Chapter 8

Hydro Energy

8.1 Summary

KEY MESSAGES

- Hydroelectricity is a mature electricity generation technology, currently used in some 150 countries.
- Hydroelectricity is an important energy source in a large number of countries, although its current share in total primary energy consumption is only 2.3 per cent globally and 0.8 per cent in Australia.
- Hydroelectricity currently accounts for the largest share of Australia's renewable electricity but there is limited potential for future further development.
- Water availability is a key determinant of future growth in hydroelectricity generation in Australia.
- Future growth in Australia's hydroelectricity generation will be underpinned by the development of small-scale hydroelectricity plants and efficiency gains from the refurbishment of large-scale hydroelectricity plants.
- Pumped storage hydroelectricity may be an important tool for managing variable renewable energy supply such as wind or solar energy.

8.1.1 World hydro energy resources and market

- Global technically feasible hydro energy potential is estimated to be over 15 500 TWh per year.
- World hydroelectricity generation was 3431 TWh in 2010, and has grown at an average annual rate of 2.7 per cent since 2000.
- The existing world hydro energy capacity was estimated to be about 1010 GW in 2010. The hydro energy sector is growing at more than 20 GW a year, with China accounting for the majority of new capacity.
- Hydro energy is the largest source of renewable energy, and currently contributes more than 16 per cent of world electricity production and about 85 per cent of global renewable electricity.
- Among the OECD economies, hydroelectricity generation is projected by the International Energy Agency (IEA) to increase at an average annual rate of only 0.6 per cent between 2010 and 2035. Growth will be restricted by limited undeveloped hydro energy potential.
- In non-OECD countries, hydroelectricity generation is projected by the IEA to increase at an average annual rate of 2.4 per cent between 2010 and 2035, reflecting large, undeveloped potential hydro energy resources in many of these countries.

8.1.2 Australia's hydro energy resources

- Australia's technically feasible hydro energy potential is estimated to be around 60 TWh per year.
- Australia is the driest inhabited continent on Earth, with over 80 per cent of its landmass receiving an annual average rainfall of less than 600 mm per year and 50 per cent of the landmass receiving less than 300 mm per year.
- Climate models suggest long-term drying over southern areas of Australia during autumn and winter, which will be superimposed on larger natural rainfall variability, resulting in Australia having variable surface water resources.
- Australia has 124 operating hydroelectricity plants with total installed capacity of about 8500 MW (figure 8.1).

8.1.3 Key factors in utilising Australia's hydro energy resources

- Potential for the development of new large-scale hydroelectricity plants in Australia is limited. However, the upgrade and refurbishment of existing hydroelectricity infrastructure will increase efficiency and extend the life of plants.
- There is potential for small-scale hydroelectricity developments in Australia, and this is likely to be an important source of future growth in capacity.

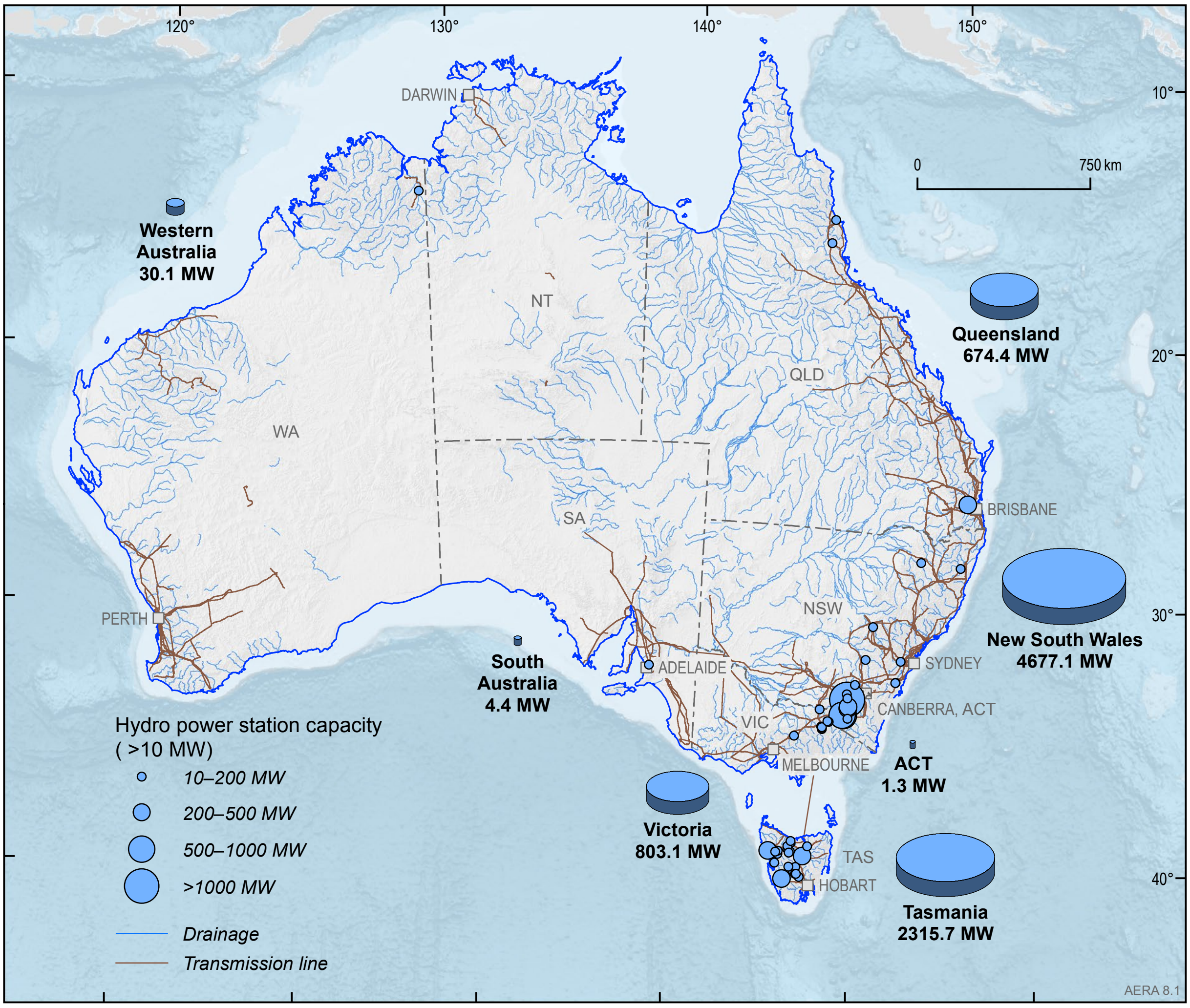


Figure 8.1 Major Australian operating hydroelectricity plants with capacity of greater than 10 MW

Source: Clean Energy Council; Geoscience Australia

- Pumped storage hydroelectricity as a form of energy storage may be important where it can be used for managing variable renewable energy supply such as wind or solar energy.
- Water availability, competition for scarce water resources, and broader environmental factors are key determinants of future growth in Australian hydroelectricity generation.

8.1.4 Australia's hydro energy market

- In 2011–12, Australia's hydroelectricity use represented 0.8 per cent of total primary energy consumption and 5.6 per cent of total electricity generation. Hydroelectricity use has declined on average by 1.6 per cent per year between 1999–2000 and 2010–11. However, hydroelectricity generation was higher in 2010–11, supported by increased water inflows after a sustained period of drought.
- In 2011–12, hydroelectricity was mainly generated in the eastern states, including Tasmania (60.5 per cent of total hydroelectricity generation), New South Wales (26.9 per cent), Victoria (7.5 per cent) and Queensland (5.1 per cent).
- Hydro energy is expected to be overtaken by wind as the leading renewable source of electricity generation in the next few decades.

