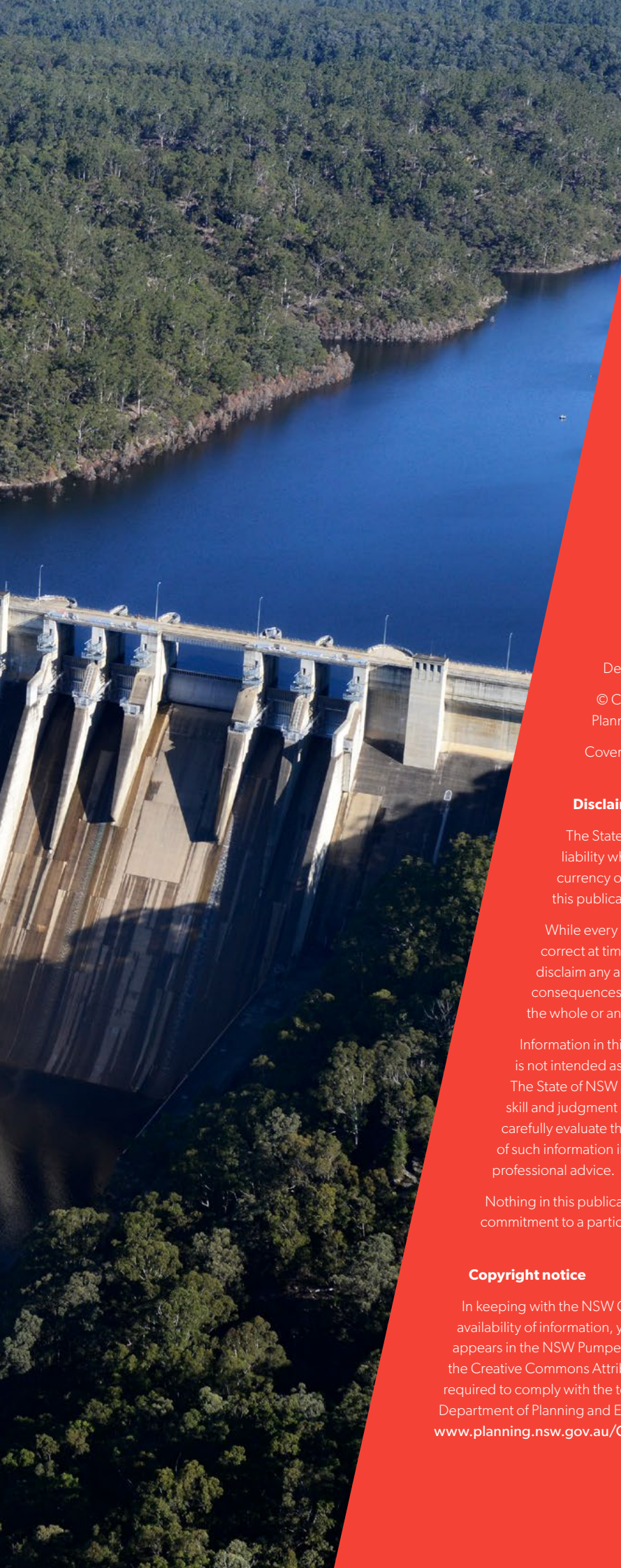




NSW Pumped Hydro Roadmap

**December
2018**



December 2018

© Crown Copyright, State of NSW through its Department of Planning and Environment 2018

Cover image: Warragamba Dam, WaterNSW

Disclaimer

The State of NSW does not guarantee or warrant, and accepts no legal liability whatsoever arising from or connected to, the accuracy, reliability, currency or completeness of any material contained in or referred to in this publication.

While every reasonable effort has been made to ensure this document is correct at time of printing, the State of NSW, its agents and employees, disclaim any and all liability to any person in respect of anything or the consequences of anything done or omitted to be done in reliance or upon the whole or any part of this document.

Information in this publication is provided as general information only and is not intended as a substitute for advice from a qualified professional. The State of NSW recommends that you exercise care and use your own skill and judgment in using information from this publication and that users carefully evaluate the accuracy, currency, completeness and relevance of such information in this publication and, where appropriate, seek professional advice.

Nothing in this publication should be taken to indicate the State of NSW's commitment to a particular course of action.

Copyright notice

In keeping with the NSW Government's commitment to encourage the availability of information, you are welcome to reproduce the material that appears in the NSW Pumped Hydro Roadmap. This material is licensed under the Creative Commons Attribution 4.0 International (CC BY 4.0). You are required to comply with the terms of CC BY 4.0 and the requirements of the Department of Planning and Environment. More information can be found at: www.planning.nsw.gov.au/Copyright-and-Disclaimer



○ Contents

Minister’s Foreword	3
Roadmap at a glance	4
Why we need this Roadmap	6
How pumped hydro works	10
Pumped hydro in NSW—the starting point	12
Action 1: Bringing forward private investment	14
Action 2: Mapping the landscape for opportunities	16
Action 3: Providing guidance on the regulatory process	26
Glossary	29
Appendix A: Method for identifying NSW opportunities	30
Appendix B: List of datasets used in mapping analysis	32



Minister's Foreword

In NSW we are leading the nation in planning for the transition to a modern energy system. This system will provide investment certainty for the long term while ensuring affordable and reliable energy for NSW households and businesses.

On-demand electricity generation will play a significant role in our energy future and that is why I am excited to launch the Pumped Hydro Roadmap. This Roadmap will encourage private sector investment in pumped hydro projects that will deliver the long term, large-scale energy storage that is vital for our energy system.

Our State is blessed with significant water resources that provide fertile ground for pumped hydro investment, so when the sun doesn't shine and the wind doesn't blow—'nature's battery' can be there to bolster our energy supply.

In NSW we already have pumped hydro projects on the horizon: a final investment decision on Snowy 2.0 is expected by the end of 2018 and the expansion of the Shoalhaven Pumped Hydro Scheme in the Kangaroo Valley is being investigated. We can see the opportunity for a significant increase in pumped hydro investment and it is time to unlock that potential.

We are seeking proposals for energy investments in WaterNSW's extensive infrastructure portfolio, including 38 large dams, and offering funding for on-demand capacity through our \$55 million Emerging Energy Program.

This Roadmap, and the strategic development of pumped hydro in NSW, will help improve the reliability of our energy network. Through our collective efforts, we will deliver clean, reliable and affordable energy for NSW customers and businesses.

The NSW Government's vision is aligned with the Australian Energy Market Operator's Integrated System Plan, which projects significant increases in new on-demand capacity at utility-scale.

I would like to acknowledge the Australian National University's important work in mapping potential opportunities for pumped hydro energy in NSW.

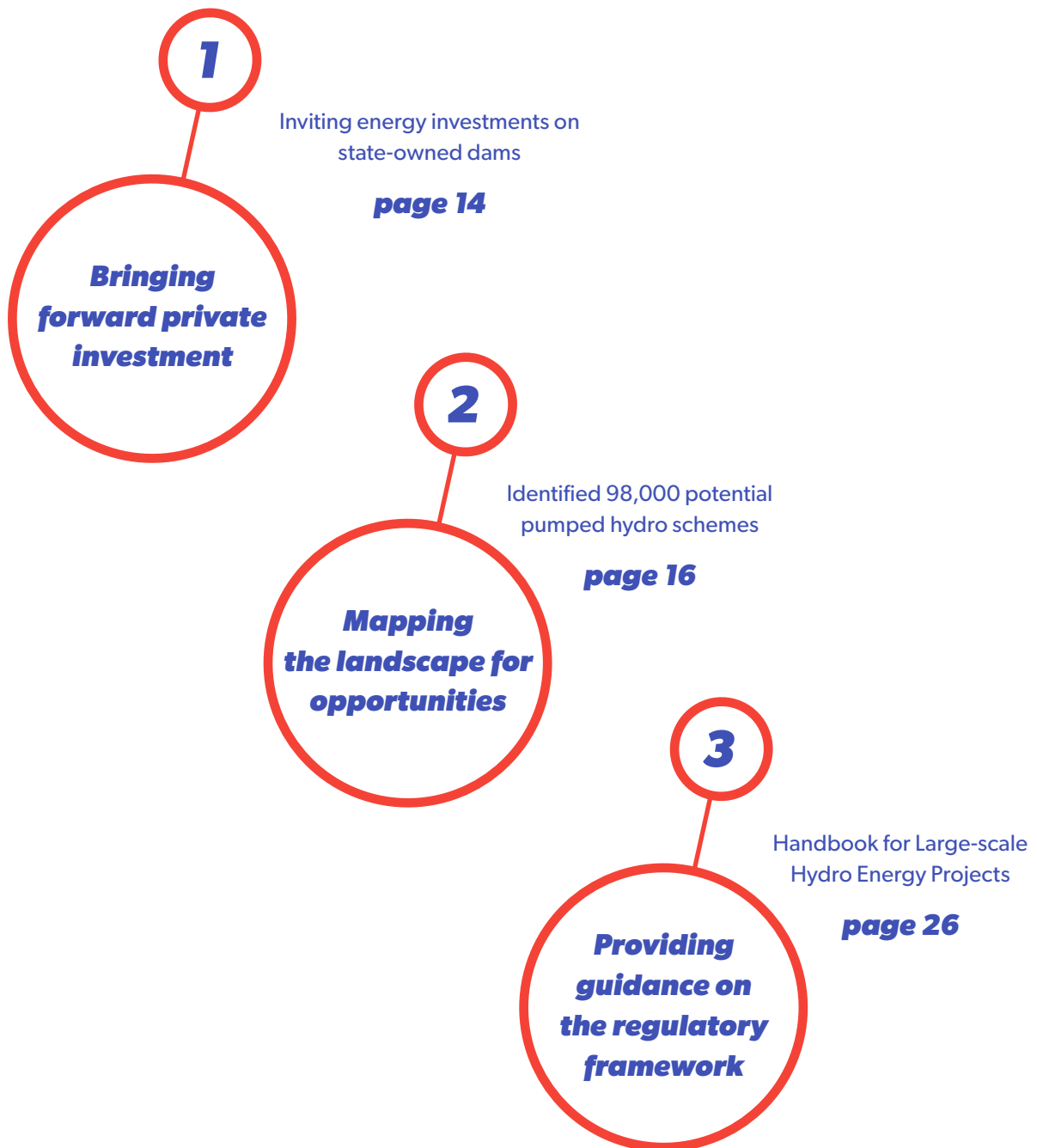
In NSW we have a \$27 billion pipeline of new energy projects and a landscape that will play a critical role in the transformation of our nation's energy system. I am excited about the part that pumped hydro will play in our energy future.

