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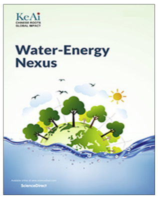

The water energy nexus in Australia – The outcome of two crises

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ABSTRACT

The world population is expected to increase from the current 8.5 billion to 11.2 billion by 2100. There will be increasing pressure on potentially diminishing water resources and a rising demand for stable and reliable power supplies which have sufficient inertia and fast frequency response to manage unexpected supply problems. There are many variables which influence water/energy ("nexus") relationships including natural resources availability and governance, the potential for climate change, increased urbanisation, the preferred built urban form, and domestic and industrial demands. Frequently, water and energy policies are developed under different arms of government with few links between them. Under the Australian constitution, the management of water is a states/territories responsibility. In the interests of improved water use efficiency, an Australia-wide water reform process was initiated in 1994. The commitment was strengthened in 2004–2006 with the 108 clause Intergovernmental Agreement on the National Water Initiative which included responsibilities for water conservation, the title to water rights and the ability to trade water rights separate from land. These arrangements served Australia well through the Millennium drought which ended in 2011. However, in most capital cities, a looming water crisis had been developing. In some cases water was restricted for cooling in thermal power stations and hydro electricity generation, restricting electricity output. There was an urgent investment in climate independent but energy demanding water sources (desalination and advanced water recycling) which, except in Western Australia, have since the end of the drought, seen little use but added considerable capital debt servicing costs. At the same time, a revolution began in the energy industries, government, private and domestically owned, with widespread investment in solar voltaic and wind generation with concomitant closure of coal-fired power stations. There were restrictions in some jurisdictions on further gas exploration. Several major black-outs in 2016 and 2017 led to the perception of a crisis in the stability and reliability of energy supplies. Policy indecision in Australia's response to the threat of global warming led to reluctance to refurbish old thermal power stations and to the closure of many. Prospects for battery technology and suggestions for increase pumped hydro energy storage have added to investment indecisiveness. There were no conspicuous links between water and energy policies, yet these will need to be developed. Meanwhile, the major water utilities, which had become commercial corporatized entities, were faced with increasing electricity costs. They have recognised the water/energy nexus. They have moved to use their resources including through mini-hydro from water supply systems and dedicated more effort into biogas electricity generation from Waste Water Treatment Plants, sometime supplemented with co-digestion of other organic wastes, to offset their energy requirements. Some have become net energy exporters.

Introduction

The world's population is projected to increase by slightly more than one billion people to reach 8.6 billion in 2030, and to increase further to 9.8 billion in 2050 and 11.2 billion by 2100 (UN, 2017). Urbanisation is continuing apace, and by 2050, seven billion people are expected to be living in cities. By 2030, the world is projected to have 41 mega-cities with more than 10 million inhabitants and cities are becoming denser (UN, 2014). There is increasing stress on water resources. Two thirds of the world's population currently lives in areas that experience water scarcity for at least one month a year (UN, 2017) By 2050, 20% of the land area in the Asia-Pacific region, with a population of 1.6–2 billion, is projected to experience severe water stress (Satoh et al., 2017). The interaction or nexus between water resources and energy needs of developing urban populations is increasingly recognised. The water-energy

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nexus addresses the interconnection or cause–effect relationships between water and energy. That is, a change in one leads to a change in the other. For example, energy is typically required to provide water, and water is typically required to produce energy (Kenway et al., 2011). Energy is required to pump, treat and deliver freshwater and to treat wastewater, while water is extensively used in the energy sector for extraction, processing and in cooling. As a pertinent example, at present about 12% of primary energy consumption in the US is related to the water sector (Sanders and Webber, 2012). Yet in the developing world, there is much further scope for pursing productively the interaction between water and energy, for example by better use of wastewater as a resource, since globally, 80 per cent of wastewater is untreated (UNESCO, 2017). The community's appreciation for the management of water as a natural resource is widely understood, but the dependence of energy sources on natural resources is less readily appreciated. Whether energy is seen to be sourced by dung, wood, coal, natural gas, nuclear sources, or electricity, they all have their origins as natural resources. The recent adoption of solar and wind power generation, notionally described as "renewable resources", is still dependent on environmental resources. It was estimated in 2011 that the world would need 40% more energy by 2030 and that it would face a shortfall between water demand and available freshwater by that year (Waughray, 2011).

Though communities are aware of the relationships between water and energy at the macro-scale, for example energy production by hydro-electricity generation and even the importance of water in managing nuclear power generation (awareness having been strengthened by the 2011 Fukushima disaster), they will be less familiar with energy relations in integrated water supply, wastewater and other waste management systems, nor the water requirements in many other energy production systems. In both water and energy systems, there has been a trend to greater diversity of sources and increasing decentralisation of supply and services. This paper describes how water and energy policies have evolved in Australia over the past 20 years, the successive crises that each sector has faced, and the endeavours by researchers and utilities to respond to these issues encompassing the water-energy nexus.