8.2 Background information and world market

8.2.1 Definitions

Hydro energy is the energy taken from falling water from reservoirs or flowing water from rivers, streams or waterfalls (run-of-river) and is converted to electricity via water turbines. The pressure of the flowing water on the turbine blades causes the shaft to rotate and the rotating shaft drives an electrical generator which converts the motion of the shaft into hydroelectricity. Most commonly, water is dammed and the flow of water out of the dam to drive the turbines is controlled by the opening or closing of sluices, gates or pipes. This is commonly called penstock.

Hydroelectricity has been used in some form since the 19th century. The main technological advantage of hydroelectricity is its ability to be used for base or peak load electricity generation, or both. In many countries, hydroelectricity is used for peak load generation, taking advantage of its quick start-up and its reliability. Hydroelectricity is a relatively simple but highly efficient process compared with other means of generating electricity, as it does not require combustion. Hydroelectricity has the advantages of low greenhouse gas emissions, low operating costs, and a high ramp rate (quick response to electricity demand). Hydro energy is considered an option for synchronous generation, where a plant has a synchronous generator that provides some natural damping of any frequency deviation by automatically releasing or absorbing stored rotational energy as appropriate.

Hydroelectricity is the most advanced and mature renewable energy technology and provides some level of electricity generation in more than 150 countries worldwide.

Plants can be built on a large or small scale, each with its own characteristics:

- Large-scale hydroelectricity plants (greater than 50 MW) generally involve the damming of rivers to form a reservoir. Turbines are then used to capture the potential energy of the water as it flows between reservoirs. This is the most technologically advanced form of hydroelectricity generation.
- Small-scale hydroelectricity plants, including mini (less than 5 MW), micro (less than 500 kW) and pico plants, are still at a relatively early stage of development in Australia, and are expected to be the main source of future growth in hydroelectricity generation. While there is no universally accepted definition of small-scale hydroelectric projects, small projects are generally considered as those with less than 10 MW capacity.

Within these two broad classes of hydroelectricity plants, there are different types of technologies, including pumped storage and run-of-river (box 8.1). The type of system chosen will be determined by the intended use of the plant (base or peak load generation), as well as geographical and topographical factors. Each system has different social and environmental impacts which must be considered.

In this report, electricity generated from wave and tidal movements (coastal and offshore sources) is treated separately to that generated by harnessing the potential energy of water in rivers and dams (onshore sources). Wave and tidal energy is discussed in chapter 11.

8.2.2 Hydro energy supply chain

Figure 8.2 is a representation of hydroelectricity generation in Australia. In Australia virtually all hydroelectricity is produced by energy plants at water storages created by dams in major river valleys. A number have facilities to pump water back into higher storage locations during off-peak times for re-use in peak times. Electricity generated by the water turbines is fed into the electricity grid as base load and peak load electricity and transmitted to its end use market.

8.2.3 World hydro energy market

Hydro energy is a significant source of low-cost electricity generation in a wide range of countries. At present, production is largely concentrated in China, North America, OECD Europe and South America. However, many African countries are planning to develop their considerable hydro energy potential to facilitate economic growth. World hydroelectricity generation is projected to grow at an average annual rate of around 2 per cent to 2035, largely reflecting the increased use of hydroelectricity in non-OECD economies (IEA 2012b).

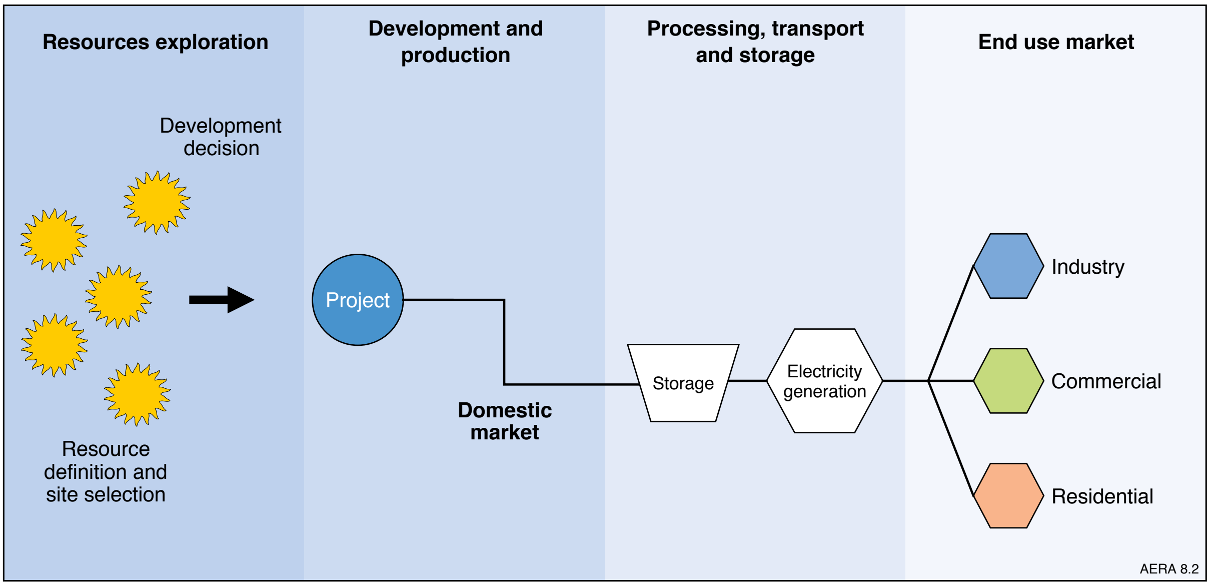


Figure 8.2 Australia's hydro energy supply chain

Source: Bureau of Resources and Energy Economics; Geoscience Australia

Resources

Most countries have some potential to develop hydroelectricity. There are three measures commonly used to define hydro energy resources:

- Gross theoretical potential—hydro energy potential that is defined by hypothesis or theory, with no practical basis. This may be based on rainfall or geography rather than actual measurement of water flows.
- Technically feasible—hydro energy potential that can be exploited with current technologies. This is smaller than gross theoretical potential.
- Economically feasible—technically feasible hydro energy potential which can be exploited without incurring a financial loss. This is the narrowest definition of potential and therefore the smallest.

The world's total technically feasible hydro energy potential is estimated to be over 15 500 TWh per year (UNESCO 2012). Regions with high precipitation (rainfall or melting snow) and significant topographic relief enabling good water flows from higher to lower altitudes tend to have higher potential, while regions that are drier, flat or do not have strong water flows have lower potential. Asia, Africa and the Americas have the highest feasible potential for hydroelectricity (figure 8.3).

