - such as hydropower - mean we have to start planning now.

Finance

A current blocker to hydropower development is uncertainty regarding long-term revenues and future energy generation. Governments should implement financial policies for hydropower that give more long-term revenue certainty to investors and so lower the risk. Since the 1950s, more than 90% of hydropower plants have been developed in conditions that provide revenue certainty, either through long-term contracts or power purchase guarantees.[56]

Similarly, the developers – typically governments, government owned businesses or vertically integrated utilities - were able to consider the wide range of benefits provided by hydropower in a holistic, system-wide manner.

As we move towards electricity markets that are increasingly dominated by variable sources such as wind and solar, it is important that the additional benefits provided by hydropower (and indeed other sources of flexible low carbon generation) are recognised. Placing a value on flexibility will be increasingly important in order to encourage and incentivise investment in infrastructure such as hydropower which has a high up-front cost but which provides low cost solutions over the very long life time of the projects.

Governments could provide subsidies or recoverable grants in order to encourage investment from the private sector. The rise of private sector green financing mechanisms is to be welcomed and provides a further opportunity to secure the funding necessary if hydropower is to play its role in stopping dangerous climate change.

Provide visibility of revenues

A wide range of market-based mechanisms have been deployed to support private investment in low carbon electricity generation. These include feed in tariffs, contracts for difference, cap and floor and capacity markets. These work by providing investors with a clear understanding of where future revenues would come from. The developers and their investors bear the risk on delivery, but know that if they deliver then they will be appropriately compensated.

Case study:

Climate Bonds Initiative

Alternative sources of finance for renewable energy are emerging. Climate Bonds Initiative (CBI) is a non-profit based in London, notable for developing a Standard and Certification to verify 'green' bonds that fund projects offering climate change solutions. The Certification is used internationally in over 30 countries and supports the growing green bond market.

In March 2021, the CBI published its criteria for certifying bonds for hydropower projects, following multi-stakeholder working groups and a public consultation. The Hydropower Criteria will help to (i) embed sustainability into new development and (ii) offer new avenues for financing projects.

Ensure remuneration for hydropower services

In many markets the wider grid system services that hydropower can and does provide - such as inertia, black start, frequency response etc. – are not remunerated. This can make the business case even more challenging, and distort market signals, leading to sub-optimal outcomes.

In addition, hydropower plants and dams should be recognised and appropriately remunerated for non-energy water services they provide such as flood control and irrigation.

Recognition of and payment for the provision of these services can ensure that hydropower's proper contribution can be assessed by all stakeholders.

Sustainability

Adoption of measurable standards to certify sustainable hydropower projects

When discussing future hydropower to tackle climate change, it follows that new development should be sustainable, minimising impacts on landscape, the environment, and local communities.

The International Hydropower Association is leading the way with work on the new Hydropower Sustainability Standard. This will set objective and measurable criteria so that projects can be independently certified (see previous chapter on sustainability). Widespread adoption would give greater confidence in new hydropower development, which should also help it to clear regulatory and financial hurdles.

Regulation

Streamlined license/permit processes

Long timeframes for regulatory approval can deter investment, especially given that hydropower plants have relatively longer construction timeframes already. In some cases they are under an inappropriate regulatory framework. For example, in India pumped storage hydropower is considered a 'river valley project' even without construction of a new dam. This results in a 3-5 year clearance process from the Ministry of Environmental and Forest and Climate Change.

Hydropower should be classified correctly as a renewable energy resource, and regulators are encouraged to establish greater flexibility in their licensing or permit processes in order to speed up clearance. Of course, this should not come at the expense of projects fulfilling the necessary environmental, social and economic criteria.

Climate resilience

Incorporating climate resilience into the planning and operation of hydropower

Power generation by hydropower plants varies according to hydrological conditions. Climate change and varying conditions can therefore make new development less effective. The risk of changing conditions and extreme weather events must be accounted for in developing any new projects. The IHA published a Climate Resilience Guide in 2019, with support from the European Bank for Reconstruction and Development and the World Bank Group, that will help the sector address these risks.

Modernisation and maximising existing infrastructure

Facilitate and invest in modernisation

The world's hydropower fleet is aging. Investing in modernisation, whether like-for-like replacement of older kit or more substantial upgrades will provide significant increased generation without the same challenges that new build infrastructure can bring.

However, investors in such modernisation need visibility of future revenues and in some cases existing regulatory frameworks may be unclear and therefore limit the business case for investment.

Assess the scope for and utilise existing infrastructure

There are a significant number of non-powered dams in the world's rivers. Using this infrastructure creatively could result in new renewable electricity generation with minimum additional social and environmental impact. Governments and policy makers should urgently assess the potential of this infrastructure.

Annex A

In order to go from energy generation in TWh/year to an installed GW capacity, we look at the capacity factor for different regions. This is the ratio of actual generation to theoretical generation. In other words, it shows us the relationship between capacity (in GW) and generation (in TWh or GWh/year).

To calculate we use 'capacity factor = (generation/(installed capacity X 8760 hours)'[57] where 8760 is the number of hours in a year, so 'installed capacity x 8760' is the theoretical yearly generation.