Energy systems dependent on water

Hydropower, unlike most other power generation systems requiring water, does not consume water *per se*, although there may be evaporative losses from hydropower, estimated at 17 m^3 per megawatt hour (MWh) (Waughray, 2011). Hydropower uses the head of water as a kinetic power resource to drive turbines. Hydropower has the capacity to respond at short notice to increased electricity demand and can thus be seen as a responsive energy-generating resource. However, the water flow should be managed to match downstream demands, whether for consumptive use in irrigation or to provide consistent environmental flows. This may require provision of water storage facilities at the foot of the headstocks after driving the turbines as well as storage at the head of the headstocks. Mini-hydro can also be developed within water systems, including as pressure reduction mechanisms to reduce water losses from leakages. These losses may amount to 30–40% from water distribution systems in many countries (Muhammetoglu et al., 2017). Mini-hydro can generate useful, albeit small quantities of electricity for use within the water management system with scope to improve the economics of operation. However, the ultimate turbine efficiency can be dependent on flow rate and head variability, characteristics which may change over time within a water supply system after the installation is made. Small power capacities may range from 2 to 20 kW (Brady et al., 2017).

The use of pumped storage hydroelectricity by harnessing the gravitational potential energy of water, pumped from a lower elevation reservoir to a higher elevation using low-cost off-peak or intermittent electric power generation provides a means of profitably storing electrical energy by releasing it through turbines at times of high value high energy demand. While energy is also stored by thermal, electro-chemical, hydrogen and liquid air storage technologies, and newly developed lithium mega-batteries, pumped hydro at 183 GW represents the vast majority of the recorded forms of energy storage, totalling 194 GW (DoE, 2018).

Most nuclear reactors whether boiling water or pressurised water reactors, require water to transfer heat from the reactor core. Nuclear power plants use water as a moderator, to slow neutrons. Like coal and gas-fired plants, they also use water for cooling to condense the steam that has been used to drive the turbines that generate the electricity. Dry cooling can be used as an alternative to once-through or recirculating water. So-called heavy water reactors use deuterium atoms as a moderator (World Nuclear Association, 2018). There is potential for nuclear energy plants to directly desalinate sea water, but none have been built commercially. However, there are examples which have been used for on-site water use or whose electricity generation is used for desalination (World Nuclear Association, 2017).

Fossil fuel power stations use water to generate steam to drive steam turbines, for cooling the exhaust steam and other operations including ash disposal, emissions control and may include a component of output for potable use. A secure water source is required. Thermal power plants consume 1.4% of total water consumption in Australia. Inland plants will require access to water resources which may be limited, whether groundwater whose balance may be understood, or climate-dependant surface water. While water can be recirculated for cooling purposes, use of water with a salinity greater than 2000 mg/L Total Dissolved Solids (TDS) is likely to generate corrosion and can also lead to scaling problems. Coastal thermal plants can use once-through sea water systems, but the discharge of warmed water may generate changes in the littoral zone and affect marine ecosystems. Dry cooling can reduce water consumption in thermal power plants by more than 90% but reduces the "sent out efficiency" of such power plants by 2–3% and may increase CO_2 emissions of coal fired plants by up to 6% (Smart and Aspinall, 2009). Concentrated solar thermal plants which may be attractive in sunny environments may also be limited in their use due to restricted access to water resources since they too depend on water for steam to drive generating turbines (Schumacher, 2009).

Thermal plants may also use oil or gas, but those energy sources may have been piped from distant well locations. Co-produced water may also have come from those wells, the amount often increasing as the age of the well increases. Any water not used on-site is often not adequately accounted for, just being allowed to evaporate (which some define as "use" within the natural water cycle). A further problem is the potential to damage aquifers by "collateral damage" during the exploration for or extraction of oil, coal seam gas or other forms of gas as energy sources such as shale gas by hydraulic fracturing ("fracking"). These processes can be successfully and safely managed (Cook et al., 2013) but the perceived risks have nevertheless raised widespread public concerns.

An oil or gas-fired power station will usually consist of a combined cycle turbine plant which uses both gas and steam to drive the turbines. Hot exhaust gases from the gas turbine are passed through a heat recovery steam generator to produce steam for the steam turbine, the steam being then condensed in a cooling system which is either water or air cooled (Smart and Aspinall, 2009).

Fossil fuels, (oil, gas and coal) have their own historical water footprint that is not easily accounted for, being the ancient water

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