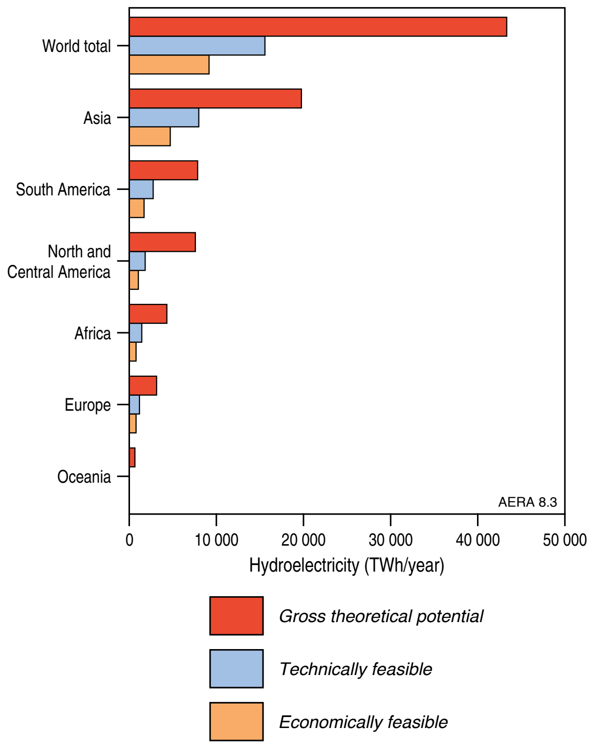


Figure 8.3 World hydroelectricity potential, by region

Source: UNESCO 2012

China's hydro energy resources are the largest of any country. China is estimated to have a theoretical potential of more than 6000 TWh per year, approximately double current world hydroelectricity generation, and a technically feasible hydro energy potential of more than 2470 TWh per year (UNESCO 2012). China is home to the largest single hydroelectricity plant in the world, Three Gorges, with an installed capacity of 22 400 MW and an expected annual electricity generation of 80 to 100 TWh (IPCC 2011). In 2012, China installed 14 000 MW of new hydro energy capacity, accounting for 64 per cent of the world's new additional hydro energy capacity (Bloomberg 2013).

In South America, the highest technically feasible hydro energy potential is in Brazil, where it exceeds 1250 TWh per year. The Itaipú hydroelectricity plant is the world's second largest plant, which supplies electricity to Brazil and Paraguay. The Itaipú hydroelectricity plant has an installed capacity of 14 000 MW with a maximum annual electricity generation of 94.7 TWh.

Other countries with substantial technically feasible hydro energy potential include Canada, Congo, Ethiopia, India, Indonesia, Norway, Peru, Russia and the United States. Nevertheless, almost all countries have some hydro energy potential.

Australia's theoretical hydro energy potential is estimated to be 265 TWh per year and has a technically feasible hydro energy potential of about 60 TWh per year, which is considered to be relatively small (figure 8.4). Rainfall in Australia is highly variable. Climate models suggest long-term drying over southern areas during autumn and winter, which will be superimposed on large natural variability such as wet years becoming less frequent and dry years more frequent (CSIRO and BOM 2012).

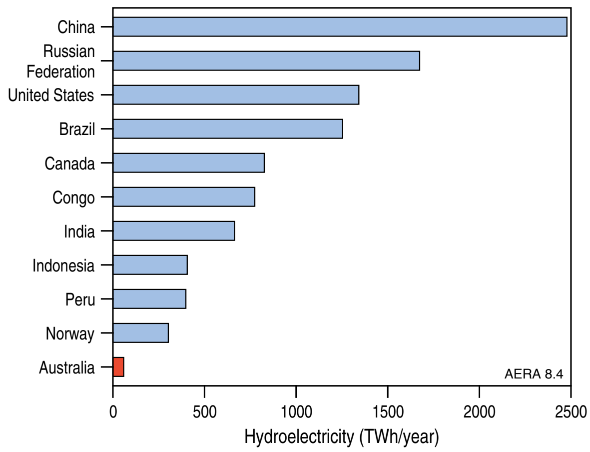


Figure 8.4 Gross theoretical hydroelectricity potential, major countries

Source: UNESCO 2012

Primary energy consumption

Hydroelectricity generation has been growing globally, reflecting its increasing popularity in developing economies as a relatively cheap, simple and reliable source of energy (figure 8.5).

BOX 8.1 HYDROELECTRICITY TECHNOLOGIES

Hydroelectricity generation

The energy created depends on the force or strength of the water flow and the volume of water. As a result, the greater the difference between the height of the water source (head) and the height of the turbine or outflow, the greater the potential energy of the water. Hydro energy plants range from very small (10 MW or less) to very large individual plants with a capacity of more than 2000 MW and vast integrated schemes involving multiple large hydro energy plants. Hydro energy is a significant source of base load and, increasingly, peak load electricity in parts of Australia and overseas.

Rivers potentially suitable for hydroelectricity generation require both adequate water volume through river flows, which is usually determined by monitoring using stream gauges, and a suitable site for dam construction. In Australia virtually all hydro energy is produced by plants at water storages created by dams in major river valleys. Many have facilities to pump water back into higher storage locations during off-peak times for re-use in peak times. In some cases, the hydro energy plant can be built on an existing dam. The development of a hydro energy resource involves significant time and cost because of the large infrastructure requirements. There is also a requirement for extensive investigation of the environmental impact of damming the river. This generally involves consideration of the entire catchment system.

Pumped storage hydroelectricity stores electricity in times of low demand for use in times of high demand by moving water between reservoirs. It is currently the only commercial means of storing electricity once generated. By using excess electricity generated in times of low demand to pump water into higher storages, the energy can be stored and released back into the lower storage in times of peak demand. Pumped-storage systems can vary significantly in capacity but commonly consist of two reservoirs situated to maximise the difference in their levels and connected by a system of waterways with a pumping-generating station. The turbines may be reversible and used for both pumping and generating electricity.

Pumped storage hydroelectricity is the largest capacity form of grid energy storage where it can be used to cover transient peaks in demand and to provide back-up to intermittent renewable energy sources such as wind. New concepts in pumped storage involve wind, solar or wave (ocean) energy to pump water to dams as head storage.

Mini hydro schemes are small-scale (typically less than 10 MW) hydroelectricity projects that typically serve small communities or a dedicated industrial plant but can be connected to an electricity grid. Some small hydro schemes in North America are up to 30 MW. The smallest hydro plants of less than 100 kW are generally termed micro hydro. Mini hydro schemes can be 'run-of-river', with no dam or water storage (see below), or developed using existing or new dams whose primary purpose is local water supply, river and lake water-level control, or irrigation. Mini hydro schemes typically have limited infrastructure requiring only small-scale capital works, and hence have low construction costs and a smaller environmental impact than larger schemes. Most recent hydro energy installations in Australia, especially in Victoria, have been small (mini) hydro systems, commencing with the Thompson project in 1989.

Small-scale systems have encountered difficulty obtaining environmental approval due to uncertainty regarding their impact on aquatic fauna. Australian Renewable Energy Agency (ARENA) is supporting a study to provide Australian developers of small-scale hydro energy technologies and projects with a more detailed understanding of the impacts from turbines on Australian native fish species.

Run-of-river systems rely on the natural fall (head) and flow of the river to generate electricity through energy plants built on the river. Large run-of-river systems are typically built on rivers with consistent and steady flow. They are significant in some overseas locations, notably Canada and the United States. Mini run-of-river hydro energy systems can be built on small streams or use piped water from rivers and streams for local electricity generation. Run-of-river hydro energy plants commonly have a smaller environmental footprint than large-scale storage reservoirs. The Lower Derwent and Mersey Forth hydro energy developments in Tasmania, for example, each comprising six plants up to 85 MW capacity, use tributary inflows and small storages in a step-like series.