The Hon Don Harwin MLC
Minister for Energy and Utilities



Roadmap at a glance

The NSW Government is committed to ensuring clean, affordable and reliable energy supplies into the future and that is why we are taking steps to encourage the development of new pumped hydro projects.



Action 1: Bringing forward private investment

Opening state-owned water infrastructure for energy investments.

The NSW Government acknowledges that some of the best opportunities for developing pumped hydro projects may exist on state-owned water infrastructure. The State's bulk water supplier, WaterNSW has invited private developers to propose sensible energy and storage investments, such as pumped hydro and floating solar, on their extensive infrastructure portfolio, including 38 dams.

Supporting the commercialisation of new, large-scale, on-demand electricity projects.

The NSW Government has launched the \$55 million Emerging Energy Program to provide funding support for the next generation of large-scale, on-demand electricity projects in NSW. Funding will be provided to support the commercialisation of projects, as well as to pre-investment studies to help get new projects off the ground. Eligible projects must demonstrate that they can provide dispatchable or on-demand energy to help meet the State's energy needs. Technologies supported by the program could include pumped hydro, concentrated solar thermal, bioenergy, hydrogen and batteries.

Further information is available at: www.energy.nsw.gov.au/clean-energy-initiatives

Action 2: Mapping the landscape for opportunities

NSW has six regions with strong pumped hydro potential.

The NSW Government has worked with the Australian National University (ANU) to provide mapping analysis which shows that NSW has

widespread opportunities for pumped hydro development. The analysis identified 20,000 reservoirs that could be used for 98,000 possible schemes through matching up of different sites. The Australian Energy Market Operator (AEMO) has projected that NSW will need 9,000 megawatts (MW) of utility-scale energy storage in 2040. Only a small number of the total possible schemes identified would need to be developed to help meet this projection.

The data from ANU can be downloaded at: re100.eng.anu.edu.au

Action 3: Providing guidance on the regulatory process

Handbook on the regulatory framework for large-scale hydro energy projects.

The energy market has changed over the past 30 years since the NSW Government built the last major pumped hydro project in the State. The government supports a private sector-led energy market and is encouraging energy developers to consider investments in pumped hydro to help modernise the energy system. We have developed a Handbook on the regulatory framework for developing hydro projects in NSW that brings together the key considerations for private developers. Providing this guidance on the regulatory processes was recommended by the NSW Energy Security Taskforce in its final report in December 2017.¹

The Handbook is available at: www.energy.nsw.gov.au/clean-energy-initiatives

¹ NSW Chief Scientist and Engineer, Final Report from the Energy Security Taskforce, 19 December 2017

Why we need this Roadmap

An unprecedented transformation is underway across the entire energy supply chain and pumped hydro energy storage is expected to play a critical role in modernising the global energy system.

Around the world, energy systems are undergoing a significant transformation as generation diversifies beyond traditional sources to include new and innovative technologies that are changing the way we generate and use electricity. NSW is part of this global energy system modernisation.

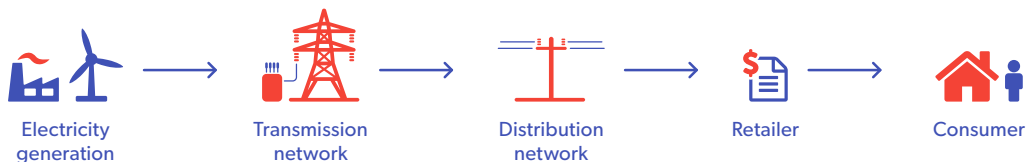
Not since the period between 1940-1980s, when NSW's coal-fired generators, the transmission network and the Snowy Scheme were built, has there been such significant change.

The traditional linear model of energy delivery is already transitioning towards a modern system, which is more complex and flexible.

Energy storage technologies at all levels are helping to balance the system and deliver affordable energy to all the households and businesses of NSW, both where and when it is needed. NSW is planning now for a portfolio of energy and storage solutions, in which pumped hydro is expected to play a critical role in the decades to come.

Figure 1 — The changing energy system

Traditional linear energy system



Modern flexible energy system

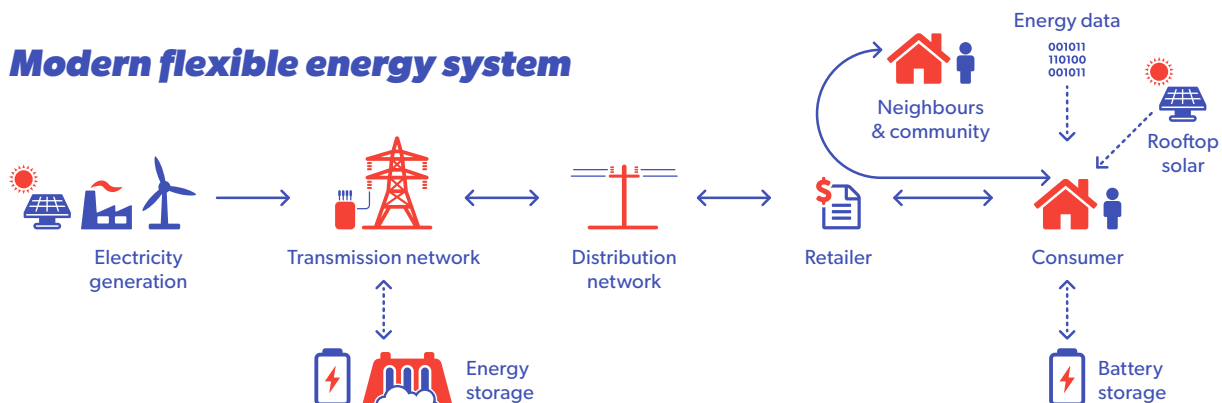


Figure 2 — Pumped hydro around the world—fast facts²

 **97%**

of all energy storage capacity is pumped hydro

 **3.2 GW**

added in 2017

 **153 GW**

total installed capacity in 2017

 **100**

new pumped hydro projects under development

If developed, these 100 projects will increase global storage capacity by 50 per cent to almost 225 GW by 2030

NSW is proactively establishing the building blocks of a modern energy system that will safeguard our energy security.

In July 2018, AEMO released the inaugural Integrated System Plan (ISP). The ISP identifies that the least-cost replacement for existing generators, which are expected to retire over the next two decades, consists of a portfolio of new generation and storage technologies. There are 20,000 MW of renewable energy projects, gas plants and generator upgrades that are either seeking or have planning approval in NSW.

The NSW Government's Transmission Infrastructure Strategy builds on the ISP and outlines initiatives to boost our interconnection with Victoria, South Australia and Queensland to access least-cost energy in times of peak demand, and to help support this project pipeline by unlocking the potential of three new Energy Zones identified in the State's New England, Central West and South West regions. These Energy Zones benefit from outstanding energy resources, have reduced environmental and planning constraints, are close to existing transmission and distribution infrastructure and load centres, and align with the Government's regional growth priorities, developed in consultation with regional communities.

² International Hydropower Association, Hydropower status report 2018, page 8.

