More joules per drop – how much water does unconventional gas use compared to other energy sources and what are the legal implications?

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Abstract

Water is used in many steps of energy production from the extraction of primary fuels, to the production of electricity. The mining and energy sector is a small volume (4% of Australian water use in 2015/16) and a high value water user ($148M of value add per gigalitre). However, there is increasing competition for fresh water and an awareness of impacts of energy production life cycle on water resources. This paper compares 'joules per drop', or the equivalent joules of energy per liter of water for selected energy sources that include unconventional gas and renewables. The volumes of co-produced water during coal seam gas operations for example vary by a factor of at least 100 depending on which geological basin and coal seam is targeted. Yet, typical unconventional gas has a much higher 'joules per drop' than solar thermal and biomass energy, which can be low and very low 'joules per drop' (8 and 0.02 MJ/L) respectively. Optimizing the future portfolio of energy sources should include a goal of reducing the lifecycle use of fresh water as water is very critical to energy security. Potential law and policy applications of this work arise throughout the different stages of law-related decisions relevant to an energy production project: from strategic decisions about a desirable energy mix, to public and private investment decisions, to assessments for granting environmental approvals and water entitlements, to providing information to consumers about the sustainability of their energy source.

INTRODUCTION

Flicking a light switch on involves not just a flow of electrons, but also a hidden flow of water. Although the 'more crop per drop' mantra continues to drive water use efficiency of food and fiber production, monitoring the 'joules per drop' of direct and indirect water use in energy and electricity production typically has been overlooked. Joules per drop (eg. mega-joules per litre or MJ/L), or water efficiency normalized to energy, is a useful metric that provides complimentary information beyond total water use, water footprint and other energy or water accounting metrics.[1]

Reliable data on energy and water use is typically not readily available, or is limited to snapshots of specific energy types at a point in time. With changing climate and energy systems that are transitioning to increased

[1] Leong, S, J. Hazleton, R. Taplin, Timms, W., D. Laurence, 2014. Mining Company Information Provision For The Needs Of The Local Community: Water Usage Disclosures For The Macquarie And Lachlan Catchments, Australia. *Journal of Cleaner Production*, vol. *84, pp 94- 106*

proportions of renewable and stored energy, data on regional and global trends and trends over time for water use in energy systems will become increasingly valuable.

Readily available data will enable a range of important questions to be evaluated in decision-making in contexts that include: strategic policy, investment, environmental approvals, environmental management and consumption. What will be the implications for water resources in Eastern Australia with an increase of unconventional gas and solar PV, and a reduction in coal-based electricity? What is the optimum portfolio of energy production for a water-stressed area to ensure reliable supply while minimizing costs, greenhouse gas emissions and diversion of fresh water? How should a consumer who wants to purchase 'sustainable' energy approach this choice? Multi-factorial analyses of optimal energy supplies are yet to include water use, within the context of complexities and trade-offs to achieve the desired economic and environmental outcomes. Future planning could explicitly consider increasing the joules produced per drop of fresh water diverted or consumed during primary energy extraction and electricity production. These and many other questions that are critical for our energy transition future must be based on reliable data and information.

This paper evaluates water use productivity associated with extraction of energy for export and generation of electricity on the East Coast of Australia. This analysis is based on information publicly disclosed across these industry sectors, for example by the industry water accounting framework (MCA, 2012)[2] and in annual reports of energy companies. A database, 'H_2O-4-Energy' is being compiled by researchers at Deakin University including primary data from Australian operations, and global data from peer reviewed literature and various reports. An important step in analyzing this data is checking, where possible, implicit assumptions in data that is collated, and converting to equivalent units to enable comparisons (eg joules). For instance, it is important to distinguish between water uses of different stages of energy production such as primary energy sources (eg. unconventional gas, oil), generated energy (eg. electricity from fossil fuel, concentrating solar power) and stored energy (eg. hydrogen gas, hydro-electricity).

An important value of the resulting water use productivity data is the ease with which it allows comparison across energy types. This lends the metric well to a wide range of potential law and policy contexts that inherently involve some degree of comparison. The final part of this paper reviews those contexts through the law-related stages of an energy development, from public strategists assessing energy sector development to determine an optimal energy mix, to governments and private firms making investment decisions about energy projects, to decision-makers considering environmental impact assessments and water entitlement applications for individual energy projects, and consumers weighing up their energy purchase options. It underscores that a joules per drop analysis has potential for immediate use in current Australian law and policy contexts.