Hydroelectricity generation accounted for 2.3 per cent of total primary energy consumption in 2010 (table 8.1). World hydroelectricity consumption has grown at an average annual rate of 2.7 per cent between 2000 and 2010, while in the OECD, hydroelectricity consumption increased at an average annual rate of 0.3 per cent.

Hydroelectricity generation in Australia was higher in 2010–11, particularly in New South Wales and Victoria, supported by increased water inflows after a sustained period of drought.

Electricity generation

Hydroelectricity's share in total electricity generation has declined from 23 per cent in 1971 to 16 per cent in 2010 (figure 8.5), because of the higher relative growth of electricity generation from other sources. The most rapid growth in hydroelectricity generation has occurred in China, which is now the largest producer of hydroelectricity. Latin America and OECD North America remain large generators of hydroelectricity. Many African economies are also developing their hydro energy potential, and have become a source of growth.

Table 8.1 Key hydro energy statistics

	Unit	Australia 2011–12	Australia 2010–11	OECD 2011	World 2010
Primary energy consumption[a]	PJ	50.7	60.5	5017	12 377
Share of total	%	0.8	1.0	2.3	2.3
Average annual growth, from 2000	%	–1.6	–0.1	0.3	2.7
Electricity generation					
Electricity output	TWh	14.1	17	1393	3437
Share of total	%	5.6	6.7	13.0	16.0
Electricity capacity[b]	GW	8.5	8.5	455	1033

OECD = Organisation for Economic Co-operation and Development
a Energy production and primary energy consumption are identical. **b** All data are for 2010

Source: BREE 2012; IEA 2012a, 2012b

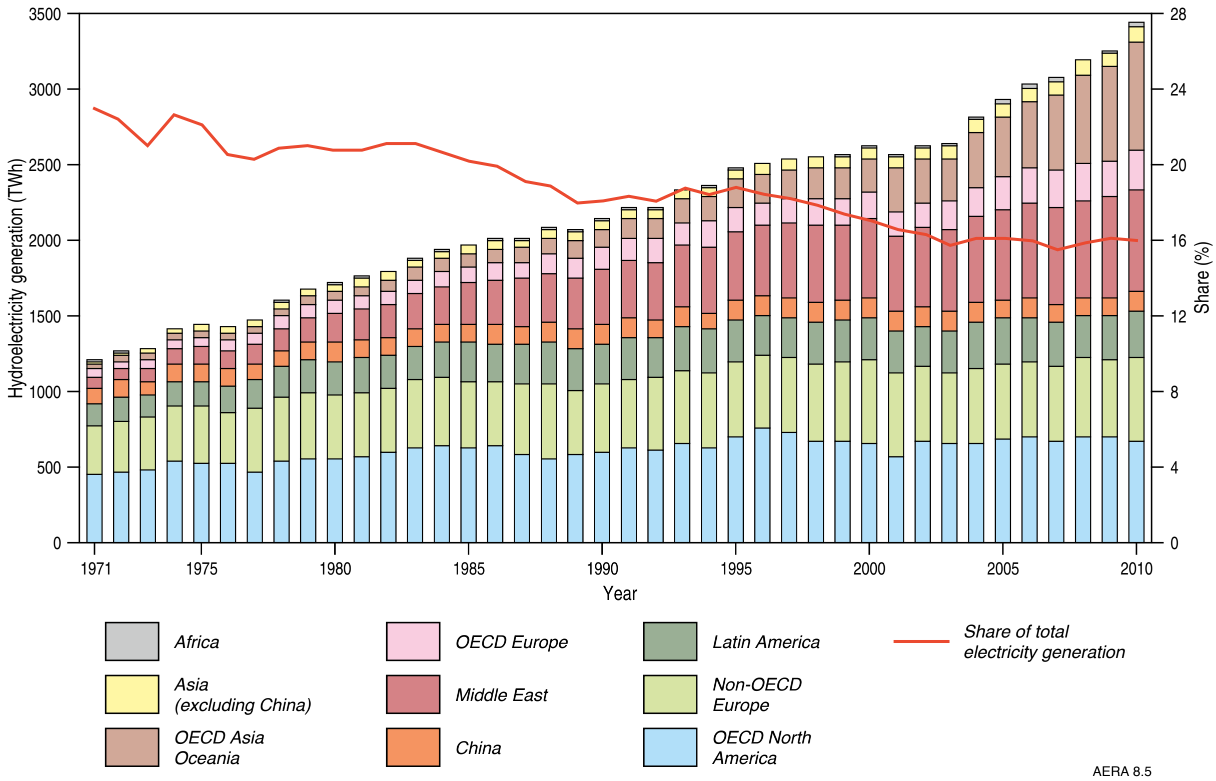


Figure 8.5 World hydroelectricity generation and share of total electricity generation

OECD = Organisation for Economic Co-operation and Development

Source: IEA 2012a

In 2010, the total installed hydroelectricity generation capacity was around 1010 GW, with around 30 GW of capacity added during 2010 (REN21 2012). China and Brazil are the most active regions for new hydro energy developments (REN21 2012). China has the world's largest installed hydroelectricity capacity with around 213 GW (21 per cent of world capacity), followed by Brazil (80.7 GW), the United States (78 GW), Canada (75.6 GW) and the Russian Federation (55 GW). These economies account for half of the world's installed hydroelectricity generation capacity.

In 2010, world production of hydroelectricity was 3431 TWh. The largest producers were China, Brazil, Canada and the United States (figure 8.6a). Australia ranked 39th in the world. Hydroelectricity accounted for a large share of total electricity generation in some of these countries including, Norway (94 per cent), Brazil (78 per cent), Venezuela (65 per cent), Canada (58 per cent) and Sweden (45 per cent) (figure 8.6b).

Hydroelectricity meets over 90 per cent of domestic electricity requirements in a number of other countries including the Democratic Republic of the Congo, Ethiopia, Mozambique and Zambia in Africa; Kyrgyzstan, Nepal and Tajikistan in Asia; Albania and Georgia in Europe; and Paraguay in South America (IEA 2012a).

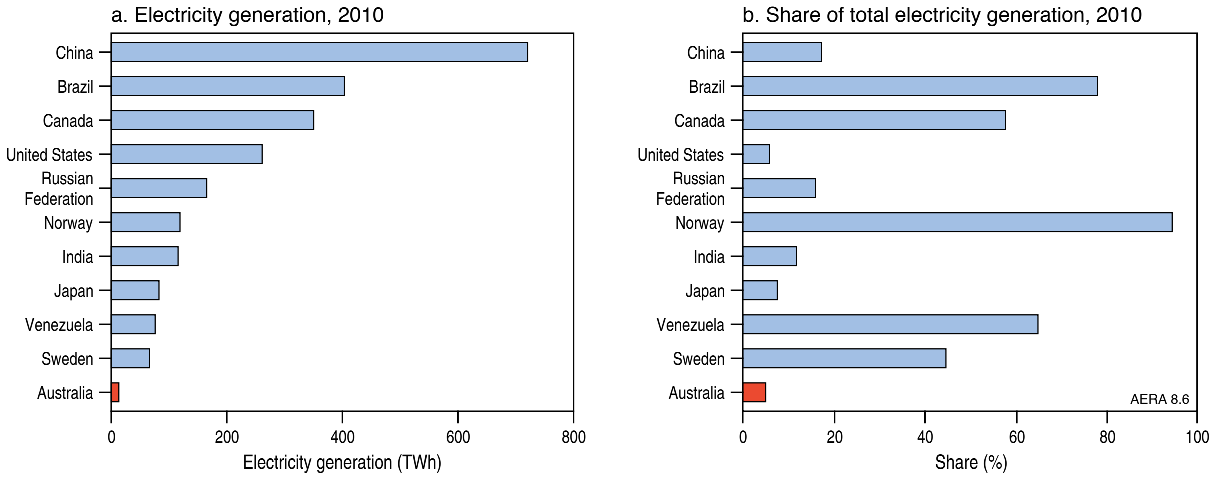


Figure 8.6 World electricity generation from hydro energy, major countries, 2010

Source: IEA 2012a

World hydro energy market outlook

In the IEA new policies scenario, world hydroelectricity generation is projected to increase at an average annual rate of 2 per cent to 5677 TWh in 2035 (table 8.2). Hydroelectricity generation is projected to grow in the OECD at an average annual rate of 0.7 per cent and in non-OECD countries by an average annual rate of 2.7 per cent.