Figure 3 — NSW pipeline of energy projects and potential Energy Zones

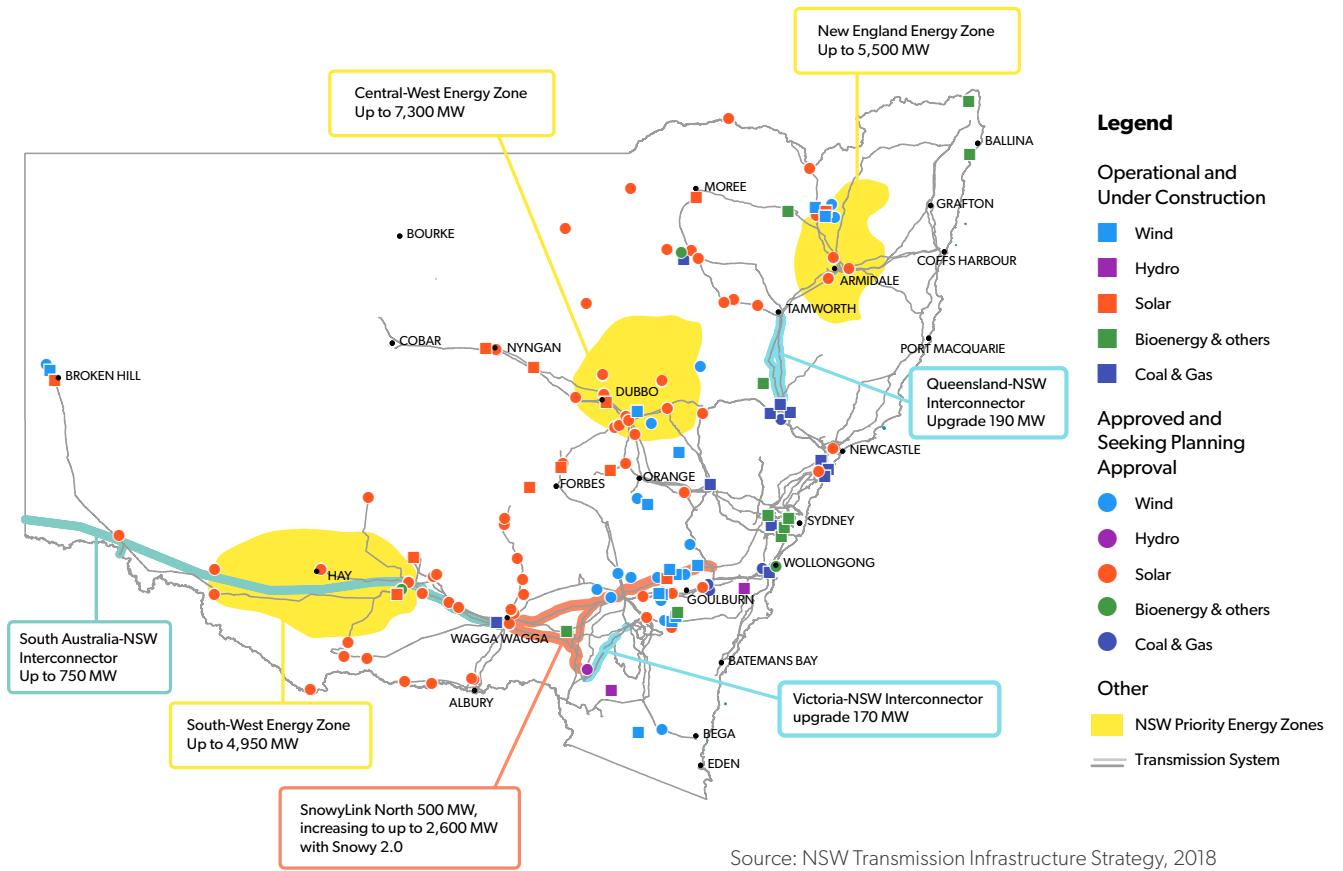
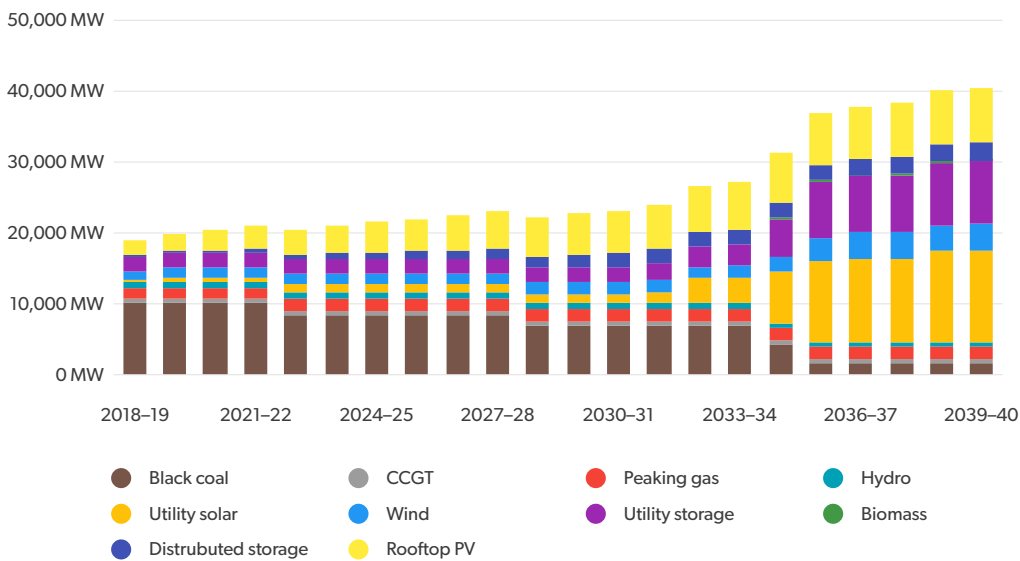


Figure 4 — Projected NSW electricity capacity – neutral economic scenario (2018-2040)



AEMO has projected that NSW needs around 9,000 MW of new utility-scale energy storage by 2040 to complement new generation. This new storage capacity could come from a range of technologies.³

Pumped hydro energy storage is an established and proven technology that can balance this new generation by offering bulk energy storage over days, weeks or even seasons and on a utility-scale not currently viable with other storage technologies. The Independent Review into the Future Security of the National Electricity Market (Finkel Review) supports the prospect of new pumped hydro projects, not only for their flexibility to supply power when needed, but also for their potential to ‘shave’ the peak off wholesale price spikes.⁴

New private sector pumped hydro projects face several key challenges:

- Pumped hydro projects have long development lead times and high upfront engineering, approval and construction costs, which increase the investment risk for the private sector (although this is partly mitigated by long project life spans of 50-100 years).⁵
- Knowledge barriers may exist because no large-scale pumped hydro projects have been built in NSW in the past 30 years and previously the State built major hydro developments.
- Selecting appropriate development sites and addressing environmental impacts can be highly complex.

This Roadmap outlines the work being carried out by the NSW Government to address these challenges and facilitate project development. All new pumped hydro projects are subject to the NSW planning assessment process, which includes environmental impact assessment and community consultation requirements.



Cataract Dam, WaterNSW

3 AEMO, Integrated System Plan (Neutral Scenario), July 2018.

4 Finkel et al, Independent Review into the Future Security of the National Electricity Market, June 2017, page 80.

5 Bloomberg New Energy Finance, Pumped Hydro—The ‘Unsung Hero’ of Energy Storage?, 2017.

How pumped hydro works

Pumped hydro energy storage is a tried-and-proven technology that has been meeting energy demands in NSW for decades and is now re-emerging as a key technology in the modern energy context.

Pumped hydro is a large-scale energy storage technology that uses hydroelectricity generation. Hydroelectricity harnesses the gravitational force of water flowing downwards, usually through a river system, with dedicated pipes or a dam spillway that flows through a turbine to generate electricity. Pumped hydro also works by water running through a turbine to generate electricity, but these plants store and move water between two reservoirs at different heights. The water from the lower reservoir is pumped to the upper reservoir and this same water can be used repeatedly to run through the turbine to create electricity.

Operators can choose to pump water up when both energy demand and electricity prices are low (or off-peak), for example at night when demand is low and wind farms are generating excess electricity. The water in the upper reservoir is then released back to the lower reservoir through a turbine to generate electricity when energy demand and electricity prices are high. In this way pumped hydro remains cost-efficient by using electricity when it is cheap and plentiful and supplying electricity when there is greater demand and higher electricity prices.

Pumped hydro projects can be very large, capable of operating at hundreds of megawatt or even gigawatt power levels for six hours or more.⁶ As a result of its scale and because it can be used strategically in response to system needs, pumped hydro can be one of the most economically efficient forms of energy storage.⁷

Depending on the size of the water reservoir, pumped hydro can generate at the plant's maximum power for hours or even days and can start generating electricity within minutes. Hydro generators also have similar capabilities to coal-fired power stations for providing system inertia, which involves supporting the short-term balance of electricity supply and demand on the grid. In the future energy system, pumped hydro would sit alongside a diverse mix of dispatchable technologies, such as battery storage, gas generators and bioenergy.

6 Cavanagh, K. et al, Electrical energy storage: technology overview and applications. CSIRO, Australia. Prepared for the Australian Energy Market Commission, 2017.

7 Godfrey, B. et al, The Role of Energy Storage in Australia's Future Energy Supply Mix, Report for the Australian Council of Learned Academies, 2017.

Figure 5 — How a pumped hydro system works

- 1 Water is pumped into the upper reservoir using cheaper energy when demand is low.
- 2 When there is a spike in demand, water is released to the lower reservoir.
- 3 The water flows quickly down the pipes which turns the turbines to generate electricity.

