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SUSTAINABILITY OF ENERGY SUPPLY AND RESOURCES IN NSW

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Committee on Environment and Planning

Sustainability of energy supply and resources in NSW

Recommendation

A 100% renewable electricity system be targeted in the interests of lowering water consumption due to electricity and improving energy security within NSW.

Please find appended to this cover letter a report investigating the current water consumption within the National Electricity Market, and the theoretical water consumption for a 100% renewable electric grid, as modelled by our research team.

D4.4(i): (Output 4) An analysis of potential STORES environmental and water consumption impacts

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Summary

Our analysis of the water consumption for a renewable electricity system shows that the environmental impact of STORES is likely to be very small, both absolutely and relative to other parts of the electricity industry, and a transition would result in less water being consumed for the provision of electricity. STORES sites are not like conventional hydroelectricity, where entire river valleys are dammed in order to provide seasonal storage – short term storage can be achieved with comparatively small dams, and therefore very small water consumption. As our search for suitable sites excluded national parks and other protected lands, but still found 22,000 good sites, only the most suitable few dozen would be needed to support a 100% renewable electricity system [1].

WATER CONSUMPTION IN THE ELECTRICITY INDUSTRY

Electricity generation in Australia is highly dependent upon water. This report will focus on the National Electricity Market (NEM) and will outline the multiple inputs for water for each form of generation, before demonstrating the positive change that could be unlocked by moving to clean, renewable power. A system built on wind and PV, supported by STORES, requires minimal water. Very few, relatively small reservoirs are needed, spread throughout the country. Many thousands of good off-river sites exist, so sites can be carefully selected to minimise problems with water (or environmental management) [1].

In determining the total volume of water “used” within the energy sector, the difference between consumption and withdrawal must be noted. Total water consumed will sometimes be much less than total water withdrawn, but the presence of sufficient volumes of water in the right condition can be critical for energy generation. Withdrawal refers to water that is removed from a reservoir with the intention of returning some or most of it to the environment at the end of a process. Water “usage” is not a helpful term in this context – in this report water will be described as consumed or withdrawn, except where quoting another work.

Table 1: Water consumption versus withdrawal

	Consumption	Withdrawal
Thermal power station with cooling tower	Water from cooling towers evaporates into atmosphere, water for ash & dust suppression	N/A
Thermal power station with once through cooling	Some cooling water evaporates from reservoir	Most cooling water is returned to reservoir
Pumped hydro energy storage	Initial fill water and top up water to replace evaporation loss is consumed, & not available for other processes	N/A

Hydroelectricity	Water lost to evaporation	Run of river hydro – water is diverted but returned quickly to the river

Coal

Coal power stations require water for their construction, everyday operation, and also in order to mine the coal itself.

Plant operation

Water is required for many processes within a coal power. The great majority of the water used on site is for cooling purposes, for example in a 1000 MW coal fired power station with 85% capacity factor and recirculated cooling, more than 75% of water consumption is due to cooling [2]. Although the Australian Bureau of Statistics (ABS) provides data on water consumption for the entire electricity and gas industry – which ranged from 288-384 GL from 2008-09 to 2015-16, most of which provided cooling for coal, this information is not provided specifically for the coal-fired power industry [3].

Electricity cannot be generated at a water-cooled thermal power station if sufficient water is not available. The high value of water to operation meant that the value of water for a coal-fired power station in 2007 was $14 -18,000 per ML, whereas the wholesale cost of water at that time was $1,500 per ML [2]. Water access can also affect project financing, due to potential risk [4].

In 2009, the Waterlines [2] report stated that many thermal power stations had already implemented changes that resulted in a 15% decrease in water consumption per MWh of electricity, due to the high cost of water. Further large water savings are only technically possible for new-build stations. These systems use direct, indirect or hybrid dry cooling – but the majority of coal power stations in Australia use open - or closed-cycle wet cooling [2].

Dry cooling can result in a 90% decrease in the water consumption, but these power stations produce less electricity per unit of fuel consumed, and higher carbon dioxide emissions per unit fuel [2]. Alternate sources of water could also lower freshwater consumption within coal-fired power systems, but each of these have problems. Possibilities include: seawater cooling, purified waste water, coal seam gas water, and desalination. The water used within the plant must be purified so that salt build up does not occur, particularly in the boiler – thus, more electricity is needed to purify any waste water used within the plant. The water cost and source for coal-fired power stations are determined during the planning stage – changing to one of these alternatives would probably mean higher associated costs and lower sent out electricity generation [2].

The temperature of the water used for cooling impacts the thermal efficiency of the plant – the higher the intake water temperature the lower the thermal efficiency [5]. There have been thermal power plants that have needed to be shut down due to the temperature of the cooling water body being too high [6], [7]. Water shortages caused by drought in Queensland in 2008 meant that 800 MW of coal-fired capacity could not be used [8].

