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Reducing Emissions While Maintaining Energy Security: Hydropower or Carbon Capture & Storage?

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Abstract

Climate change will present Australia with a number of serious social, environmental, and economic challenges. How to use energy more efficiently and environmental-friendly in the future is a gradually emerging problem. The increased penetration of renewables, coupled with an ageing fleet of coal-fired generators, poses the question of where future investment should lie. Hydropower, especially pumped hydroelectric storage (PHS), has the potential to be integrated with wind and solar PV generation to provide a secure and reliable grid at a low cost and with minimal environmental impacts. The cost of Carbon Capture and Storage (CCS) seems uneconomical due to uncertainty surrounding the future of coal-fired generation, and there are concerns about the safe long-term storage of captured CO2. Based on our research, we recommend focusing investments in hydropower and discouraging the future development of CCS plants. This could be a partial solution to alleviate the energy problem to some extent.

Keywords

Carbon Capture and Storage, Energy Security, Energy Problem

1. Introduction

Climate change will present Australia with a host of social, environmental, and economic challenges. One of the most polarising issues is the transition to renewable energy as a solution to providing all Australians with access to clean. This report will explore why the government and industry should invest in renewable energy sources such as hydropower in combination with wind and solar PV to stabilise our energy network. It will also examine why the government should be challenged to invest in short-term solutions to reducing Australia's emissions, such as CCS, which relate to the cost of implementation and unknown environmental impacts of using this system [1].

2. Hydropower Technologies

Hydropower plants can be large or small scale. Table 1 shows the generation capacities of different-scale plants. Large-scale plants are generally built by damming rivers and other huge water bodies, while small-scale plants are installed in streams or lakes [2].

Both large and small-scale plants can be operated by using run-of-river systems or pumped storage. Pumped Hydroelectric Storage (PHS) is a relatively new technology with enormous potential for energy storage. Water is pumped from a lower water reservoir to an upper reservoir and stored there. In this case, water can be used repeatedly [2].

Table 1. Capacities of different scales of hydroelectric plants [3]

Hydro Category	Power Range	No. of Homes Powered
Pico	0 kW – 5 kW	0 – 5
Micro	5 kW – 100 kW	5 – 100
Mini	100 kW – 1 MW	100 – 1,000
Small	1 MW – 10 MW	1,000 – 10,000
Medium	10 MW – 100 MW	10,000 – 100,000
Large	100 MW+	100,000+

3. Current Utilisation of Hydropower Generation

Hydropower accounts for 16% of the electricity produced around the world. China, Brazil, Canada, and the USA are currently the major producers [2].

The gross theoretical potential for hydropower in Australia is 265 TWh/year, based on geography and rainfall patterns. Taking into account current technologies, 60 TWh/year of this gross theoretical potential is technically feasible in Australia. Of this technically feasible potential, 30 TWh/year is economically feasible i.e. can be harvested without an economic loss. Only 60% of this potential is already being exploited [2].

In 2014, Australia had a total of 124 hydropower plants and in 2011-2012, Australia's hydroelectricity generation was 14.1 TWh. Tasmania generated 65% of total hydropower electricity, NSW and the ACT 26.9%, Victoria 7.5% and Queensland 5.1%. This amounted to 5.6% of the total electricity produced in Australia [2]. Figure 1 shows the distribution of medium to large-scale hydroelectricity plants across Australia.

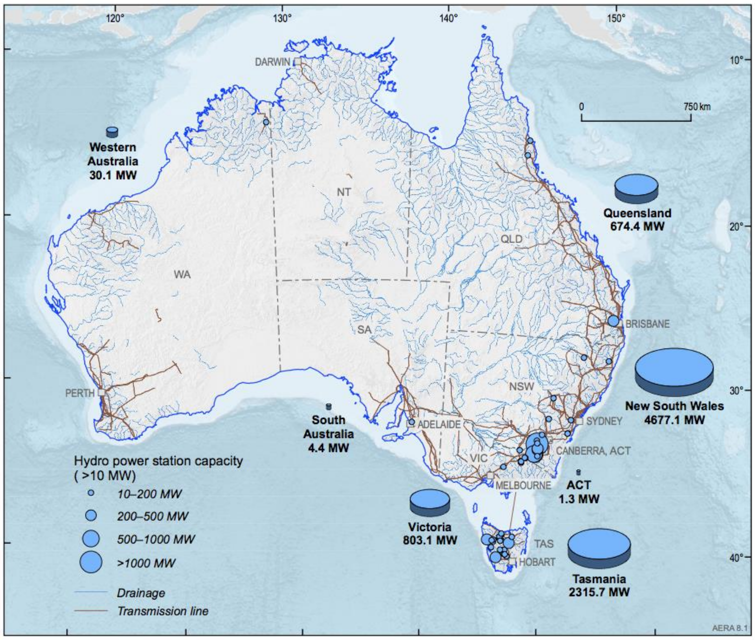

Figure 1. Major Australian hydroelectricity plants with 10 MW or more capacity [2].