Calculating this using 2020 real world data gives us:

Table 7: Capacity factor by region 2020, data from IHA Hydropower Status Report 2021

Region	Capacity (GW, 2020)	Generation (TWh/year, 2020)	Capacity factor
Africa	38	139	42%
East Asia and Pacific	501	1642	37%
Europe	254	676	30%
North America	205	724	40%
South America	177	690	45%
South and Central Asia	154	498	37%

The next step is to use the same formula with the estimated potential TWh/year generation in Table 5, working backwards to calculate potential installed capacity (GW). This time we rearrange the formula to give 'capacity = generation/(capacity factor x 8760)'. We know the potential generation and use the 2020 capacity factors to calculate capacity. Performing this calculation for the different regions gives us the indicative potential GW capacity of:

Table 8: Indicative potential capacity (incomplete calculation, see 'Potential' section above for final figures) by region

Region	Feasible potential generation, average (TWh/year)	Indicative potential capacity (GW)	Capacity factor 2020
Africa	2302	626	42%
East Asia and Pacific	2777	857**	37%
Europe	537*	204*	30%
North America	2036	616	40%
South America	1991	505	45%
South and Central Asia	2777	857**	37%

* the figure for Europe is an underestimate since Gernaat et al excluded Norway, Sweden, Iceland and Finland. An alternative GW capacity for Europe is provided at the end of this analysis.

** Because these studies calculate based on 'Asia' as a region, whereas the IHA distinguishes between East Asia and Pacific, and South and Central Asia, a more accurate figure is provided at the end of this analysis. In this table the estimates are from dividing the 'Asia' data by two.

The final step is to correct for the regional anomalies noted above. A total potential capacity for 'Asia', reflecting the studies above, would be around 1714 GW. A recent study on South Asian hydropower estimates the total potential for the region (Afghanistan, Bangladesh, Bhutan, India, Nepal and Pakistan) to be 300 GW.[58] Russia is included in IHA's South and Central Asia classification, and is estimated to have 9% of the world's hydropower resources.[59] Using a World Energy Council estimate of a feasible 872TWh/year generation[60], this would give an estimated potential capacity of approximately 260 GW. Again, this is a rough estimate but shows the high potential in Russia. Taking into account Georgia and other Central Asian countries, an estimate for the region's potential hydropower capacity would be at least 600 GW. This leaves at least 1100 GW for East Asia and Pacific.

For Europe, estimates vary for the percentage of hydropower potential that is already developed. It ranges from 46%[61] to 50%[62], to 65%[63] Knowing that the current installed capacity is 254 GW, a conservative estimate would put indicative potential for Europe between 300-350 GW (including Turkey, excluding Russia as per IHA classification).

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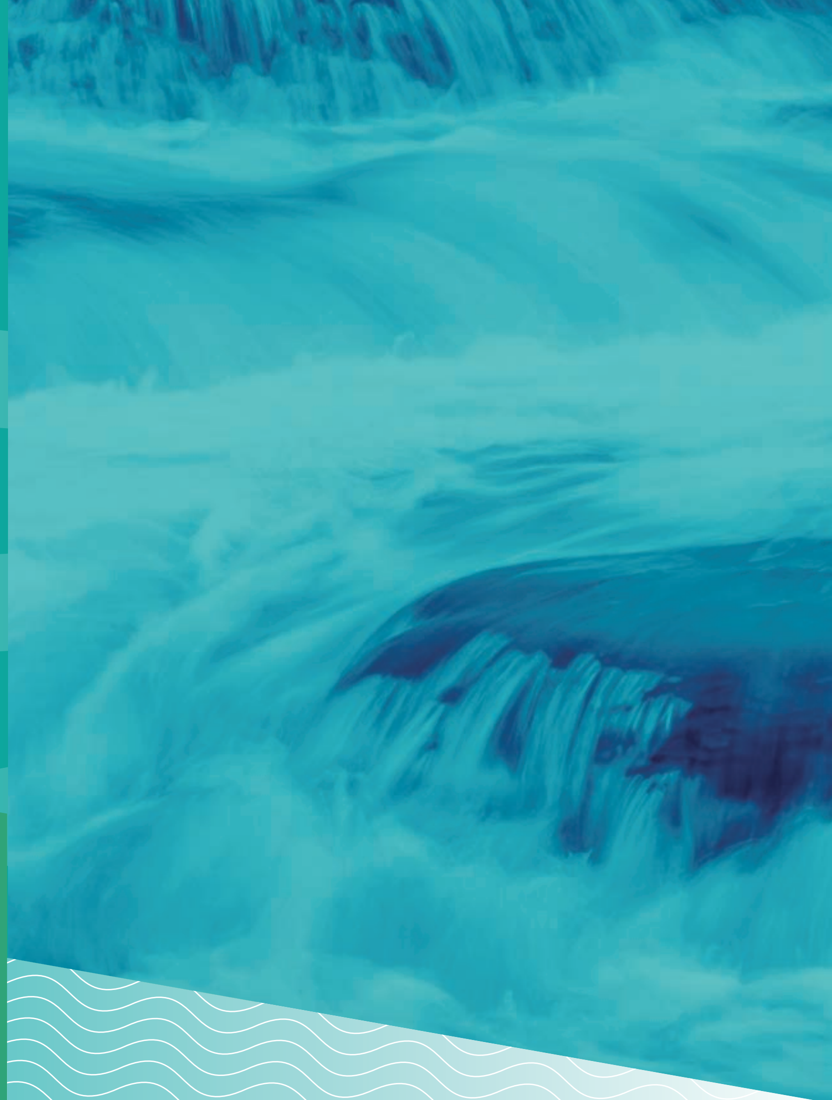

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Our mission is to **advance sustainable hydropower by building and sharing knowledge** on its role in renewable energy systems, responsible freshwater management and climate change solutions.