Several coal-fired power stations use saline or seawater for cooling purposes, including Gladstone, Vales Point, and Eraring [2]. Currently decommissioned plants in the NEM that used sea or salt water included Munmorah [2] and Wangi [9] in NSW, Northern and Playford B in SA [10]. These plants do not consume freshwater, but the withdrawal does affect a broader ecosystem. Regardless, as this study is investigating freshwater consumption, the saline and sea water from these plants will be removed from the total results.

Mining and Processing

Water is required in coal mining. In 2015-16, coal mining in Australia consumed 136 GL [11].

Although black coal can be used with minimal processing, often it is washed in order to remove ash, rock and minerals – improving overall quality. Washing requires "immersing the crushed coal in a liquid of high specific gravity in which coal floats and can be recovered while the heavier rock and minerals sink and are discarded". The resultant waste is transferred to a tailings dam[12], [13].

Gas

Combined-cycle gas turbines (CCGTs) are amongst the most efficient of the thermal power plants, because higher thermal efficiency means less waste heat is generated. As expected, this lowers the water withdrawal and consumption requirements per megawatt-hour [14].

Natural gas production in the US increased by almost 40% between 2005 and 2015. The boom in production led to an increase in the number of gas-fired plants, some of which have been built with hybrid and dry cooling technologies, and also with access to alternative water supplies, such as reclaimed water. Coal-fired power plants have been displaced as a result. Overall, in the period between 2008 and 2014 there has been a drop in the total withdrawal of water, and also in the total consumption in the US [15]. In Australia, there has been no such boom in gas plant operation.

Conventional Hydroelectricity

Hydroelectricity has historically provided the major portion of renewables into the NEM, with 7% of the total energy generation during 2015-16. The arid climate of Australia which restricts the number and volume of rivers, along with the environmental damage that can occur when rivers are dammed, has led most people to believe that hydroelectricity cannot contribute much further to the generation mix. This is likely true for conventional hydroelectricity.

Diverting water from the natural flows of river systems has led to environmental problems. Competition within the Murray Darling Basin has led to tension between environmentalists, irrigators, and power generators.

These large water bodies also lead to water loss from evaporation. This needs to be accounted for in arid Australia and is managed in the design and operation stages. The Snowy Hydro operators have historically kept water levels at just 10% for the Tantangara Dam, because the above average wind in the area means evaporation is high for this shallow water body. Changes to the water system management now mean that the dam will now be kept at 20% [16].

Evaporation and Rainfall for Hydroelectricity and PHES

Pan-evaporation is measured using a metal cylindrical pan with a diameter of 1.2 metres. The rate of evaporation is dependent upon many factors. The small diameter, coupled with the exposed metal sides, mean that edge effects increase the evaporation from one of these containers when compared to the evaporation from a larger water body. This difference is commonly reported as 30% less evaporation in the real-world case[17], [18].

The purity of the water also impacts evaporation. The salt in saline water lowers evaporation rates [17]. Evaporation will vary by the year, and by the management of the water system.

Local conditions, including wind and incident solar, also affect evaporation. If a lake or lagoon is surrounded by wooded hills, evaporation will likely be lower than one surrounded by flat pastureland. The value for pan evaporation for different locations within Australia can be seen in Figure 1. Australia's major hydroelectric plants are located in Tasmania and the Alpine region near the NSW/Vic border – where evaporation rates are quite low. Given the dependence upon location, rather than using a generic value from the literature, evaporation from these specific systems has been calculated.

Tasmania has relatively low evaporation and high rainfall when compared with the rest of Australia, and so there are many natural and manmade water bodies that are used to power hydroelectric plants. The water bodies in the Snowy Hydro scheme are much smaller than those in Tasmania.

Evaporation suppression is generally not appropriate for conventional hydroelectric dams. Most of these have mixed uses, including swimming, boating, fishing, irrigation, environmental flows, and urban water supply. Typical suppression techniques mean that the public cannot use the water, and some can result in chemicals leaching into the water. There are some trials of floating solar collectors for evaporation reduction and cooler operation.