4. Carbon Capture and Storage Technology

The aim of CCS is to capture CO2 emissions from fossil fuel electricity plants and transport them to a safe, feasible geological site where they are then deposited underground so that they do not enter the Earth's atmosphere. As of

2016, there were fifteen large-scale projects operating worldwide across a range of applications, including coal-fired power generation, with six more expected to commence in 2017-2018 [4].

5. Current Utilisation of CCS

There are no CCS projects currently operating in Australia; however, the Gorgon Project in the Greater Gorgon Area gas fields in Western Australia was completed in 2017 [5]. However, [6] reports that because of delays due to leaking valves, the site is not expected to commence injection until early 2019.

6. Potential for Hydropower Generation in Australia

The potential for hydropower generation in Australia largely varies according to the type of project. The primary options are as follows:

6.1 Small to medium-scale hydro plants

In 2014, there were 65 small-scale hydropower plants (less than 10MW) in Australia with a combined capacity of over 175MW. Recent and ongoing projects include [2]:

- Construction of six mini-hydro plants with a total capacity of 7MW for Melbourne Water
- Australia's first hydropower plant generating electricity from wastewater at Sydney Water's North Head wastewater treatment plant, with a capacity of 4.5MW
- A 14.4MW hydropower plant at Jounama Dam operated by Snowy Hydro
- Stanwell Corporation's 37MW Burdekin project in Queensland.

6.2 Refurbishment of existing large-scale plants

There is limited potential for new large-scale hydro plants in Australia; however, upgrading and refurbishing existing plants can improve efficiency and prolong operational life. Ongoing projects include [2]:

- A $300 million investment in refurbishment and maintenance for the Snowy Hydro Scheme. The upgrade will gain up to 40MW capacity.
- Refurbishment of the Lake Margaret power station in Tasmania. The upgrade will gain 8.4MW capacity.
- A $60 million modernization of the Tungatinah plant, Kaplan turbine program and Rowallan Dam by Hydro Tasmania.

6.3 Pumped Hydroelectric Storage

Australia has many potential sites for PHS. Table 2 shows 22,000 sites found in an initial survey by [7]. Each site has an energy storage potential between 1 and 200GWh and none of these sites are in national parks or urban areas.

Table 2. Potential PHS sites in Australia, as of 2017 [7]

	Approximate number of sites	**Approximate energy storage capacity (GWh)**	**Minimum head (m)**
NSW/ACT	8600	29,000	300
Victoria	4400	11,000	300
Tasmania	2050	6,000	300
Queensland	1770	7,000	300
South Australia	195	500	300
Western Australia	3800	9,000	200
Northern Territory	1550	5,000	200
TOTAL	**22,000**	**67,000**	

7. Potential for Carbon Capture & Storage in Australia

Most CCS schemes and projects in Australia remain in the research phase. Some of these include:

- Southwest Hub CCS—a CCS proposal for the Lesuer Sandstone formation of Western Australia [8].
- Western Australian Energy Research Alliance—received a $48.4m grant from the government in 2012 to establish a National Geosequestration Laboratory [9].
- Coal 21 ACA Low Emission Technology—a fund started in 2003 that finances the demonstration and deployment of CCS technology [10].
- CarbonNet—A project researching the potential of integrating all CO2 points in the Latrobe Valley, Victoria via a pipeline, with injecting sites in Gippsland [11].
- Carbon Transport and Storage Company (CTSCo) Project—a project exploring the potential of the Surat Basin, Queensland as a future injection or storage site [11].

8. Environmental Assessment

8.1 Hydropower

Hydropower is a mature source of renewable energy and provides the following environmental benefits [2]:

- Low GHG emissions
- Provides irrigation to wildlife to sustain biodiversity
- Water storage can reduce vulnerability to local populations affected by drought

It is estimated that a small run-to-river plant will emit around 0.01 to 0.03 pounds of carbon dioxide equivalent per kwh. A case study of Bogong Hydro Power Station in Victoria showed that the plant is capable of saving 88,000 tonnes of GHG emissions per year [12].