The growth in hydroelectricity generation in the OECD is expected to come from utilisation of remaining undeveloped hydro energy resources. Growth is expected to occur in small (including mini and micro) and medium-scale hydroelectricity plants. Improvements in technology may also improve the reliability and efficiency and, hence, output of existing hydroelectricity plants, as would refurbishment of ageing infrastructure.

Nearly 90 per cent of the growth in world hydroelectricity generation over the projection period is expected to come from non-OECD countries. Strong demand and underutilised potential is expected to underpin growth in this region. Much of the growth is expected to be in small-scale hydroelectricity, although there are plans in many African countries to build large-scale hydroelectricity generation capacity. Growth is expected to occur in Asia, particularly China and India.

The implementation of global climate change policies is likely to encourage the development of hydroelectricity as a renewable, low emissions energy source. In the IEA's 450 policy scenario, the share of hydroelectricity in world electricity generation is projected to increase to 19.7 per cent in 2035, compared with 15.5 per cent in the new policies scenario. In the OECD regions the share of hydroelectricity in total electricity generation in the 450 policy scenario is projected to increase to 14.2 per cent in 2035 compared with 12.2 per cent in the new policies scenario.

Table 8.2 IEA new policies scenario projections for world electricity generation from hydro energy

	Unit	2010	2035
OECD	TWh	1351	1622
Share of total	%	12.5	12.2
Average annual growth, 2010–35	%		0.7
Non-OECD	TWh	2079	4054
Share of total	%	19.7	17.4
Average annual growth, 2010–35	%		2.7
World	TWh	3431	5677
Share of total	%	16.0	15.5
Average annual growth, 2010–35	%		2.0

OECD = Organisation for Economic Co-operation and Development
Note: totals may not add due to rounding

Source: IEA 2012a, 2012b

8.3 Australia's hydro energy resources and market

8.3.1 Hydro energy resources

Australia is the driest inhabited continent on Earth, with over 80 per cent of its landmass receiving an annual average rainfall of less than 600 mm per year and 50 per cent less than 300 mm per year (figure 8.7). There is also high variability in rainfall and temperatures between years, resulting in Australia having very limited and variable surface water resources. Of Australia's gross theoretical hydro energy resource of 265 TWh per year, only around 60 TWh is considered to be technically feasible (UNESCO 2012). Australia's economically feasible capacity is estimated at 30 TWh per year, of which about 56 per cent has already been harnessed (UNESCO 2012).

The first hydroelectric plant in Australia was built in Launceston in 1895. Australia has 124 operating hydroelectricity plants with total installed capacity of

8500 MW (figure 8.1). These coincide with the areas of highest rainfall and elevation and are mostly in New South Wales (55 per cent) and Tasmania (29 per cent). The Snowy Mountains Hydro-Electric Scheme, with a capacity of about 3800 MW, accounts for around half of Australia's total hydroelectricity generation capacity but considerably less of actual production. There are also hydroelectricity schemes in north-east Victoria, Queensland, Western Australia, and a mini hydroelectricity project in South Australia. Pumped storage accounts for about 1490 MW.

The Snowy Mountains Hydro-Electric Scheme is one of the most complex integrated water and hydroelectricity schemes in the world. The scheme collects and stores the water that would normally flow east to the coast and diverts it through trans-mountain tunnels and power plants. The water is then released into the Murray and Murrumbidgee rivers for irrigation. The Snowy Mountains Hydro-Electric Scheme comprises sixteen major dams, seven power plants (two of which are underground), a pumping station, 145 km of interconnected trans-mountain tunnels and 80 km of aqueducts. The scheme produces on average about 4500 GWh per year and provides around 70 per cent of all renewable energy that is available to the eastern mainland grid of Australia, as well as providing peak load power (Snowy Hydro 2012).

The hydroelectricity generation system in Tasmania comprises an integrated scheme of 30 power plants, numerous lakes and over 50 large dams with a total capacity of over 2600 MW. Hydro Tasmania, the owner of the majority of these hydroelectricity plants, supplies both base load and peak power to the national electricity market, firstly to Tasmania and then to the Australian network through Basslink, the undersea interconnector which runs under Bass Strait (Hydro Tasmania 2012). A potential future option for hydro energy in Tasmania is as energy storage for excess wind energy and wave energy, as is currently the case in Scandinavian countries.

8.3.2 Hydro energy market

Australia has developed much of its large-scale hydro energy potential. Electricity generation from hydro energy has declined in recent years because of an extended period of drought in eastern Australia, where most hydroelectricity capacity is located. However, the share of hydroelectricity increased in 2010–11 following higher inflows. Hydro energy is becoming less significant in Australia's generation mix as growth in generation capacity is being outpaced by that in other renewable energy technologies.