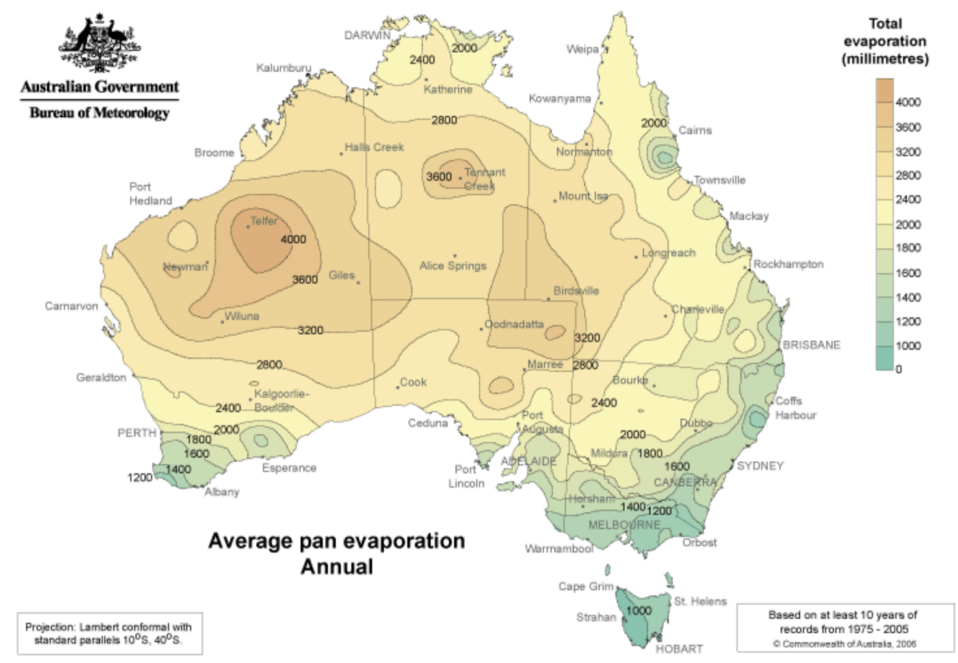

Figure 1: Average annual pan evaporation (larger image can be seen in Appendix) [19]

Pumped hydro energy storage

Water for STORES is consumed, because once this water has entered the closed system, (ideally) it will not be returned to the environment. Unlike many fossil-fuel systems, STORES require most of the water consumption up-front, before the plant can operate, but then requires only small volumes of water in order to keep the system running. These small top ups may not be necessary, depending upon the local rainfall and run off, and whether evaporation inhibitors are used. In order to model this initial water volume, the total was divided by the 50-year lifetime of the facility.

Evaporation suppression

There are many different types of evaporation suppressors. Most techniques work by eliminating air movement near the water surface, which blows away a humid boundary layer leading to further evaporation. These range from simple floating plastic containers, to chemical monolayers. Windbreaks can also be helpful in lowering evaporation. The simplest way to limit evaporation in a new water body is to design it so that it is deep and narrow so as to reduce wind speeds on the reservoir – but this is not always possible. Trees can reduce evaporation by up to 20% – but if they are planted too close to the reservoir, they may use the water themselves.

Chemical monolayers are one of the simplest forms of evaporation suppression. These chemicals form a layer on top of the water and reduce evaporation by up to 40%. Unfortunately, they are not a long-term option, as the monolayer itself is broken down by bacteria. They are also strongly affected by the weather. Wind and waves will easily disturb a monolayer [20].

Suspended shade structures can provide up to 75% reduction in evaporation. Structures can be used whether the water body is full or empty. Installation can be difficult if the surrounding soil is of low quality. These structures can also be damaged in high winds [20].

Floating Covers: There are many different floating cover products on the market. Manufacturers claim evaporation reduction rates of close to 100% – but rarely provide information on independent trials. Completely closed covers would entirely remove evaporation, but also stop rain water from entering the catchment. If the reservoir is at risk of drying out, the floating cover must be removed as it could become bogged down. Depending upon the material used, algal bloom can also be eliminated. The effect of high wind is also product dependent [20].

Evaporation suppression can be achieved through plastic balls. Dark plastic is more resistance to UV light, which increases the useful lifetime of the product, although results in greater solar heating of the water. These balls need to contain ballast material to prevent the balls from being blown away in the wind and becoming litter. Covering a reservoir with plastic balls blocks out all light which means algae cannot grow, and birds and animals are unlikely to drink from the reservoir. Plastic balls were used in California on several reservoirs in order to prevent bromate from forming due to the interaction of sunlight with bromide and chlorine [21]–[23].

Plastic balls are produced from HDPE. Although using black HDPE rather than lighter colours increases the lifetime of the product, all plastics are expected to eventually breakdown. Still as the water in a pumped hydro system is cycled, and is not released to the environment, this degradation is less problematical. Periodic replacement of the balls is indicated [24], [25].

Floating solar PV panels could be used for conventional hydroelectric dams. Particularly on the largest dams, these would provide evaporation suppression by interrupting the flow of wind, and the dam could provide a good location for solar generation. A well-placed array would have no shading, and lower operational temperatures due to the water. Land would not need to be repurposed for this solar array. Lismore Council and Goulburn Council have both installed floating solar arrays on water bodies. However, these were on drinking water and waste water reservoirs, rather than reservoirs that are available for public use. For STORES systems, the large daily and seasonal cycling of the reservoirs (from nearly empty to full) means that floating PV might be impractical.