The largest environmental cost of implementing hydropower as a renewable energy source is in the construction of the plants themselves, due to the use of concrete and steel. Once in operation, savings in CO2 and methane emissions that would be present in the production of coal, oil and gas indicates that this is a small cost [13].

8.2 Carbon Capture & Storage

CCS is typically said to be able to capture approximately 90% of CO2; however, research into the environmental impacts of CCS suggest that while it can be successful in reducing carbon emissions in the short term, its most substantial threat to the environment is leakages [14].

So far, the impacts of leakages after 10-20 years of carbon being stored underground have been managed. However, if leakage does occur, this could negate CO2 emissions reductions and the impact could be catastrophic [15].

An independent review concerning the proposed South West Hub CCS Project in Western Australia found limited industry stakeholder support, where none were prepared to underwrite liability for potential leakages [16].

Fossil fuel combustion releases a variety of GHG emissions. Some of the major gases, other than CO2 include Methane (CH4), Nitrous Oxide (N2O), Hydro fluorocarbons (HFC-23), Perfluorocarbons (HFC-32), and Sulphur Hexafluoride (SF6). The process of carbon capture and storage does not extend to these other gases [17].

9. System Security & Reliability

Hydro and coal-powered generation are both sources of synchronous baseload electricity. Synchronous generators provide natural inertia, which helps to maintain frequency and voltage stability within a network [18]. In contrast, intermittent technologies such as wind and solar PV do not inherently contribute to system strength [19] and therefore require complementary storage in the absence of synchronous generation.

Figure 2 shows the key services provided to system security by different technologies. As can be seen, synchronous generation such as hydro is fully capable of providing the whole range of required services.

Pumped hydroenergy storage (PHS) is the largest capacity grid storage currently available, typically able to supply continuously for up to 20 hours, depending on reservoir size [1, 2]. Snowy 2.0 will have the ability to operate continuously for seven days at full capacity with losses from pumping estimated at 24% [18].

In a widely distributed network, local storage can add resilience in case of transmission line failure and also provide essential complementary storage for wind and solar PV generation in the case of high renewables penetration [7].

Service description				Supply side		Network						Demand side		
				Centralised generation		Transfer between regions		Transfer within regions	Stabilising devices			Load	Decentralised resources	
System Attribute	Requirement	Service	Spatial level of need	Synchronous generator	Non-synchronous generator	DC interconnection	AC interconnection	Transmission and distribution networks	Grid reactor, grid capacitor, static VAR compensator	Static synchronous compensator	Synchronous condenser [1]	Large industrial, residential, commercial	Solar PV	Battery storage
Resource adequacy	Provision of sufficient supply to match demand from customers	Bulk energy	System wide	●	●	➔	➔	➔	○	○	○	●	●	●
		Strategic reserves	System wide	● [2a]	◐ [3a]	➔	➔	➔	○	○	○	●	◐ [3b]	◐ [3b]
	Capability to respond to large continuing changes in energy requirements	Operating reserves	System wide	● [2b]	◐ [3a]	➔	➔	➔	○	○	○	●	◐ [3b]	◐ [3b]
	Services to transport energy generated to customers	Transmission & distribution services	Local	● [4]	● [4]	●	●	●	●	●	●	● [4]	◐	◐
Frequency management	Ability to set frequency	Grid formation	Regional	●	◐ [5]	⇨ [5]	●	●	○	○	○	○	○	◐ [5]
	Maintain frequency within limits	Inertial response	Regional	●	◐ [6]	◐ [6]	➔	➔	○	◐ [7]	●	○ [8]	○	◐ [6]
		Primary frequency control	Regional	●	● [9]	➔	➔	➔	○	○	○	●	●	● [9]
		Secondary frequency control	Regional	●	● [9]	➔	➔	➔	○	○	○	●	●	● [9]
		Tertiary frequency control	Regional	●	● [9]	➔	➔	➔	○	○	○	●	●	● [9]
Voltage management	Maintain voltages within limits	Fast response voltage control	Local	●	●	●	○	○	●	●	●	●	◐	●
		Slow response voltage control	Local	●	●	●	○	○	●	●	●	●	◐	●
		System strength	Local	●	○	○	⇨	➔	○	○	●	○	○	○
System restoration	Ability to restore the system	System restart services	Local	●	◐ [10]	◐ [10]	●	➔	○	○	○	○	○	◐ [10]
		Load restoration	Local	●	●	●	●	⇨	●	●	●	●	◐	◐