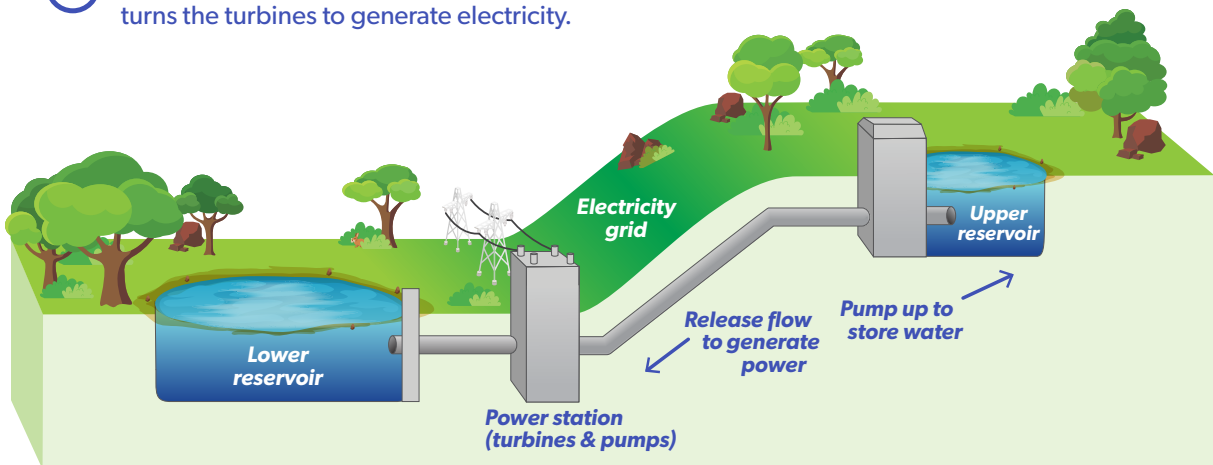
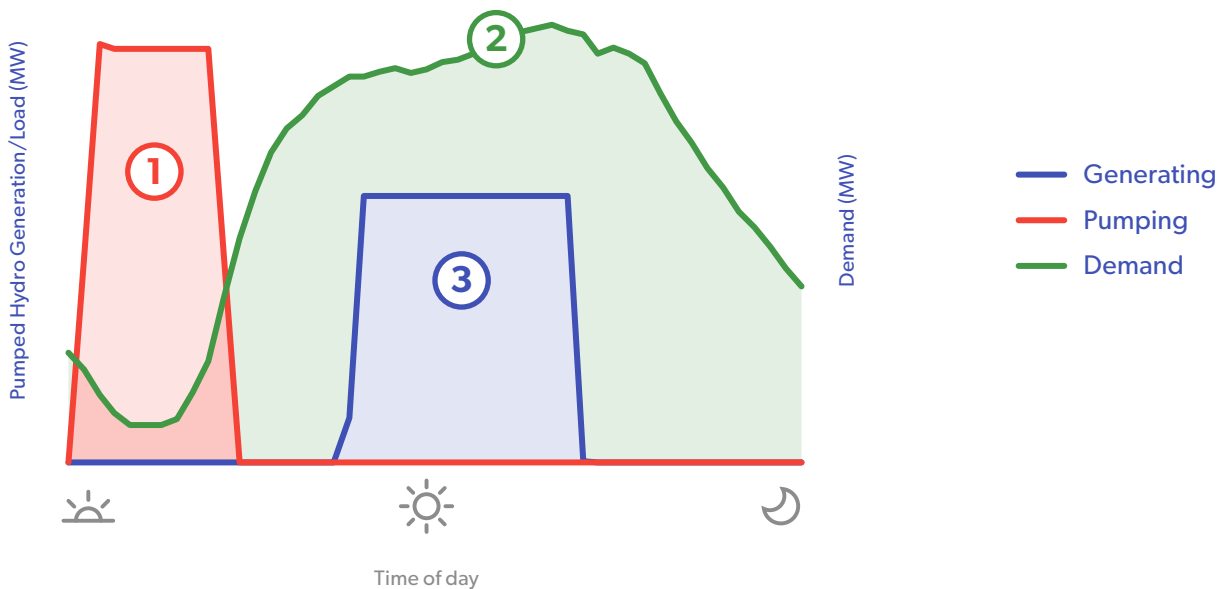


Figure 6 — How pumped hydro can shift energy to meet demand needs



Pumped hydro in NSW— the starting point

Pumped hydro is an ‘on-demand’ energy supply that complements other modern energy technologies to provide secure and reliable electricity supply.

NSW is fortunate to have two major operating pumped hydro schemes: the Snowy Hydro Scheme and the Shoalhaven Scheme. Expanding pumped hydro capabilities in NSW has been supported by the Finkel Review, the NSW Energy Security Taskforce Final Report and AEMO’s ISP.

Snowy Scheme

Operating since the early 1950s, the Snowy Mountains Scheme was completed in 1974 and is the single largest generator in the NEM. The Scheme was created primarily to divert water from the Snowy Mountains to support irrigation for agriculture and counteract drought in the Murray Darling Basin. The Scheme also includes nine major power stations including 33 turbines with a total generation capacity of 4,100 MW which produces around 4,500 gigawatt-hours of renewable electricity each year to help meet peak demand. The Scheme’s Tumut 3 power station has pumped hydro capabilities.

The proposed Snowy 2.0 project is being designed to provide a 2,000 MW—or 50 per cent—increase in the Snowy Scheme’s hydroelectric generation capacity and allow it to operate for more than seven days straight. The Snowy 2.0 proposal is to link the existing Tantangara and Talbingo reservoirs through 27 kilometres of underground tunnels, with a new pumped hydro power station located in between the reservoirs almost one kilometre below ground.

On 25 October 2018, Snowy Hydro Limited submitted an application for the ‘Main Works’ for the Snowy 2.0 project to the NSW planning system, which includes the generation units and associated infrastructure. The Snowy 2.0 project has been declared Critical State Significant Infrastructure under the *NSW Environmental Planning and Assessment Act 1979*. The NSW Government has sold its 58 per cent shareholding of Snowy Hydro Limited to the Commonwealth for just over \$4 billion. The NSW Government has decided the proceeds of this sale will be used for infrastructure projects in regional NSW.



Tumut 3 © Snowy Hydro Limited 2018



Shoalhaven Scheme

The Shoalhaven Scheme in the Southern Highlands includes Tallowa Dam, Fitzroy Falls Reservoir, Bendeela Pondage and Wingecarribee Reservoir. It was commissioned in 1977 to help ensure water security for Sydney, but the Scheme also includes hydroelectricity generation.

The pumped hydro capacity of the Scheme is 240 MW, including the Kangaroo Valley Power Station and the Bendeela Power Station.

The Bendeela Power Station can lift water around 125 metres (m) from Lake Yarrunga to Bendeela Pondage, which is then lifted an additional 480 m by Kangaroo Power Station to Fitzroy Falls Reservoir. The water can then be used to generate electricity by running all the way back to Lake Yarrunga through the turbines at the power stations.

The owner of the power stations at the Shoalhaven Scheme, Origin Energy, has recently announced a proposed upgrade that would double the capacity of the Scheme to 475 MW.

Figure 7 — NSW current hydroelectricity capability—at a glance⁸



Snowy Scheme



Shoalhaven Scheme



NSW has 38 other small hydro plants

6.6%

of total electricity generation in NSW came from hydro sources on average over the past 5 years

i 790

people work in hydroelectricity across NSW

⁸ Capacity figures from Snowy Hydro Limited, Origin Energy and NSW Department of Planning and Environment. Generation figure from NSW Department of Planning and Environment. Jobs figure from Australian Bureau of Statistics, 'Employment in Renewable Energy Activities, Australia, 2016-17'.

Action 1: Bringing forward private investment

Opening state-owned water infrastructure for energy investments

The NSW Government is working with the private sector to explore energy and storage projects on WaterNSW's extensive existing infrastructure portfolio that could improve NSW's energy security and reliability.

In 2018, the State's bulk water supplier and dam operator, WaterNSW, launched a unique procurement process to seek interest from the private sector to develop energy and storage projects on 38 large state-owned dams. The initiative represents a standalone, competitive and transparent process for proposing new energy projects on WaterNSW's assets, land and resources. The process is allowing private developers to explore proposals with WaterNSW to build new, upgraded or expanded projects that will 'dual-purpose' state assets for both water and energy. Engaging with the market in this process will help maximise the benefits of existing infrastructure and unlock opportunities for new projects that could deliver the on-demand energy supplies that NSW needs.

The Expression of Interest stage closed on 10 September 2018 and attracted significant interest from the private sector. WaterNSW received a large number of quality submissions from leading industry participants, both local and international, across a range of technologies, including proposals for pumped hydro energy storage. It's clear there is appetite for investment in the State's water assets.

All proposals are required to prioritise WaterNSW's water security, operational and dam safety obligations, and ensure there will be no impact on water quality or customers' water bills. Any proposal that progresses through this process, and further potential stages, is subject to the formal planning approval process. This includes full project assessment, including community consultation.

WaterNSW is Australia's largest supplier of bulk and raw water, providing two-thirds of the water used in NSW, and is a major developer of infrastructure solutions for water supply security and reliability. WaterNSW operates and maintains large dams across NSW and delivers water for agriculture and drinking water supply to customers. In addition, WaterNSW protects the health of declared catchments to ensure the highest quality drinking water is consistently available.

For further information please visit:

www.waternsw.com.au

Supporting the commercialisation of new, large-scale, on-demand electricity projects

The NSW Government is bringing forward the next generation of large-scale energy and storage projects to help provide the on-demand energy that NSW needs to modernise the energy system.

The \$55 million Emerging Energy Program provides funding support towards the commercialisation of new, large-scale NSW electricity projects that use emerging, dispatchable technology, as well as supporting pre-investment studies to help get new projects off the ground. The Program is technology-neutral and aims to bring forward a pipeline of electricity projects that provide energy on-demand and help drive emerging technologies down the cost curve to support an orderly transition to a clean, reliable and affordable energy future.

Pumped hydro projects are long-term and complex infrastructure investments with high upfront costs that increase development risk. The technology is re-emerging in the 21st Century because its capabilities are complementary to the needs of the modern energy system, especially the ability to help integrate variable generation, such as from solar and wind farms, and meet peak demand events.

Companies proposing pumped hydro projects, including those shortlisted under WaterNSW's Expression of Interest process, can apply to the Emerging Energy Program if they meet the eligibility and merit criteria. Applicants will need to demonstrate a true funding gap to ensure the government is getting value-for-money and not supporting projects that would have been built otherwise. The program is expected to leverage hundreds of millions of dollars in additional private sector investment and a significant number of jobs for regional NSW.

For more information, please visit:

www.energy.nsw.gov.au/clean-energy-initiatives

Action 2: Mapping the landscape for opportunities

There are widespread opportunities for pumped hydro across NSW. The private sector is encouraged to investigate the best and most collectively beneficial sites.

The NSW Government has worked with the Australian National University (ANU) to uncover opportunities for pumped hydro across the State. This analysis found an incredible 20,000 reservoirs in the natural landscape that could be used as storages for pumped hydro energy. These could be paired-up in different ways to create 98,000 potential off-river pumped hydro sites—representing over 50 terawatts (TW) of firm generation capacity. In 2018, AEMO has projected that NSW will need investment in 9,000 MW of utility-scale energy storage by 2040, which is less than 1 per cent of the opportunities mapped. The government supports a private sector-led energy market and has undertaken this research to identify opportunities and raise awareness in the marketplace of the significant potential in NSW. Pumped hydro schemes require a large infrastructure investment and so any opportunity will require investigation and due diligence by proponents on a case-by-case basis. All proposals are subject to the NSW planning assessment process, which includes environmental impact assessment and community consultation requirements.