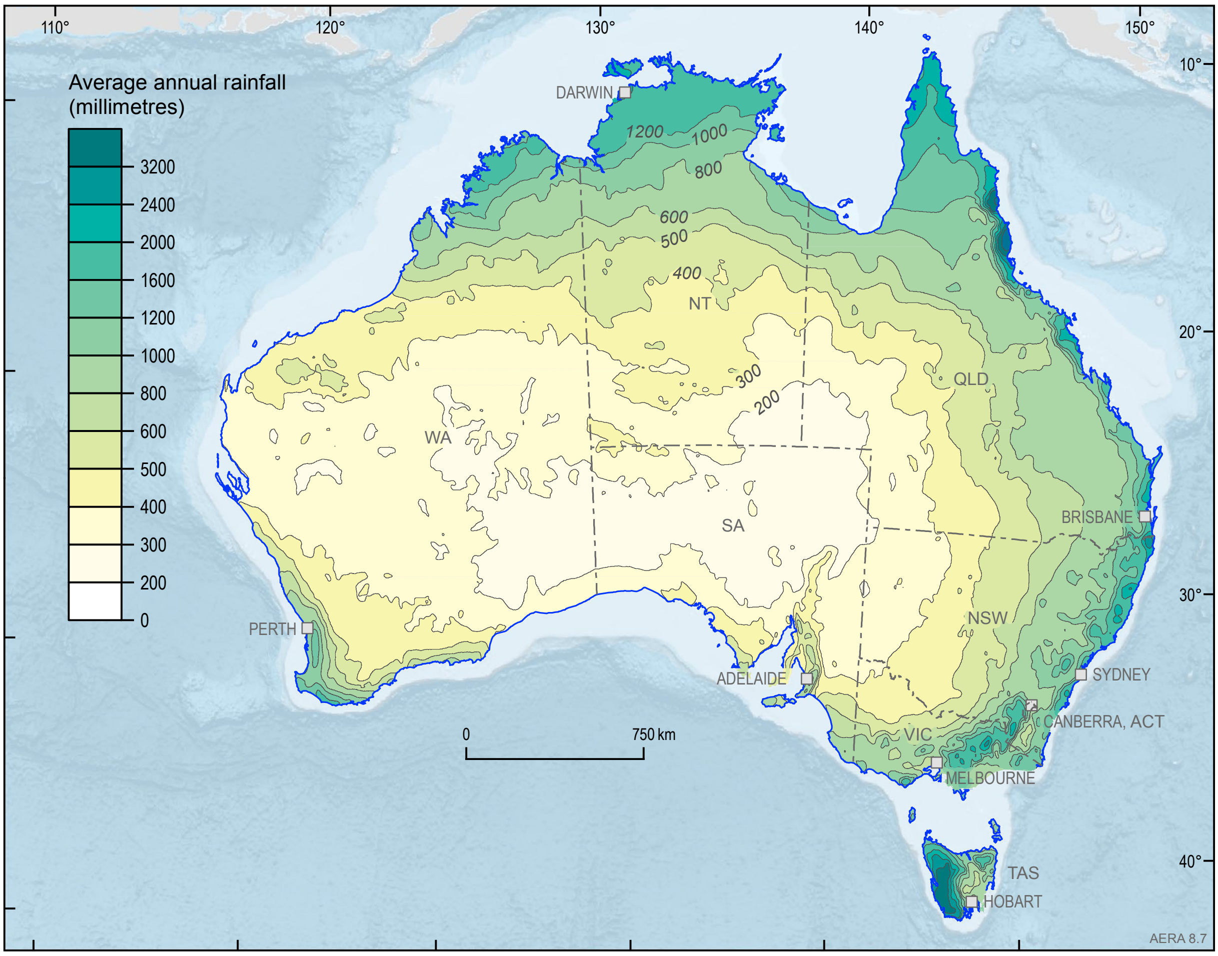


Figure 8.7 Average annual rainfall across Australia

Source: Bureau of Meteorology

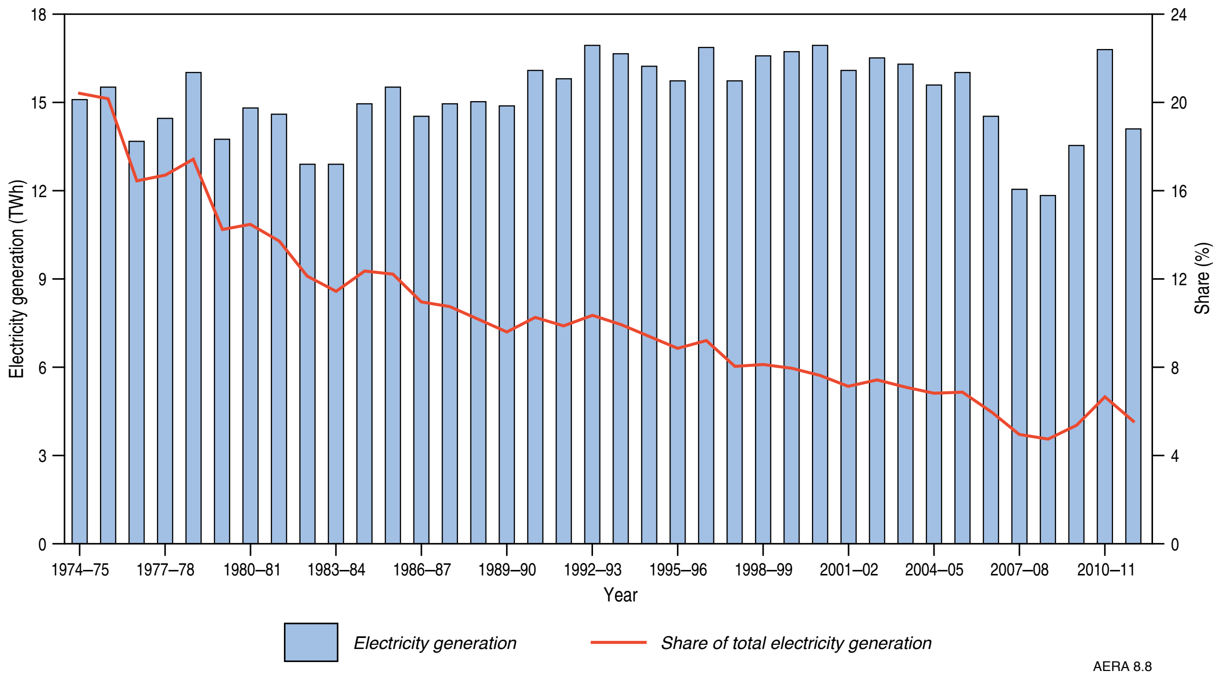


Figure 8.8 Australia's hydro generation and share of total electricity generation

Source: BREE 2012

Primary energy consumption

As hydro energy resources are used to produce electricity, which is used in either grid or off-grid applications, production is equivalent to hydro energy consumption. Hydroelectricity use has declined on average by 0.1 per cent per year between 1999–2000 and 2010–11. In 2011–12, hydroelectricity use represented 0.8 per cent of total primary energy consumption.

Electricity generation

In 2011–12, Australia's hydroelectricity generation was 14.1 TWh or 5.6 per cent of total electricity generation (figure 8.8). Over the period 1974–75 to 2011–12, hydroelectricity generation has fluctuated, reflecting periods of below or above average rainfall. However, the share of hydroelectricity in total electricity generation has generally declined over this period, reflecting the higher growth of alternative forms of electricity generation.

Tasmania has always been the largest generator of hydroelectricity in Australia, accounting for 60.5 per cent of total generation in 2011–12 (figure 8.9). New South Wales (including ACT) is the second largest, accounting for 26.9 per cent of total electricity generation in 2011–12 (sourced mostly from the Snowy Mountains Hydro-Electric Scheme). Victoria and Queensland account for the remainder.

Installed generation capacity

Ninety per cent of Australia's installed capacity is shared between New South Wales, Tasmania and Victoria (figure 8.10a). Australia has only four hydroelectricity plants with a capacity of 500 MW or more; three are located in the Snowy Mountains Hydro-Electric Scheme and the fourth is the Wivenhoe power station in Queensland (figure 8.10b). The largest hydroelectricity plant in Australia has a capacity of 1500 MW, which is mid sized by international standards. More than 75 per cent of Australia's installed hydroelectricity capacity is contained in 14 hydroelectricity plants with a capacity of 100 MW or more. At the other end of the scale, there are some 65 small and mini hydroelectricity plants (less than 10 MW capacity) with a combined capacity of just over 175 MW.

However, installed hydroelectricity generation capacity does not directly reflect actual electricity generation. The smaller installed capacity in Tasmania produces more than double the output of the Snowy Mountains Hydro-Electric Scheme. Tasmania is the only state that uses hydroelectricity as the main means of electricity generation.

8.4 Outlook for Australia's hydro energy resources and market

Growth in Australia's hydroelectricity generation is expected to be limited and outpaced by other renewables, especially wind energy.