Bioenergy

Bioenergy currently provides 2% of the generation within the NEM. The feedstocks used in 2015-16 included bagasse, wood and wood waste, municipal and industrial biomass waste, sulphyte lyer (black liquor) and biofuels, landfill biogas and sludge biogas. Bagasse and landfill biogas were used to produce 75% of the total energy from biomass. Apart from wood, each of these biomass products are waste products, and so the water associated with growing crops and collecting them does not need to be included in the electricity generation water footprint. The operational water consumption is generally similar to any thermal power plant. There are some bioenergy plants that burn fuel in open cycle gas turbines to produce electricity directly, with no steam required.

It is likely that the bioenergy market will continue to grow slowly. Bagasse waste is by no means exhausted, and landfill biogas is particularly cost competitive [26].

Large-Scale Photovoltaics

Although many companies now offer photovoltaic cleaning services, or even the installation of automatic cleaning systems [27], companies operating within Australia have discovered that there is no need to wash modules, and that energy losses from dirt have been in the range of 1%, depending upon location.

Small-scale photovoltaics

A well designed residential solar system should be installed so that normal rainfall will keep panels relatively clean over the course of the year. Ideally, there won't be any overhanging objects upon which birds can perch and so increase the need for cleaning. Water consumption for cleaning residential and business solar panels is difficult to ascertain, and rather than being counted within the total industrial water used for electricity and gas, as the ABS does now, this would be included within urban water consumption.

Wind

Wind turbines do benefit from washing as a part of routine maintenance. This does not require significant volumes of water.

Water for Generation Technologies

The Australian Bureau of Statistics provides a breakdown of electricity generation by source from 2008-09 onwards. These values were used to model water use in the baseline electricity system.

In order to model a renewable energy scenario for the National Electricity Market, hourly historical demand data was combined with historical wind and solar data to find the lowest cost generation mix that fulfilled the NEM stability requirement. The original model provided information for the period 2005-10, but as the ABS provides information from 2008-09 onwards, only two years of the renewable scenario have been included below [28]. This system made use of legacy conventional hydroelectric and bioenergy plants – however, although this model assigned bioenergy to provide 887 and 1147 GWh for 2008-09 and 2009-10 respectively, it is likely that owners of biomass plants will exhaust their supply each year rather than save feedstocks for the future. More information on this model can be found at this reference: [29].

Values for the water footprint (WF) of these technologies, that is, the volume of water required per unit of energy, were found in the literature. These values can be found in Table 2 below. The following section describes the method used to calculate the water consumption for each technology. The water footprint for some of these technologies has been calculated for the Australian context.

Coal

The water footprint for the operation of coal-fired plants was taken from Table 2. As discussed above, some black coal-fired power stations use either saline or seawater for cooling purposes. As this study is investigating freshwater, but operational data aren't available for the individual plants, the total energy output was lowered by a scaling factor of 24%, according to the capacity of the plants that use salt water and dry technology for cooling. These plants do use freshwater for other purposes. Dry cooling is used for 12% of coal capacity in the NEM, and salt water for 18% of capacity.

Coal as fuel is also required. As discussed above, this fuel has an additional water footprint. The fuel factor from Table 2 was used to determine this water consumption.

Gas

Water consumption for open cycle gas turbines (OGCTs) and CCGTs is taken from Table 2. OCGT does not require cooling water. Gas also has a factor in the fuel supply line, taken from the same Table.

Conventional Hydroelectricity

The ABS do not define water use in conventional hydroelectricity as “consumption” because the water is returned to the environment [3]. However, creating huge reservoirs results in water loss to evaporation. These reservoirs are often used for many other purposes, some of which would not be available had the systems not been constructed. These uses include environmental flows, fishing, water sports, the associated services to tourists, water storages for irrigation, and urban water supplies. Rather than apportion the water loss to evaporation to each of these uses, we present the full loss in the table below.

Evaporation will vary by the year, and by the management of the water system. Pan evaporation levels across Australia can be seen in Figure 1. As discussed above, a scaling factor of 70% was used to convert the pan evaporation to real-world levels.

Hydroelectric plants in Australia are mostly located within the Snowy Hydro systems in NSW, Victoria and Tasmania. These areas are characterised by lower than the national average evaporation.

Snowy Hydro publishes information detailing the height and the total capacity of the dams within the system. This information is shown in Table 5 in the Appendix. Information about the long-term average level of Lake Eucumbene, which is currently 59% of gross capacity, and the level of Lake Tantangara, which will now be held at 20%, is also provided [16]. These data do not allow the area of the dams to be calculated, particularly given the irregular shape of many of the dams.

Google Earth provides some historical imagery. Unfortunately, the period 2008-09 and 2009-10 used in this model is not included in the available imagery of many water bodies in the scheme – the available information is tabulated below, in Table 6 and Table 7. This information is important for this model, because the evaporation depends upon the surface area of the water body, but the plant operators are generally more concerned with the lake level presented as a percentage. Although the official surface area of Lake Eucumbene is 14,542 hectares, the April 2011 historical image shows the lake was closer to 7,300 hectares.