The government has overlaid 35 datasets to help rate the potential schemes on a comparative basis across the entire state. This took into consideration their technical credentials, commercial characteristics and environmental constraints. The results of the analysis are presented in the maps over the page. Each hexagon covers 115km² and represents the average 'opportunity score' of all the possible schemes located within it. The average opportunity

scores range from 7 to 20 representing a spectrum of opportunity from strong to exceptional. This has highlighted six clusters of opportunities across the State in the North East, Lower North Coast, Central West, Shoalhaven, South East, and Riverina. An explanation of the methodology and the list of datasets used to produce these opportunity maps and the regional information are available in Appendix A and B.

The analysis identified an abundance of sites and used a high threshold to reduce the total number of potential schemes. The opportunities identified represent potential new utility-scale, greenfield, off-river pumped hydro schemes with a minimum elevation between the lower and upper reservoirs (head height) of 300 m and minimum storage capacity of one gigalitre. The opportunity in terms of capacity for each is calculated assuming six hours of generation across all potential schemes. The average energy capacity in each region has been calculated assuming the project is utilising the full storage capacity of a pair of reservoirs. All water quantities mentioned are also subject to regulation and much of the water throughout NSW is already the subject of a property right through water licensing. Developers will likely need to trade with current water access licence holders to obtain water for the initial fill of their reservoirs (see Action 3 below).

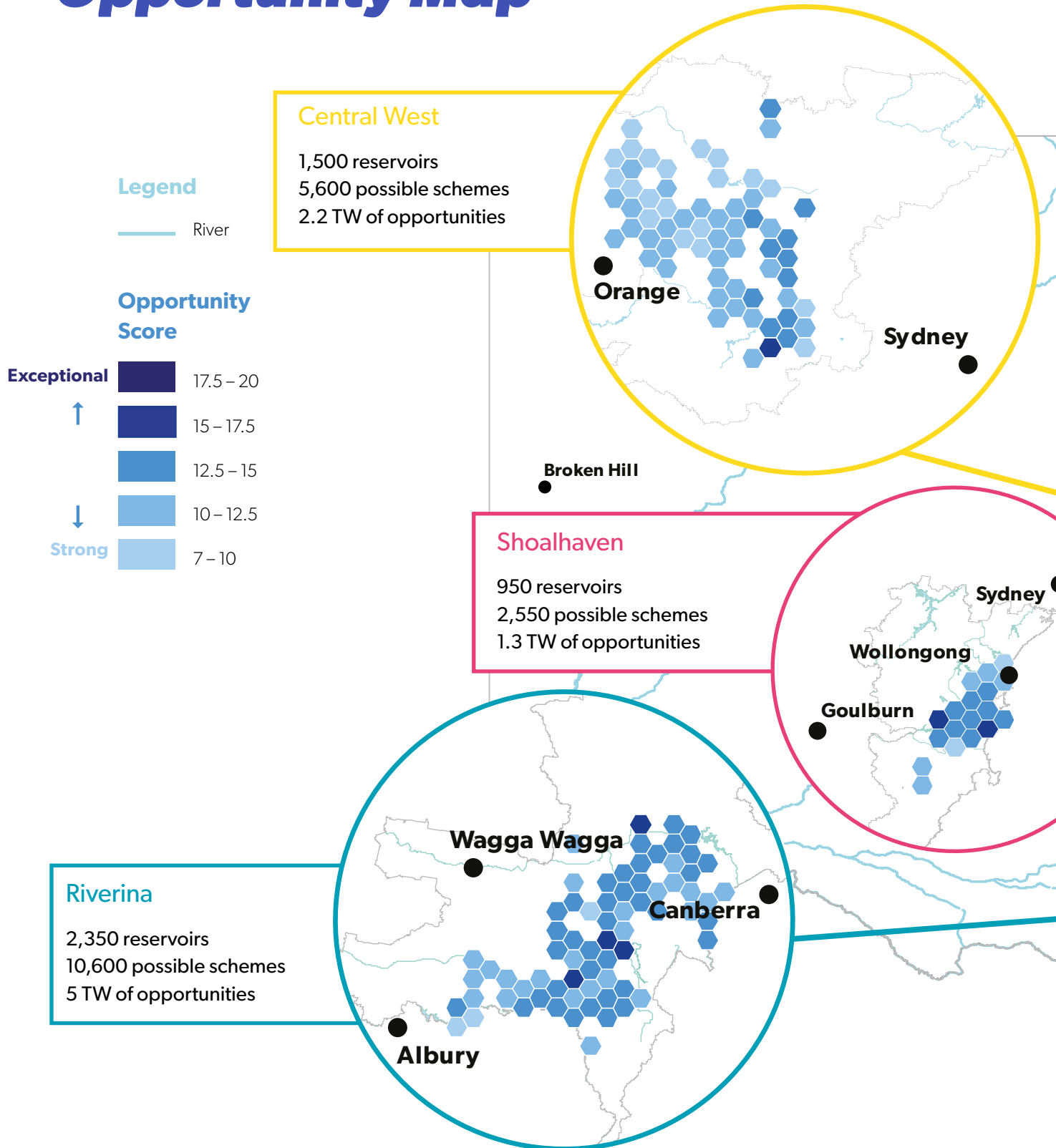
To download the data from the ANU, please visit: re100.eng.anu.edu.au

An aerial photograph of a large dam and reservoir. The reservoir is filled with blue water and has several islands. The dam is a concrete structure with a spillway. The surrounding area is covered in green trees. A red callout graphic is overlaid on the image, consisting of a large red circle containing the number '50' and the word 'terawatts', and a smaller red circle containing the text 'of off-river pumped hydro opportunities identified across NSW'.

50
terawatts

**of off-river
pumped hydro
opportunities
identified
across NSW**

NSW Pumped Hydro Opportunity Map



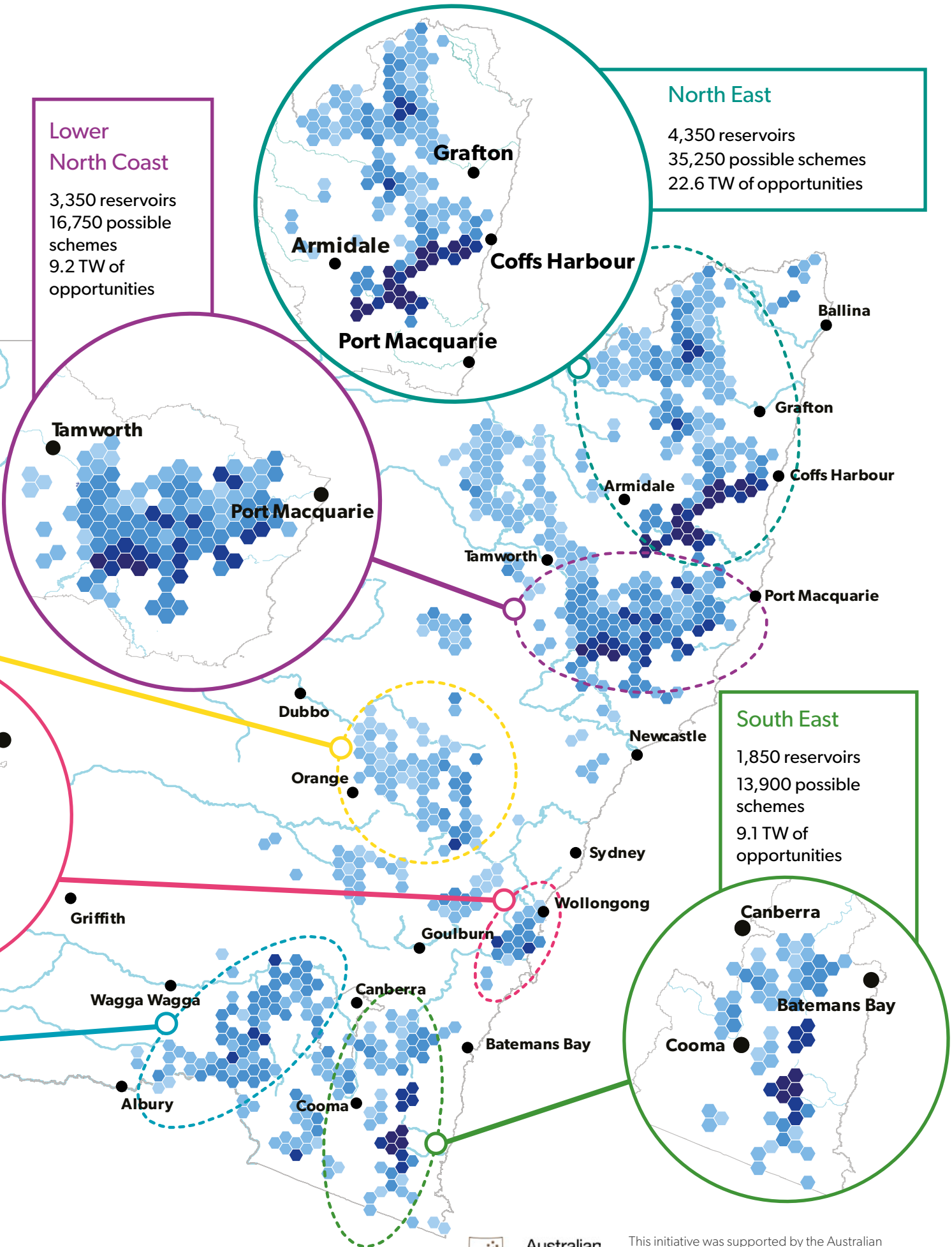
Note: There are ample potential opportunities for pumped hydro schemes and this exercise has ruled out areas on national parks, world heritage sites and valuable agricultural land.