1 This includes generators with ability to operate in synchronous condenser mode.
2a While many synchronous generators can provide energy reserves, some less firm technologies (solar thermal or pumped hydro storage) will be limited by the amount of energy storage they include.
2b While many synchronous generators can provide flexibility services, coal generators are limited in their ability to provide such services.
3a Limited by duration for which service can be delivered.
3b Limited by duration for which service can be delivered; existing controllability is limited.
4 The provision of local voltage support from generators and loads can improve the network transport capability near their respective connection points.
5 Grid forming power electronic converters are available and have been proven on small power systems. Development of grid forming converters for large power systems is an emerging area of international research.
6 Some fast frequency response capabilities can provide emulated inertia response, but are not yet proven as a total replacement for synchronous inertia.
7 Static synchronous compensators with energy storage devices are being trialled as an emerging provider of inertial response.
8 Except for load relief.
9 Includes fast frequency response capabilities.
10 System restoration services from variable non-synchronous generators is an emerging area of international research. If they are grid scale, batteries are likely to provide some system restoration support.

Ability to provide service		
●	◐	○
Fully capable	Partial or emerging	Unable
➔	⇨	
Enables delivery	Partial or limited delivery	

Note: Classifications are indicative of the general ability of each technology type. The extent to which technologies can provide each service must be assessed on the specifics of each individual system.

Figure 2. Summary of required system services, and capability of technologies to provide them [20].

10. Capital & Operating Costs

10.1 Hydropower

Figure 3 shows a breakdown of costs for hydropower. The main costs involved in hydropower relate to initial investment in infrastructure. For example, the projected cost for Snowy 2.0 is $3.8-4.5 billion [21]. However, compared with most other power generation methods, hydropower has lower operating costs.

	OECD	Non-OECD
Capital costs of hydroelectric plants (per KWh)	US$2400	below US$1000
Operating costs of hydroelectric plants (per KWh)	US$0.03—US$0.04	US$0.02—US$0.06

Figure 3. Capital & operating costs for hydropower [21].

The emergence of extreme climate conditions in Australia, changes in precipitation, supply of surface water, and competition for scarce water resources may increase the cost of hydropower development [2].

10.2 Carbon Capture & Storage

The operational cost of CCS will depend on fuel, specific technology, and plant location [14]. In most CCS systems, the cost of capture (including compression) is the biggest cost, with the additional cost of generating electricity from CCS coal-fired plants expected to be 20 - 70 US$/tonne of CO2 avoided [22].

The cost and feasibility of retrofitting CCS to existing power plants depend on site-specific factors such as plant size, age, efficiency and type. Additional factors such as physical constraints, and the potential need for upgrades or installation of additional equipment can also add to capital costs [14].

11. Discussion

Taking into account system security, emissions, cost, and potential, hydropower is well-positioned to provide reliable and affordable generation in line with Australia's emissions reduction commitments.

In the face of climate change, energy security will become an increasingly important factor in Australia's energy network. Australia is vulnerable to a host of natural disasters including bushfires, flash-flooding, drought, cyclones, and heatwaves.

CCS could act as a short-term solution to reducing CO2 and methane emissions produced by the remaining coal-fired power plants, but it would be both fiscally and environmentally irresponsible to allocate funding to a system that bears much uncertainty on its environmental impacts in the decades to come.

Unlike hydropower, which is considered a mature technology, scientists agree there is a lack of understanding around the risk of leakages of CO2 sequestered underground. As more coal-fired plants reach the end of their operational lives, coupled with uncertainty over a future investment, it does not seem financially viable to invest in CCS given its high cost of implementation.

12. Recommendations

It is strongly urged that no further investment in coal-fired power plants, nor CCS is backed by government or private investors. Instead, given the opportunities for social, environmental, and economic growth that can be brought about by hydropower systems across Australia, it is recommended that the following measures be taken:

- Government and industry to engage with the Clean Energy Finance Corporation (CEFC) to place a focus on providing green bonds for PHS projects in Australia.
- No further investment be made in retrofitting existing coal-fired power plants to facilitate CCS. This is based on the excessive cost of capital and environmental risks associated with the process.
- Establish a framework around ecology and biodiversity that will look to conserve surrounding ecosystems of new and existing hydropower plants to reduce any potential environmental impacts.
- Undergo consultation with industry to establish and develop locations for PHS across the east coast of Australia. This is based on the findings that 20 PHS sites would have the capacity to fulfil storage requirements.
- Run a campaign to engage with consumers on the environmental and cost benefits of hydropower.

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