Tasmanian Hydro provides information on lake levels, but many of the water bodies in this system are very small, and official data is not publicly available. Google Earth was used to find the surface area of these dams.

Once the total surface area of the water bodies was determined, evaporation was found in each area by applying the relevant pan evaporation value. Given the lack of historical information, a single figure was determined for evaporation for both years. This figure was 14,901 m^3/TJ, which is comparable to the value from the literature of 15,100 m^3/TJ, found in Table 2.

PHES

The required PHES power demand of 16 GW and 31 hours of capacity was taken from the renewable model. These figures were entered into a simplified PHES calculator to find the appropriate reservoir surface area, which required values for the head (the altitudinal difference between top and bottom reservoir), and the average reservoir depth. These values were: head 400 m, average reservoir depth 40 m, area of combined reservoirs 3,350 ha.

22,000 potential upper reservoirs have been mapped throughout Australia, which are in some areas more than 1000 times the PHES installations that would be required to provide balancing services to a renewable electricity grid. Few sites would be needed, which means that only the best need be considered. A good installation will have large head, and low construction costs (these are determined by the morphology of the site). Higher dam walls are typically more expensive, but result in dams with less surface area per unit volume, and hence less evaporation.

The total water capacity of the PHES system must be sourced before the plant can operate. This water consumption was levelised over the 50-year lifetime of the system.

PHES plants are generally most appropriately sited when they are close to distributed power generation, and close to major transmission lines. Sites that match with the requirement of a large altitudinal difference are found along the Great Dividing Range. The pan evaporation value for this region was used to determine PHES evaporation, along with the correction factor.

Evaporation suppression was also included in this model. For more information on the suppression methods, please see below. The following chart shows the annual theoretical evaporation and the yearly component of the initial fill, for the entire PHES fleet.

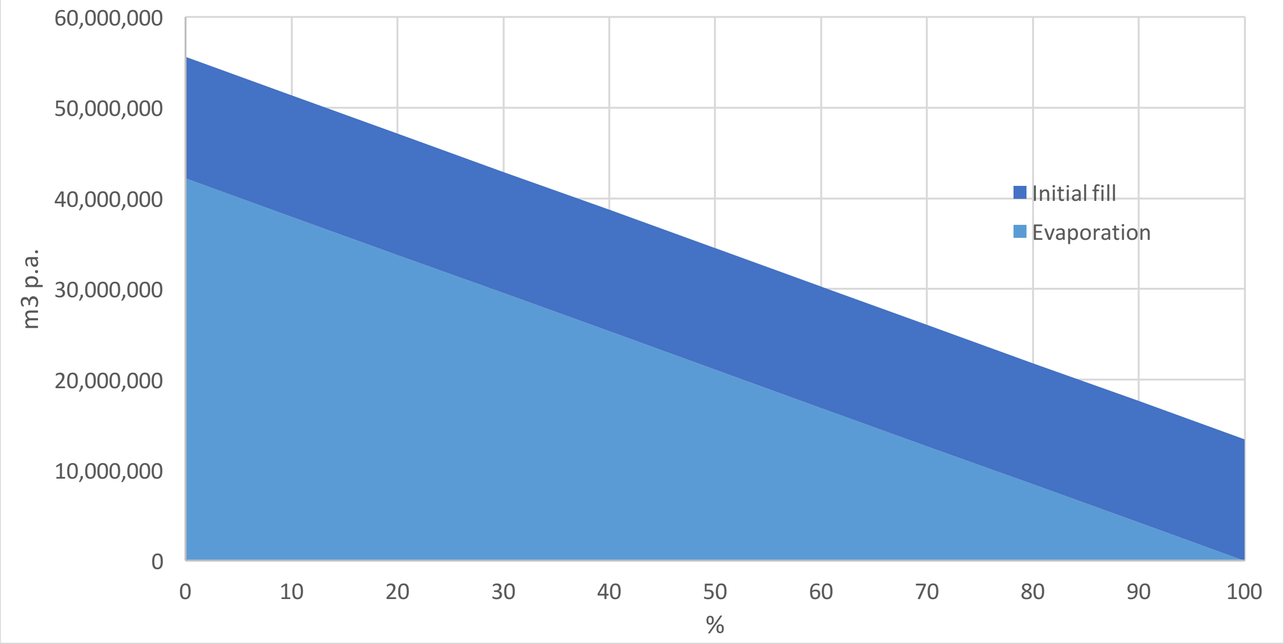

Figure 2: Evaporation and distributed initial fill per year for different levels of evaporation suppression

Evaporation suppression is rarely perfect, and so only levels up to 90% have been modelled.