Lower North Coast

3,350 reservoirs
16,750 possible schemes
9.2 TW of opportunities

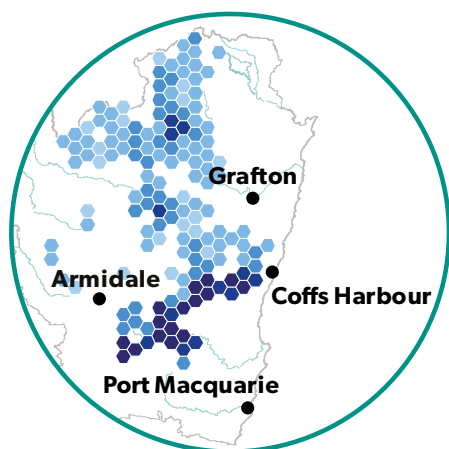
North East

4,350 reservoirs
35,250 possible schemes
22.6 TW of opportunities



This initiative was supported by the Australian Government through the Australian Renewable Energy Agency

North East



The North East has excellent pumped hydro potential, with high opportunity scores across the region, and particularly strong opportunities in the area between Armidale and Coffs Harbour. The analysis found 4,350 reservoirs that could be combined into over 35,000 potential pumped hydro schemes in the area, more than any other region. The potential schemes represent an opportunity of around 22 TW of installed capacity. The average head height between paired reservoirs is 642 m, with a maximum of 1,312 m—the highest across all regions.

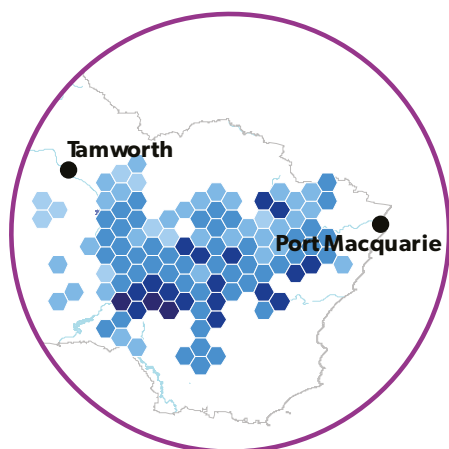
In terms of water availability, there are around 120,000 megalitres (ML) to be traded under water access licences in the region, with an additional 385,000 ML of regulated water sourced from the Border Rivers. On average, up to 500 ML are available per hexagon on the map, with the highest amounts in the north east and south east.

According to NSW and ACT Regional Climate Modelling (NARCLiM), mean temperatures in the area are expected to increase by 2.2°C by 2070, compared to the period 1990-2009. The south-eastern area towards Coffs Harbour will likely be limited to a maximum increase of 1.9°C in this period. In the period up to 2070, rainfall is expected to increase. Rainfall over possible reservoir locations between Coffs Harbour and Armidale is expected to increase by close to 10 per cent on average. The rest of the possible reservoir locations in the region are expected to see average increases closer to 5 per cent.

The region offers significant transmission capacity, with around 800 MW currently available across the Lower North Coast and in the North East. This may increase following the retirement of traditional power stations. The NSW Government is looking to increase transmission capacity in the area through its Transmission Infrastructure Strategy. An upgrade to the Queensland-NSW Interconnector could provide an additional 190 MW of transmission capacity.

The region also overlaps with the government's priority Energy Zone in New England and there is scope for co-location of projects. There are almost 4,000 MW of wind, solar and bioenergy projects seeking planning approval in the region, more than 500 MW of projects are already approved and almost 300 MW of projects are under construction.

Lower North Coast



The Lower North Coast offers significant potential for pumped hydro development, with 3,350 reservoirs that could be combined into almost 17,000 potential pumped hydro schemes, representing an opportunity worth 9.2 TW of installed capacity. The average head height between reservoir pairs is 550 m, with a maximum of 1,050 m.

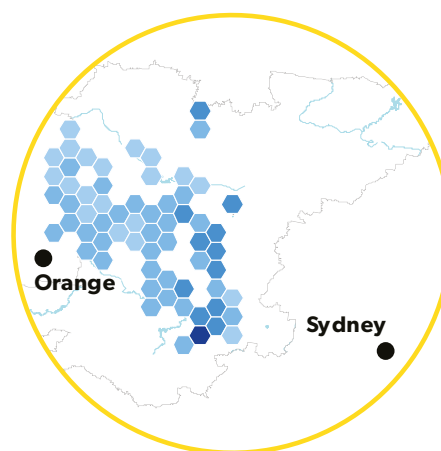
The water availability in the region includes around 140,000 ML to be traded through water access licences across the region, with 30,000 ML of regulated water in the Peel Regulated River Water Source. Each hexagon on the map has between 500–5,000 ML of tradable water, with higher volumes towards the South of the region.

According to NARClIM, mean temperatures are expected to increase by 2.2°C by 2070, compared to the period 1990-2009. The south eastern part of the region towards the coast and Port Macquarie will likely be limited to a maximum increase of 2°C in this period. In the period up to 2070, rainfall is expected to increase on average 5 to 10 per cent around the possible reservoir locations. The southern part of the region north of Gloucester is likely to see an increase in average rainfall beyond 10 per cent.

The transmission capacity for this region (shared with the North East region) is currently around 800 MW and may increase following the retirement

of traditional power stations in the region, beginning with the Liddell Power Station in 2022. The region will also benefit from the proposed upgrade to the Queensland-NSW Interconnector which would allow an additional 190 MW of energy to flow into major load centres. The NSW Government is helping to facilitate early delivery of this network infrastructure through its Transmission Infrastructure Strategy.

Central West



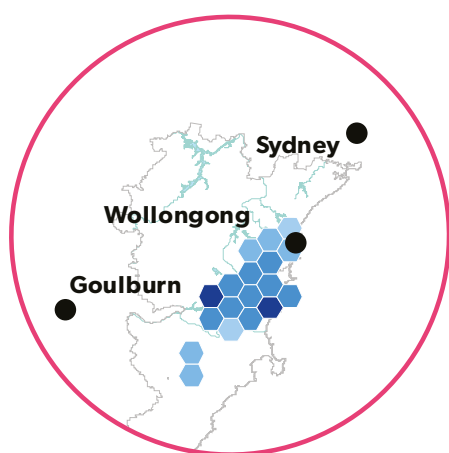
The Central West has 1,500 reservoirs that could be combined into 5,600 potential pumped hydro schemes, representing an opportunity worth 2.2 TW installed capacity. The average head height between paired reservoirs is 398 m, up to a maximum of 653 m.

The region has large unregulated tradable water resources, with around 850,000 ML. This is as high as over 100,000 ML per hexagon on the map in the East, and 2,000-10,000 in the North and South. According to NARClIM, in the western half of the region mean temperatures are expected to increase by 2.1°C by 2070, compared to the period 1990-2009. The eastern half will likely be limited to a maximum increase of 1.9°C. In the period up to 2070, rainfall is expected to increase on average by between 5 to 10 per cent around the possible reservoir locations.

The region also currently has significant transmission capacity of around 1,000 MW. In its ISP, AEMO proposed increasing transmission capacity at the substation in Wollar, which would directly benefit this region. The NSW Government's Transmission Infrastructure Strategy also identifies an Energy Zone slightly further to the west, around Dubbo. This zone may offer increased opportunities for new transmission capacity or benefits from co-locating near wind and solar resources.

The area has a high density of both historical and operational mine sites, in addition to industrial sites west of Newnes and near Kandos. Some of these correlate with potential reservoir locations so could provide opportunities to develop brownfield sites.

Shoalhaven



The Shoalhaven has strong opportunities for pumped hydro development. There are 950 reservoirs which could be combined into 2,500 potential pumped hydro schemes, representing an opportunity worth 1.3 TW of installed capacity. There is an average head height between paired reservoirs of 467 m, with a maximum of 690 m.

While the number of highlighted reservoirs is lower, there is a very large volume of unregulated water tradable through water access licences, at 1,055,000 ML, and the volume of water per hexagon on the map is around 350,000 ML. Mean temperatures are

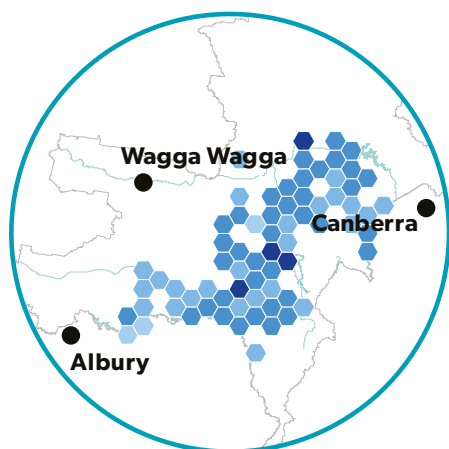
expected to increase by 1.9°C by 2070, compared to the period 1990-2009. The greatest increases are expected to be around 2.1°C in the summer months. In the period up to 2070, annual rainfall is expected to increase on average 5 to 10 per cent around the reservoir locations. However, rainfall is expected to become more seasonal, with winter and spring likely to see some decrease in rain.

The Shoalhaven region is already home to one of NSW's major operating pumped hydro schemes. The Shoalhaven Scheme has a capacity of 240 MW across two power stations, with a proposed expansion to 475 MW currently in the feasibility stage (for more information see page 13).