Future growth in hydroelectricity generation capacity is likely to come mainly from the installation of small-scale plants. The use of pumped storage hydroelectricity as a form of energy storage may be important where it can be used for managing variable renewable energy supply such as wind or solar. There is potential for hydro energy to use synchronous generation, where a plant has a synchronous generator that provides some natural damping of any frequency deviation by automatically releasing or absorbing stored rotational energy as appropriate (AEMO 2013). Water availability will be a key determinant of the future expansion of hydroelectricity in Australia.

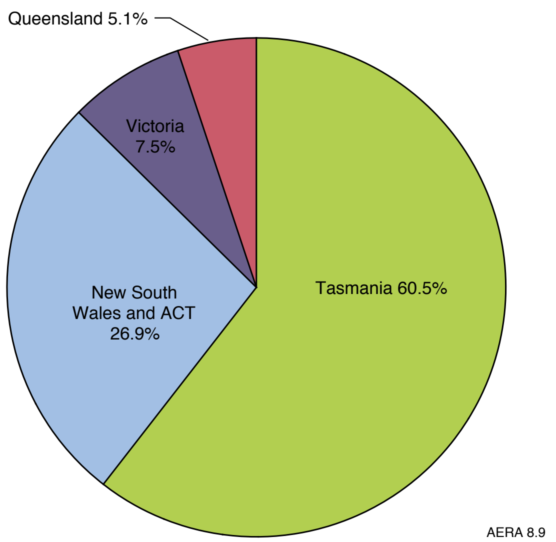


Figure 8.9 Australia's hydro generation by state, 2011–12

Source: BREE 2012

8.4.1 Key factors influencing the outlook

Opportunities for further hydroelectricity generation in Australia are offered by refurbishment and efficiency improvements at existing hydroelectricity plants, and continued growth of small-scale hydroelectricity plants connected to the grid. Hydroelectricity generation is a low-emissions technology, but future growth will be constrained by water availability and competition for scarce water resources.

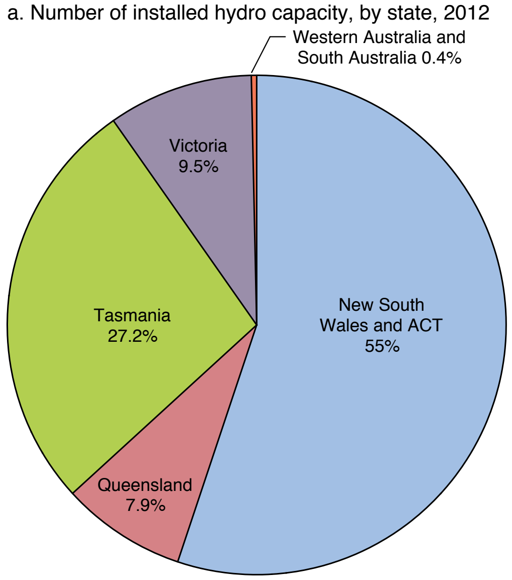
Hydroelectricity is a mature renewable electricity generation technology with limited scope for further large-scale development in Australia

Most of Australia's best large-scale hydro energy sites have already been developed or, in some cases, are not available for future development because of environmental considerations. There is some potential for additional hydro energy generation using the major rivers of northern Australia but this is limited by the region's remoteness from infrastructure and markets and the seasonal flows of the rivers.

Upgrading and refurbishing ageing hydro energy infrastructure in Australia will result in capacity and efficiency gains

Many of Australia's hydro energy plants are now more than 50 years old and will require refurbishment in the near future. This will involve significant expenditure on infrastructure, including the replacement and repair of equipment. The refurbishment of plants will increase the efficiency and decrease the environmental impacts of hydroelectricity. Further technology developments will be focused on efficiency improvements and cost reductions in both new and existing plants (box 8.2).

The Snowy Mountains Hydro-Electric Scheme is currently undergoing a maintenance and refurbishment process, at a cost of approximately A$400 million over seven years. The modernisation will include the replacement of ageing and high-maintenance equipment, increasing the efficiency and capacity of turbines, and ensuring the continued reliable operation of the component systems of the scheme. Major works in the Lower Tumut region have been completed with the six generating units at Tumut 3, the largest power



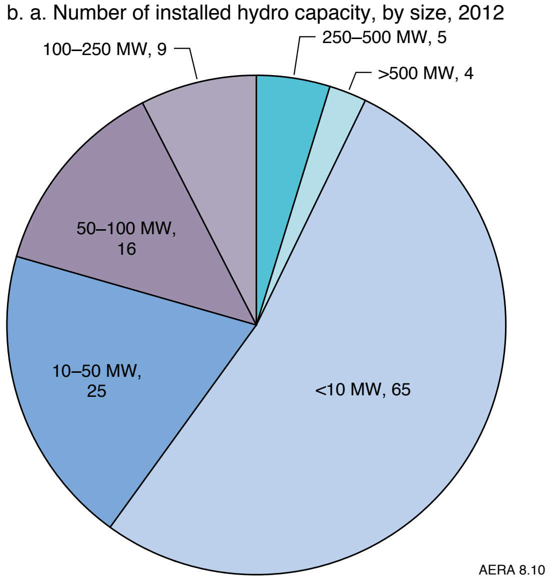


Figure 8.10 Installed hydro capacity by state and size, 2012

Source: Clean Energy Council 2012

station in the Snowy Hydro fleet, modernised and upgraded. Work has now commenced on the Upper Tumut project (Snowy Hydro 2012).

Refurbishment of the power station at Lake Margaret, Tasmania—one of Australia's oldest hydroelectricity facilities (commissioned in 1914)—commenced in 2008. The main objective of the project was to repair the original wooden pipeline, which had deteriorated (Hydro Tasmania 2008). The project involved additional maintenance on the dam, minor upgrade of the machines, as well as replacement of a transformer. This upgrade, completed in late 2009, cost about A$14.7 million to gain 8.4 MW of capacity at a capital spend rate of A$1.75 million per MW, considerably less than the costs of a new plant (Hydro Tasmania 2009). Hydro Tasmania is undertaking a number of maintenance and technical upgrade projects to maximise generation and ensure reliable supply. Projects that occurred over 2012–13 included the Tungatinah modernisation project, Kaplan turbine program and the Rowallan Dam upgrade (Hydro Tasmania 2012).

Small-scale hydro developments are likely to be an important source of future growth in Australia

With the exception of the Bogong project, most hydroelectricity plants installed in Australia in recent years have been mini hydro schemes. These plants have the advantage of lower water requirements and a smaller environmental impact than larger schemes, especially those with large storage dams.

Although the majority of Australia's most favourable hydroelectricity sites have been developed, mini hydroelectricity plants are potentially viable on smaller rivers and streams where large dams are not technically feasible or environmentally acceptable. They can also be retrofitted to existing water storages. At present mini hydro plants account for around 2 per cent of installed hydro capacity. Research, development and demonstration activity is likely to increase the cost competitiveness of small-scale hydro schemes in the future (box 8.3).

BOX 8.2 HYDROELECTRICITY COSTS

Hydroelectricity generation costs

The most significant cost in developing a hydro resource is the construction of the necessary infrastructure. Infrastructure costs include the dams as well as the power plant itself. Building the plant on an existing dam will significantly reduce capital outlays. Costs incurred in the development phase of a hydro facility include (Forouzbakhsh et. al. 2007):

- civil costs—construction of the project components including dams, headponds, and access roads
- electro-mechanical equipment costs—the machinery of the facility, including turbines, generators and control systems
- power transmission line costs—installation of the transmission lines.