Bioenergy

The great majority of feedstock used for bioenergy in Australia comes from waste material, such as cane sugar waste, landfill gas, or sewage gas. As such, there is no additional water consumption for the fuel. Bioenergy plants in Australia either use steam turbines, or simply use the gaseous fuel in a gas turbine.

Photovoltaics

ABS data were used to determine the energy generated from PV in the baseline model, and the renewable scenario generation was taken from [29]. As mentioned in the section above, some commercial solar farms in Australia do not wash their panels, as overall losses are not enough to warrant the expense. Water to wash residential PV is difficult to ascertain – some owners set and forget, whereas others may wash carefully on a schedule. This consumption would be attributed to urban water use. Regardless, the water consumption for both small- and large-scale PV has been included in this study – calculated using the operational factor in Table 2. These values are the median values taken from data encompassing many different studies, and which had very large ranges. Given that the majority of solar globally is installed in East Asia and Europe [30], which have different hydrological and pollution conditions than Australia, this result will be higher than that of an Australian solar farm water consumption. The water for PV remains much lower than that for any fossil fuel.

Wind

Wind turbine maintenance includes washing – the operational factor in Table 2 was used to calculate the total consumption.

Table 2: Consumptive water footprint (m^3 per TJ) for electricity and heat generation, over the period 2008-12 [31],[34]

	Firewood	Hydropower	Nuclear	Oil	Coal and lignite	Geothermal	Natural gas	Solar	Wind
Operation	400	15,100	610	440	440	340	240	50	0.2
Construction	0.4	0.3	0.3	1.1	1.1	2.1	1.1	90	1.1
Fuel Supply	156,000	0	68	55	54	0	6	0	0

Table 3: Current fossil-centric system and associated water consumption [28]

	2008-09 GWh	2009-10 GWh	2008-09 m^3 water	2009-10 m^3 water
Non-renewable fuels				
Black coal	118,533	114,112	165,736,883	143,600,744
Brown coal	56,981	56,068	101,335,722	99,711,865
Natural gas	21,231	26,447	18,802,085	23,421,109
Oil products	884	615	1,575,644	1,096,286
Other a	1,427	1,971		
Total non-renewable	199,056	199,213	287,450,334	267,830,004
Renewable fuels				
Bagasse, wood b	1,763	1,762	2,539,296	2,536,992
Biogas b	903	885	1,300,320	1,274,688
Wind	3,149	4,388	2,267	3,159
Hydro	11,869	13,549	720,267,800	720,267,800
Large-scale solar PV	-	-	-	-
Small-scale solar PV	136	363	24,552	65,340
Geothermal	1	1	612	612
Total renewable	17,821	20,947	724,134,847	724,148,591
Total	**216,877**	**220,160**	**1,011,585,181**	**991,978,595**

Table 4: Possible renewable system and associated water consumption [29]

	2008-09 GWh	2009-10 GWh	2008-09 m^3 water	2009-10 m^3 water
Renewable fuels				
Bioenergy	887	1,147	1,277,226	1,651,483
Wind	170,995	165,468	123,116	119,137
Hydro	17,891	20,348	720,267,800	720,267,800
Large-scale solar PV	12,525	12,586	2,254,469	2,265,486
Small-scale solar PV	22,805	23,139	4,104,840	4,165,059
Pumped hydro	16,537	16,200	55,599,041	55,599,041
Total	**241,639**	**238,888**	**783,626,491**	**784,068,006**
Total excl. legacy	**222,862**	**217,393**	**62,081,466**	**62,148,723**
Total excl. leg & incl. EvapSup			**24,099,952**	**24,167,210**

These figures can be compared with commercial water extraction from the Murray Darling Basin to demonstrate the scale of the change. The nominally sustainable extraction level of the latter is 11,000 GL per year [32], whereas the electricity system current system consumes 1,001 GL per year. The renewable option consumes 784 GL per year, most of which is evaporation from the existing hydro reservoirs. An Australian electricity system deriving 90% of its annual energy from PV and wind with PHES support consumes 62 GL per year (excluding existing hydro and bio). Including 90% efficient evaporation suppression on the PHES further lowers this to 24 GL per year. This is just 2% of the status quo.

OTHER ENVIRONMENTAL IMPACTS OF STORES

Environmental impacts of STORES include water consumption, alienation of land used for reservoirs, and the disturbances associated with pressure pipelines, feedwater pipelines, roads, power stations, switchyards and powerlines. The environmental impacts of STORES excluding water impacts is discussed in this section. It is not possible to be specific since the location of STORES systems is not presently known. However, a general analysis is presented.

The conclusion of our analysis is that the environmental impact of STORES is likely to be very small, both absolutely and relative to other parts of the electricity industry. Two important points inform this conclusion:

- We have excluded national parks and other land on the protected lands database (CAPAD) from our site searching
- We found 22,000 good sites, but only a few dozen would ever need to be developed to support a 100% renewable electricity system. This means that sites with small environmental impact can be selected, thus bypassing sites with larger potential environmental impact

Land use: The amount of energy storage required to support a 100% renewable electricity system is about 450 GWh [8]. This corresponds to a required area of reservoir of about 3600 Ha (calculated through the well-known equations for energy storage potential). This is a tiny fraction (5 parts per million) of Australia's landmass (769,000,000 Ha).