Transmission capacity in the Shoalhaven is also high, with around 900 MW of existing capacity. The region has the advantage of being located close to the 'backbone' of the transmission network that connects the major load centres of Wollongong, Sydney and Newcastle. Two 330 kilovolt transmission lines transport energy from the region into Sydney. The Transmission Infrastructure Strategy also proposes transmission upgrades that will link into this "backbone" at the Bannaby substation, to the west of the Shoalhaven region, and enable energy to be transported both to and from South Australia, Victoria and the Snowy region. The electricity transmitted from South Australia along the South-West of NSW is likely to be variable renewable energy, providing ample opportunity for firming services from new pumped hydro developments.

There are significant opportunities for brownfield development, with a high concentration of historical mines in the North of the region. Industrial sites are also common, with some in the northern most areas of the region corresponding with potential reservoir locations around the Wollongong area.

Riverina



The Riverina is well placed to take advantage of changes in the energy market because the region may experience significant renewable energy and transmission development. The region has 2,350 reservoirs that could be combined into 10,600 potential pumped hydro schemes, representing an opportunity worth 5 TW of installed capacity. The average head height between paired reservoirs is 458 m, with a maximum of 1,129 m—the second highest across all regions.

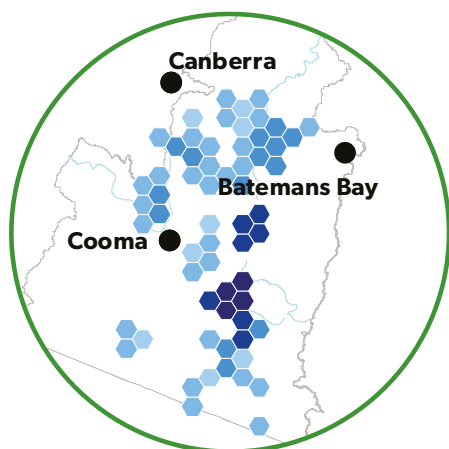
There are 47,000 ML of unregulated water access licences in the region, but a significant 2.4 gigalitres of regulated water from the NSW Murray Regulated River Water Source in the south west, and 3,500 ML from the Murrumbidgee Regulated River Water Source in the north and centre of the region.

According to NARClIM, mean temperatures are expected to increase by 2.0°C by 2070, compared to the period 1990-2009. The greatest increases are expected in the north eastern half of the region—around 2.4°C—with the south western half expecting more modest increases. In the period up to 2070, rainfall is expected to decrease up to 5 per cent on average across most of the reservoir locations. More extreme seasonality is expected, with increases of up to 10 per cent during summer and autumn counteracted by similar decreases during spring.

Current transmission capacity across the Riverina and South East regions is around 1,000 MW. The region is also located close to Wagga Wagga, which is at the heart of several proposed transmission upgrades both in the Transmission Infrastructure Strategy and the Integrated System Plan. This includes the proposed new interconnector with South Australia, which may unlock 750 MW of additional capacity between Wagga Wagga in NSW and Robertstown in South Australia and new infrastructure to unlock the Snowy Scheme which will include a transmission line from Tumut to Bannaby, via a substation at Wagga Wagga.

There are several opportunities for brownfield developments, with mine sites scattered around the region. Historical mine sites are located near to potential reservoir locations close to the Victorian border, while several operational mine sites are also near to potential reservoirs close to Wagga Wagga.

South East



The South East has 1,850 reservoirs that could be combined into 13,900 potential pumped hydro schemes, representing an opportunity worth 9.1 TW installed capacity. The average head height between reservoir pairs is 572 metres, with a maximum of 1,024 metres.

The region has large unregulated tradable water of 407,000 ML across the region, with 35,000 ML per hexagon on the map in the north and lesser volumes of around 2,000-5,000 ML per hexagon in the centre and central-south of the region. According to NARClIM, mean temperatures are expected to increase by 2.1°C by 2070 compared to the period 1990-2009. The greatest increases—up to 2.3°C—are expected in the north western corner of the region. In the period up to 2070, rainfall is expected to increase on average 1.5 per cent around the possible reservoir locations. Rainfall is expected to become more seasonal and extreme, with increases of up to 10 per cent during autumn and decreases of similar magnitude during spring. Some local areas are expected to see average rainfall decreases of up to 5 per cent.

The region is already home to a large number of energy projects, including eight operational wind farms and one solar farm and an additional 10 wind and 10 solar farms either with or seeking planning approval. This provides ample opportunities for co-locating pumped hydro developments with wind and solar projects to provide firming capacity. Developers should note that due to the high density of energy projects in the region, gaining and maintaining a social licence is very important and should be front of mind, as it should be in all regions.

There are currently 1000 MW of available transmission capacity across the South East and Riverina regions. The region could also benefit from proposed transmission infrastructure upgrades in both the NSW Government's Transmission Infrastructure Strategy and AEMO's Integrated System Plan to support the proposed Snowy 2.0. These proposals would increase capacity flowing through the South East region via new transmission to Bannaby north east of the region, and upgrades to the interconnector with Victoria in the centre of the region.



Action 3: Providing guidance on the regulatory process

Pumped hydro is regulated under a broad range of legislation. The private sector is encouraged to be aware of these matters up front and seek early, independent, expert advice.

In past decades, the NSW Government built and financed large-scale hydroelectricity projects. Today, the government supports a private sector-led energy market and is encouraging prospective investors to lead the required market change with sensible, commercially viable investments.

The Handbook for Large-scale Hydro Energy Projects has been produced to bring together the key matters that proponents seeking to carry out development should be aware of when approaching new projects. The information in the Handbook is based on projects with a capital investment value of \$30 million or more, which is likely to be the case for pumped hydro.

The NSW Department of Planning and Environment (the Department) recommends that proponents seeking to carry out development seek independent, expert advice, including legal advice, early in the development process and contact the relevant government departments and agencies well before submitting applications for the relevant approvals. The Handbook provides general and high-level information, but as the circumstances of each project will differ, it should be taken as a starting point only.

Broadly there are three processes that proponents of pumped hydro projects will need to undertake, although projects may be subject to additional requirements.

Planning assessment process

The land-use planning process for large-scale hydro energy projects in NSW is governed by a range of laws and related instruments, including environmental planning instruments. Applicants are responsible for securing access to the site, identifying the nature and likely cost of their proposed project, as well as identifying the correct planning assessment pathway.

Further information about planning assessment is available at www.planning.nsw.gov.au.

Critical matters for proponents of large-scale hydro projects to determine include:

- Is the project 'development' or 'infrastructure'?
- Who is the proponent/applicant?
- What is the purpose (in a planning sense) and location of the project?
- What is the project design?
- Is the project permissible?
- What planning assessment pathway should be followed?
- Does the project impact any Matters of National Environmental Significance?
- Are any works required that impact on the environment?

Many large-scale hydro energy projects in NSW are likely to be either State Significant Development (SSD) or State Significant Infrastructure (SSI), due to their capital value typically exceeding \$30 million or because they will be carried out by a public authority. Whether a project is SSD or SSI also depends on its permissibility, as defined by applicable environmental planning instruments.

Securing access to land

Anyone proposing to build a pumped hydro project will need access to land for the project site, water pipes and transmission lines. Land access can be secured by either purchase, easement, lease, licence, or option depending on who currently owns the relevant land. Landholder consent is also likely to be a requirement for any development application.

If the relevant land is privately owned, access can be secured by direct commercial negotiations with the landholder. More consideration is needed if any part of the land required is a national park, Crown Land, land managed or owned by state-owned corporations such as WaterNSW and Forestry Corporation of NSW, or land previously used for mining or industry.

Securing access to water

Pumped hydro project developers will likely need readily available water to operate their project. In order to access water for a project, developers may need a number of separate licences or approvals depending on the characterisation of the development and whether or not the development is SSD or SSI. These may include:

- A water access licence (WAL) that entitles the holder to extract water from the water source, a water use approval that entitles the holder to use water for a particular purpose at a particular location, a water management work approval or an activity approval;
- An allocation of water to the licence, that defines the volume of water that can be extracted from the water source; and
- Approval to construct required infrastructure to extract and use the water. This can be obtained through application to WaterNSW or the Natural Resources Access Regulator (NRAR), or through the SSD or SSI planning assessment process.

Further detailed information is contained in the Handbook, see: www.energy.nsw.gov.au/clean-energy-initiatives

Water access licences (WAL)

A WAL confers an entitlement to a share of available water in a source under a water sharing plan, and an entitlement to take water at a specified time and place. It is generally a tradeable right and can have multiple joint owners.

NRAR manages applications for certain large-scale projects and projects proposed by government agencies, see: www.industry.nsw.gov.au/natural-resources-access-regulator

For smaller projects and non-SSD projects, applications for a new zero-share WAL are managed by WaterNSW. All applications relating to transferring, subdividing, assigning rights under or amending a WAL are managed by WaterNSW, see: www.waternsw.com.au/customer-service/water-licensing

A water broker can identify available WALs, or allocations, and facilitate trading, see: www.awba.org.au

(note: The Department does not endorse particular brokers listed)



Cordeaux Dam, WaterNSW

Glossary

AEMO	The Australian Energy Market Operator (AEMO) is responsible for operating Australia's largest gas and electricity markets and power systems including the National Electricity Market (NEM) in Australia's eastern and south eastern seaboard and the Wholesale Electricity Market (WEM) in Western Australia.
ARENA	The Australian Renewable Energy Agency (ARENA) supports the development of local renewable energy technology. It provides funding to researchers, developers and businesses that have demonstrated the feasibility and potential commercialisation of their renewable energy project.
Finkel Review	The 2017 report into the Future Security of the National Electricity Market, commissioned by the Federal Government and carried out by Australia's Chief Scientist, Dr Alan Finkel.
Hexagon	Each hexagon in the Opportunity Map represents has an area of 115km ² and a diameter of 12km across.
ISP	The Integrated System Plan (ISP) is a 2018 report recommended by the Finkel Review and carried out by AEMO which makes projections on Australia's energy needs during the next 20 years and suggests cost-based transmission responses. AEMO is expected to release new versions of the report annually.
NEM	The National Electricity Market (NEM) is the agreement for the connection of electricity transmission grids (interconnectors) for Australia's eastern and south-eastern states and territories to create an interstate electricity market.
NSW Energy Security Taskforce	A 2017 taskforce set up by the Minister for Energy and Utilities and chaired by the NSW Chief Scientist and Engineer to advise on the resilience of the NSW electricity system and provide recommendations on areas of vulnerability.
Social Licence	The level of approval by local communities and local stakeholders of companies that are planning developments.
Watt	A unit of power that represents one joule per second. A kilowatt is one thousand watts, a megawatt is one million watts, a gigawatt is one billion watts, and so on.
Watt hour	A measure of power expenditure of one watt for one hour. A kilowatt hour is one thousand watts expended in an hour, a megawatt hour is one million watts expended in an hour, a gigawatt hour is a billion watts expended in an hour, and so on.