Indirect costs include engineering, design, supervision, administration and inflation impacts on costs during the construction period. Construction of small and medium plants can take from 1 to 6 years, while large-scale plants can take up to 30 years (for example, the Snowy Mountains Hydro-electric Scheme took 25 years to build).

The costs of building Australian hydroelectricity generation plants have been varied. The Snowy Mountains Hydro-electric Scheme, Australia's largest hydroelectricity scheme, was constructed over a period of 25 years at a cost of A$820 million (Snowy Hydro 2007). Australia's most recent major hydroelectricity development, the Bogong project (site 1), commenced construction in 2006 and was commissioned in late 2009 at a cost of around A$234 million. The project—which includes the 140 MW Bogong power station, a 6.9 km tunnel, head works and a 220 kV transmission line—will provide fast peaking power. In comparison, the Ord River hydroelectricity scheme, which was built on the existing dam which created Lake Argyle in Western Australia, was constructed at a cost of A$75 million (Pacific Hydro 2009). While this plant is relatively small (30 MW), it demonstrates the potential reduction in construction costs where an existing dam can be used.

While hydroelectricity has high construction and infrastructure costs, it has a low cost of operation compared to most other means of electricity generation. In the OECD, capital costs of hydroelectricity plants are estimated at US$2400 per kW, and operating costs are estimated at between US$0.03 and US$0.04 per kWh (IEA 2008). For non-OECD countries, capital costs are often below US$1000 per kW. The operating costs of small hydroelectricity facilities are estimated at between US$0.02 and US$0.06 per kWh. Operating and capital costs depend on the size and type (for example, run-of-river) of plant, and whether it includes pumped storage capabilities. Most hydroelectric plants have a lifetime of over 50 years, during which minimal maintenance or refurbishment is required, so the relatively high capital costs are amortised over a long period.

The average investment cost for small-scale hydro is typically US$1300–8000 per kW, which is comparable to large-scale hydro average investment costs of US$1050–7650 per kW (IRENA 2012). The annual operations and maintenance costs are quoted as a percentage of the investment cost per kW. Large-scale hydro will average around 2 to 2.5 per cent, whereas small-scale hydro can range between 1 and 6 per cent (IRENA 2012).

Surface water availability and competition for scarce water resources will be a key constraint to future hydro developments in Australia

Australia has highly variable rainfall across the continent (figure 8.8). This means that annual inflows to storages can vary by up to 50 per cent and seasonal variations can be extreme. The recent drought in much of south-eastern Australia saw a substantial decline in water levels in the major storages in New South Wales (notably the Snowy Mountains Hydro-Electric Scheme), Victoria and Tasmania and declining capacity factors for hydroelectricity plants. Water levels in storages during the 2002 to 2009 drought declined to an average of below 20 per cent of capacity in the Murray–Darling Basin and below 40 per cent in Tasmania (BOM 2012). In contrast, water levels across Australia rose to over 80 per cent of capacity and hydroelectricity generation increased in 2010–11 following increased water availability.

The *State of the climate 2012* report notes that the long-term warming trend has not changed, and that there has been a general trend towards increased spring and summer monsoonal rainfall across Australia's north and a decrease in autumn and winter rainfall across southern Australia (CSIRO and BOM 2012). Record rainfall fell in spring and summer in the south-east of Australia in 2010 and 2011. Climate models suggest long-term drying over southern areas during autumn and winter, which will be superimposed on large natural variability such as wet years becoming less frequent and dry years more frequent. Droughts are expected to become more frequent in southern Australia; however, periods of heavy rainfall are still likely to occur (CSIRO and BOM 2012).

Competition for water resources will also affect the availability of water for hydroelectricity generation. Demand for water for urban and agricultural uses is projected to increase. It is likely that these uses for scarce water resources will take precedence over hydroelectricity generation. Generators face increasing demands to balance their needs against the need for greater water security for cities and major inland towns. The maintenance of environmental flows to ensure the environmental sustainability of river systems below dams is also an important future consideration which may further constrain growth of hydroelectricity generation.

Water policies may also play a role in the future development of hydroelectricity in Australia. Policies that limit the availability of water to hydro energy plants, restrict the flow of water into dams, require generators to let water out of dams, or prioritise the use of water for agriculture could change the viability of many hydroelectricity generators, and limit future growth. The extended drought in much of Australia has led to water restrictions being put into place in most capital cities, and regulation of the Murray–Darling Basin river systems has strengthened.

8.4.2 Outlook for hydro energy market

Hydroelectricity generation is projected to remain broadly unchanged in Australia due to the limited availability of suitable locations for the expansion of capacity and water supply constraints.

Due to increasing generation from other sources, the contribution of hydro energy is projected to fall in the future. The potential for return of hydroelectricity output to pre-2006 levels will be strongly influenced by climate and by water availability.

Recent and proposed development projects

- Since January 2010, there have been small hydroelectricity plants commissioned and upgrades to existing plants.
- Australia's first hydro generation plant using treated sewage water was commissioned in April 2010 at the Sydney Water's North Head wastewater treatment plant in New South Wales. The plant generates energy from treated waste water falling down a 60-metre shaft. In conjunction with a co-generation plant producing energy from methane, the combined power plant will generate 4.5 MW, and supply 40 per cent of the treatment plant power.
- In early 2010, Snowy Hydro commissioned a mini hydro electricity plant (14.4 MW) attached to the river diversion conduit of the Jounama Dam to capture energy from water releases.
- Snowy Hydro has embarked on a A$400 million scheme modernisation project. As at September 2012, the Lower Tumut project had been completed, with six upgraded units now capable of providing 25–50 MW of additional capacity each. Work is continuing on the Upper Tumut project, which is expected to expand capacity by 40 MW and is scheduled to be commissioned in 2014 (Snowy Hydro 2012).
- Hydro Tasmania completed significant redevelopment of its Lake Margaret mini hydro energy plants in 2010 and has commenced work on the A$60 million modernisation of the Tungatinah plant.
- Stanwell Corporation is at the feasibility stage of its Burdekin project (37 MW) in Queensland.

BOX 8.3 TECHNOLOGY DEVELOPMENTS IN HYDROELECTRICITY

Research is being undertaken to improve efficiency, reduce costs, and to improve the reliability of hydroelectricity generation. There are different research needs for small and large-scale hydro (table 8.3). Small hydro energy plants, including micro and pico plants, are increasingly seen as a viable source of energy because of their lower development costs and water requirements, and their lower environmental footprint. Small-scale hydropower plants require special technologies to increase the efficiency of electricity generation and thereby minimise both the operating costs and environmental impacts of hydroelectricity generation (ESHA 2006).

The environmental impacts of hydroelectricity are also being investigated, and ways to mitigate these impacts developed. This includes the development of new and improved turbines designed to minimise the impact on fish and other aquatic life and to increase dissolved oxygen in the water. The introduction of greaseless bearings in the turbines would reduce the risk of petroleum products entering the water, and is also currently being investigated (EERE 2005).

Table 8.3 Technology developments for hydro energy

Large hydro	Small hydro
Equipment Low-head technologies, including in-stream flow Communicate advances in equipment, devices and materials	**Equipment** Turbines with less impact on fish populations Low-head turbines In-stream flow technologies
Operation and maintenance Increasing use of maintenance-free and remote operation technologies	**Operation and maintenance** Develop package plants requiring only limited operation and maintenance
	Hybrid systems Wind-hydro systems Hydrogen-assisted hydro systems

Source: IEA 2008

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