A renewable Australian electricity system based on 30% wind energy, 30% ground-mounted single axis tracking PV, 30% roof-mounted PV and 10% existing hydro and bio requires about 22 GW of wind turbines and 39 GW of single axis tracking PV systems (assuming average capacity factors 20% and 35% for ground-mounted single-axis-tracking PV and wind respectively). Land alienated by these systems is estimated as follows:

- Wind: 22 GW comprising 4,400 turbines with a rating of 5 MW each. Each turbine directly alienates a 500 m^2 block of land, plus a 4 m wide, 1000 m long access road, giving a total of 2,000 Ha
- Ground mounted PV: 39 GW of 20% efficient panels requires 1 Ha per 2 MW of panel. Allowing spacing of 3:1 between the panels means that the required land area of about 1.5 Ha per MW, or 59,000 Ha per 39 GW although this land could have secondary agricultural use such as sheep grazing between the panels.
- Roof-mounted PV: no additional land is alienated
- STORES pumped hydro: 3,600 Ha

Thus, total land alienation of a 90% PV/wind/PHES electricity system is about 65,000 Ha, 90% of which is associated with the PV systems. This is a tiny fraction of Australia's land surface area (less than one part in 10,000). The area of hydroelectric reservoirs in the Snowy Mountains and Tasmanian systems is 134,000 Ha, which is about double this area.

Other impacts: Apart from land alienation and water use, the potential environmental impacts of PHES systems includes visual intrusion, weed and feral animal invasion along infrastructure routes, erosion, fragmentation of ecosystems, small alterations to waterflow on minor streams and drainage basins, and small noise generation from turbine/pump operation and vehicle access. Standard environmental and engineering controls can be used to minimise these impacts.