Appendix A: Method for identifying NSW opportunities

The opportunity map was developed over six phases. First, analysis of the NSW topography by Australian National University (ANU) generated a total of 53,000 potential upper and lower reservoirs that could be constructed with either a 10m or 40m dam height. These two dam heights were chosen to reduce time constraints, while still including the 10m dam height more suitable for turkey nest style dams, especially in areas with existing reservoirs. Of these 53,000 reservoirs, 20,000 of them could potentially be paired to create viable pumped storage schemes. The other 33,000 reservoirs were ruled out by a height to penstock ratio of 1:15. From the 20,000 individual reservoirs, a total of 122,000 possible schemes through different combinations were identified by the ANU analysis. The total number of possible schemes was reduced further by eliminating those that were impractically close to existing infrastructure, such as highways.

Second, the resulting reservoirs and the possible schemes ('paired reservoirs') were overlaid with publicly available and government geographic information system (GIS) datasets, to undertake a constraints analysis. The purpose of this constraints analysis, or multi-criteria analysis (MCA), was not to assess the viability of any one reservoir pair, but rather as a macro-level, comparative analysis of the large number of potential reservoir pairs.

Third, the separate reservoir locations identified were then assessed against the datasets using commercially available spatial analysis software. In general, each of the datasets was assessed by one of the following methodologies:

- Shortest distance between a reservoir and a feature (e.g. a road)
- Quantity and type of a feature contained within a reservoir (e.g. number of heritage sites)
- Area of a feature contained within a reservoir (e.g. tree cover)
- Value of feature at the centre-point of the reservoir (e.g. rainfall).

Fourth, as part of the constraints analysis, eight minimum requirements, or 'show-stoppers', were then identified to establish the minimum technical, commercial and environmental conditions. These conditions were set to ensure the identified reservoir pairs would be suitable for large transmission-scale pumped hydro developments. The minimum requirements were:

- 1** A minimum head between the upper and lower reservoirs of 300m
- 2** A maximum slope 1:15 (height-to-penstock ratio)
- 3** A minimum reservoir size of 1GL
- 4** Exclusion of Biophysical Strategic Agricultural Land
- 5** Exclusion of National Parks
- 6** Exclusion of World Heritage Sites
- 7** Exclusion of reservoirs within 50m of rail infrastructure, motorways and primary roads, and residential areas
- 8** Exclusion of reservoirs which overlay with Named Waterbodies

The full MCA included a total of 36 different constraints, combined into 11 criteria, which formed the comparative analysis of the reservoir pairs provided by ANU. These 11 criteria were given a possible score of 0-2, with 2 being the highest score and 0 being the least favourable. The data ranges within each of the criteria scores were determined using mainly a k-means clustering approach. This uses an iterative approach to find the optimal number of data classes, and their sizes in a way which represent the natural range of the data.

Finally, to map the comparative level of opportunity across the State, all paired reservoirs were allocated into hexagon cells, with a diameter of 12km and are of around 115km², to show the average opportunity score visually across the State. The average opportunity scores range from 7 to 20 representing a spectrum of opportunity from strong to exceptional. For those areas with lower average opportunity scores these still represent high-quality opportunities. Based on the distribution of paired reservoirs the six clusters were identified in the North East, Upper Hunter, Central West, Shoalhaven, Riverina and South East.

Appendix B: List of datasets used in mapping analysis

No	Analysis Layer	Source	Description
1	Reservoir Outlines	Australian National University	Outlines of the potential reservoirs identified by the Australian National University
2	List of reservoir pairs	Australian National University	The list of reservoirs that could potentially be paired to create viable pumped storage schemes

No	Scoring Layer	Source	Description
1	Statewide Geology	Geoscience Australia	Surface geology for NSW on a 1:250,000 ratio
2	Roads	NSW Spatial Services	Location of roads across NSW
3	Railway	NSW Spatial Services	Location of railways across NSW
4	Strategic Agricultural Land	NSW Department of Planning and Environment	Outlines of strategic agricultural lands, as identified by the State Environmental Planning Policy
5	Named Watercourses	NSW Spatial Services	Outline of Named Watercourses across NSW
6	WaterNSW Storages	NSW Office of Environment and Heritage	Outline of WaterNSW water assets across NSW
7	NSW Coastline	Open Streetmap	Outline of the NSW coastline
8	Elevation	SRTM4-1	Topographic data obtained by the NASA Shuttle Radar Topography Mission
9	Annual Decadal Rainfall	Bureau of Meteorology	Average annual rainfall data from 1996-2005
10	Annual Evaporation	Bureau of Meteorology	Average annual evaporation data per annum based on records 1975 to 2005

11	Powerlines	NSW Spatial Services	Outline of transmission powerlines of 132kV and above from across NSW
12	Land Zoning	NSW Department of Planning and Environment	Outlines of Local Environmental Plan land zones from across NSW local government areas
13	Land Zoning	NSW Department of Planning and Environment	Outlines of State Environmental Planning Policy land zones across NSW
14	Critically Endangered Species	NSW Office of Environment and Heritage	Outlines of where critically endangered species have been reported
15	Endangered Communities	NSW Office of Environment and Heritage	Outline of where critically endangered communities have been reported
16	Wild River Catchments	NSW Office of Environment and Heritage	Catchments of declared wild rivers in NSW under the <i>National Parks and Wildlife Act 1974</i>
17	Important Wetlands in Australia	Commonwealth Department of the Environment and Energy	Outline of the Important wetlands across NSW
18	Australian Marine Parks	Commonwealth Department of the Environment and Energy	Outline of Australian Marine Parks across NSW
19	Ramsar Wetlands	NSW Office of Environment and Heritage	Outline of Ramsar wetland designations across NSW
20	World Heritage NSW	Commonwealth Department of the Environment and Energy	Outline of World heritage designations across NSW
21	Aboriginal Places	NSW Office of Environment and Heritage	Outline of Aboriginal assets across NSW
22	Aboriginal Co-Managed Areas	NSW Office of Environment and Heritage	Outline of indigenous and co-managed conservation areas across NSW
23	Aboriginal Reserves	NSW Office of Environment and Heritage	Outlines of Aboriginal reserves across NSW
24	National Heritage List Australia	Bioregional Assessment Programme	Outline of areas in NSW designated under the National Heritage List Australia

25	Commonwealth Heritage List Australia	Bioregional Assessment Programme	Outline of areas in NSW designated under the Commonwealth Heritage List Australia
26	Local Heritage	NSW Department of Planning and Environment	Outline of heritage features listed as part of Local Environmental Plans (LEP) from across NSW local government areas
27	State Heritage	NSW Department of Planning and Environment	Outline of heritage features listed as part of the State Environmental Planning Policy (SEPP)
28	European Sites	NSW Office of Environment and Heritage	Outline of European Heritage sites across NSW
29	Koala Habitats	NSW Office of Environment and Heritage	Outline of koala habitat areas provided by various local government areas
30	Biocertifications	NSW Office of Environment and Heritage	Outline of areas where species covered under the <i>Threatened Species Conservation Act 1995</i> have been reported
31	Travelling Stock Routes	NSW Office of Environment and Heritage	Outlines of the parcels of Crown Lands reserved under legislation for use by travelling stock across NSW
32	Coastal and Litoral Rainforest	NSW Department of Planning and Environment	Outlines of the coastal and litoral rainforest across NSW, protected under the State Environmental Planning Policy
33	Tree cover	Geoscience Australia	Dynamic Land Cover which presents land cover information across Australia on a 250m grid
34	CLUM Code	Department of Agriculture	Outlines of the Catchment-scale Land Use Management (CLUM) areas, as derived by the Bioregional Assessment Programme
35	CAPAD	NSW Office of Environment and Heritage	Outline of protected areas included in the Collaborative Australian Protected Area Database (CAPAD)

No	Regional Information	Source	Description
1	Water Availability	NSW Department of Industry, Lands and Water Division	Information on the status of regulated and unregulated water licences
2	Transmission Network Availability	TransGrid	Information on available transmission capacity as at September 2018
3	Climate Conditions	NSW and ACT Regional Climate Modelling (NARClIM)	Information based on high resolution climate change projections generated from four global climate models dynamically downscaled by three regional climate models
4	Aboriginal Heritage	NSW Office of Environment and Heritage	Information on heritage and culture of Aboriginal communities in the local regions
5	Brownfield Land	NSW Department of Planning and Environment	Outlines the brownfield items in a given locations, such as industrial sites and historical mines.
6	Geology	Arup	Expert advice on the local geology







energy.nsw.gov.au