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Appendix

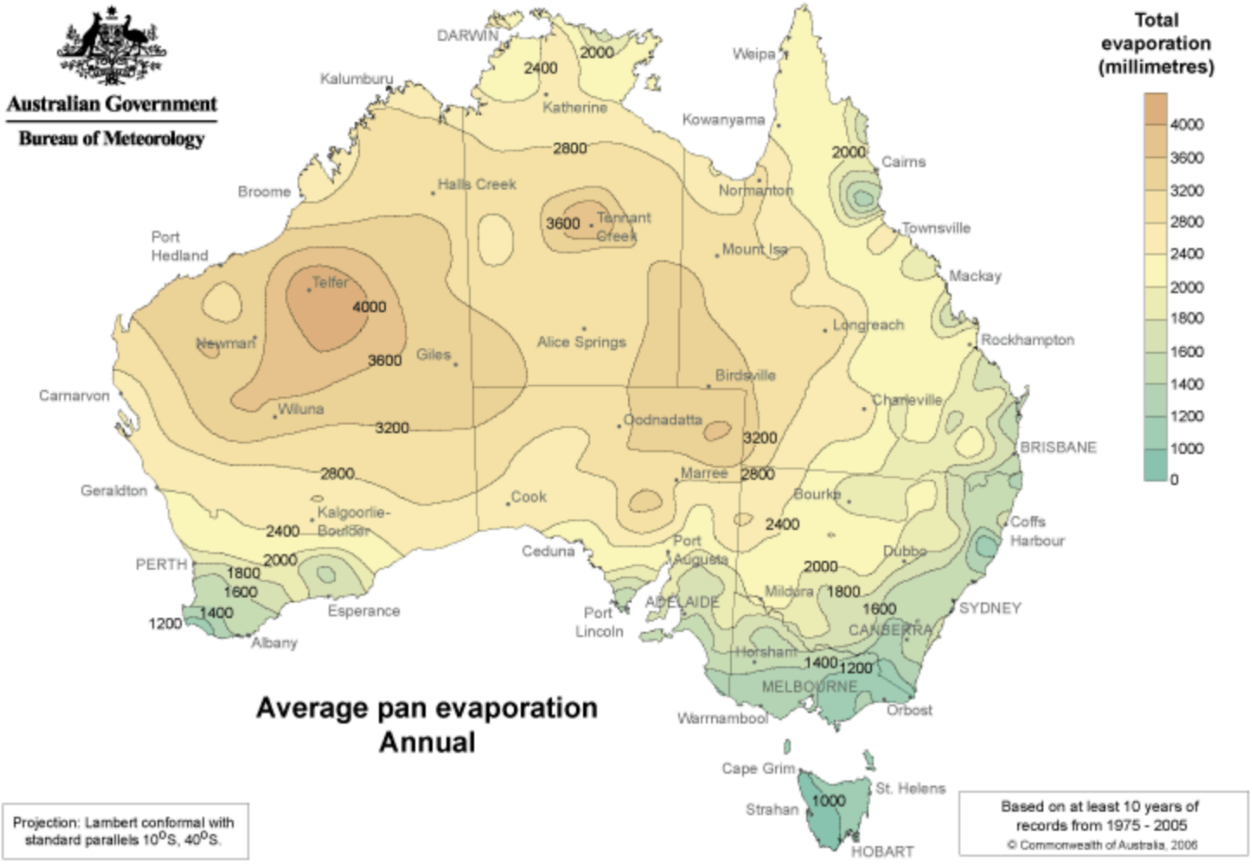

Figure 3: Average annual pan evaporation in Australia [19]

Table 5: Snowy Hydro Dams, heights, crest length and gross capacity [33]

NAME	TYPE	HEIGHT (m)	CREST LENGTH (m)	GROSS CAPACITY (10^3 m^3)
Talbingo	Rockfill	161.5	710	920,600
Eucumbene	Earthfill	116.5	579.1	4,798,400
Blowering	Rockfill	112.2	807.7	1,632,400
Geehi	Rockfill	94.1	265.2	21,100
Tumut Pond	Concrete Arch	86.3	217.9	52,800
Jindabyne	Rockfill	71.6	335.3	689,900
Tooma	Earthfill	67.1	304.8	28,100
Island Bend	Concrete Gravity	48.8	146.3	3,020
Tumut 2	Concrete Gravity	46.3	118.9	1,500
Tantangara	Concrete Gravity	45.1	216.4	254,100
Jounama	Rockfill	43.9	518.2	43,500
Murray 2	Concrete Arch	42.7	131.1	1,760
Guthega	Concrete Gravity	33.5	139	1,550

Happy Jacks	Concrete Gravity	29	76.2	270
Deep Creek	Concrete Gravity	21.3	54.9	5
Khancoban	Earthfill	18.3	1066.8	21,500

Table 6: Snowy Hydro official area vs model area [33] *and Google Earth*

	Official area (ha)	Area during model period (ha)	Historical image date
Talbingo	1,936	180	31/10/13
Eucumbene	14,542	7,500	18/4/11
Blowering	4,460	1,300	31/10/09
Geehi	700	48	24/2/12
Tumut Pond	203	84	3/3/10
Jindabyne	3,034	2,600	27/10/11
Tooma	180	129	18/4/11
Island Bend	327	13	22/10/12
Tumut 2	182	182	Not available
Tantangara	2,118	282	16/4/10
Jounama	3,804	200	31/10/13
Murray 2	190	12	5/11/13
Guthega	19.4	12	24/2/12
Happy Jacks	5	0	3/3/10
Deep Creek	2	2	Not available
Khancoban	4,694	275	31/10/09

Table 7: Tasmanian Hydro water body reservoir areas, from Google Earth

Lake	km^2		Lake	km^2	
Trevallyn Pond	1.3	19/11/09	Bronte Lagoon	4.4	14/3/10
Lake Mackenzie	0.98	19/11/09	Bradys/Binneys/Tungatinah	8.57	14/3/10
Lake Rowallan	7.84	27/3/11	Laughing Jack Lagoon	2.81	27/1/12
Lake Parangana	0.93	22/11/10	Lake Liapootah	1.98	14/3/10
Lake Cethana	3.75	22/11/10	Wayatinah Lagoon	2	14/3/10
Lake Barrington	6.38	15/12/07	Lake Catagunya	1.56	14/3/10
Lake Gairdner	0.77	22/11/10	Lake Repulse	1.17	14/3/10
Lake Paloona	1.4	22/11/10	Cluny Lagoon	1.4	19/1/12
Lake Augusta	6.27	27/3/11	Meadowbank Lake	5.67	11/3/10
Arthurs Lake	57.4	13/9/10	Lake Burbury	45.5	13/9/13
Great Lake	137	27/3/11	Lake Margaret	1.5	16/1/12
Little Pine Lagoon	1.78	14/3/10	Whitespur Pond	0.1	19/1/12
Shannon Lagoon	2.1	14/3/10	Lake Newton	0.4	19/1/12
Penstock Lagoon	1.42	2/9/11	Lake Plimsoll	3	19/1/12
Woods Lake	11.3	11/3/10	Lake Murchison	3.1	19/1/12
Lake St Clair	26.3	27/3/11	Lake Mackintosh	27.9	19/10/11
Lake King William	36.7	25/2/12	Lake Rosebery	6.59	25/12/13

Lake Echo	36.5	28/3/10	Lake Pieman	4.86	14/2/12
Dee Lagoon	6	28/3/10	Lake Pedder	230	7/3/13
Pine Tier Lagoon	0.65	14/3/10	Lake Gordon	201	8/2/10