Background on Energy and Water

Water is used in extracting gas from the ground, mining coal and other materials needed for energy production, and by the electricity sector. At the aggregate national level, mining is a small volume water user at 4% (or 661 gigalitres GL) of Australian water use in 2015/16. This volume included 26 GL from oil and gas

[2] MCA, 2012. Water accounting framework for the minerals industry User Guide. Minerals Council of Australia.

extraction (not differentiated), and 135 GL by coal mining.[3] Yet, mining is a high value water user with $148M of value add per GL, much higher than value added by other water users.[3] The electricity sector used 1.8% (or 228 GL) of water in Australia in 2015/2016, with relatively little change over the past decade.[4]

Renewable energy accounts for 9% of net domestic energy in Australia, with only a 1% increase over the past decade.[5] However, the proportion of renewables in electricity production has increased from 9 to 15% over this period, driven particularly by increased solar PV and wind energy. The main fuel sources of electricity in 2015-2016 were black coal 44%, brown coal 19% and gas 20%. Total net energy use in Australia is gradually increasing with a growing population, although energy use per person and household is decreasing.[6] Of the average household energy bill, 18% is for gas, 33% is for electricity, and the remainder for transport fuel.**Error! Bookmark not defined.** The gas demand forecast for 2018 was 1901 PJ, of which 1314 PJ was for export and the remainder for domestic use.

On a global basis, energy production now accounts for 15% of total water use.[7] The energy and mining industry is under increasing scrutiny because water crises, such as insufficient freshwater, are in the top 5 global risks in terms of impact.[8] The most recent trends of water use in unconventional gas in the US have highlighted growing water intensity.[9] Since 2014, there has been a decrease in joules per drop of water in major producing basins, particularly for shale gas. The permanent loss of water used for hydraulic fracturing into shale formations, rather than co-produced water during coal seam gas (CSG) extraction, has exacerbated concerns of water-stress in drier regions of the US. New data by Kondash et al.[9] updates an earlier study by these authors evaluating the risks to water resources from unconventional oil and gas production.[10] Their latest findings highlight that it is critical to track the evolution of water risks with technological advances and changing market and environmental conditions in different areas of the globe.

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[3] Deloitte Access Economics, 2013. Economic Value of Groundwater in Australia. Report to the National Centre for Groundwater Research and Training, October 2013 http://www.groundwater.com.au/news_items/media-release-future-mining-dining-booms-depend-on-water

[4] ABS water account 2015 – 2016 http://www.abs.gov.au/AUSSTATS/abs@.nsf/allprimarymainfeatures/F58F2E66A4D538E2CA25839E00198085?opendocument

[5] ACCC, 2017. Gas inquiry 2017-2020. Interim report. https://www.accc.gov.au/system/files/Gas%20Inquiry%20-%20Interim%20Report%20-%20September%202017.pdf

[6] Australian Energy Council, 2018. Available at: https://www.energycouncil.com.au/analysis/australian-energy-update-whats-changed-in-energy-supply-and-use/

[7] US EIA, 2017. *Annual Energy Outlook*. Energy Information Administration https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf

[8] WEF, 2018. Global risks 2018: fractures, fears and failures. Report available at http://reports.weforum.org/global-risks-2018/global-risks-2018-fractures-fears-and-failures/

[9] Kondash AJ, NE Lauer, A Vengosh, 2018, The intensification of the water footprint of hydraulic fracturing *Science advances* 4 (8), eaar5982, http://advances.sciencemag.org/content/4/8/eaar5982

[10] Vengosh, A., Jackson, R. B., Warner, N., Darrah, T. H., & Kondash, A. 2014. A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States. *Environmental science & technology, 48*(15), 8334-8348.

JOULES PER DROP – FOR PRIMARY ENERGY SOURCES

Available data indicate a significant range of joules per drop for primary energy sources (Figure 1). Low joules per drop is shown for a biomass example (0.01 MJ/L) and a solar thermal site (0.1 MJ/L). By contrast, the most water efficient energy sources shown include wind (5000 MJ/L) and CSG in the Sydney Basin at Camden (909 MJ/L). Local data were compared with international data (Figure 1) for coal, conventional oil and gas, uranium (including mining, enrichment etc), and renewable energy including solar PV and wind energy. The paper discusses water use of each primary energy source in more detail in the following sections.

Unconventional Gas

Currently, production of unconventional gas in Australia is in the form of CSG, with shale gas and other tight gas mainly at the exploration stage of development.[11] Other unconventional gas forms such as hydrates are not within the scope of this paper. The CSG industry has developed rapidly in Australia since 1996, particularly since the world's first liquefied gas export facilities commenced in 2015. There are more significant prospective resources of unconventional gas than conventional gas in Australia[12], particularly as shale gas.

CSG can have a much higher 'joules per drop' than many forms of primary energy. However, a very large range of values is observed depending on the project. The volumes of co-produced water during coal seam gas operations, for example, vary by a factor of at least 100 in Australia, as evident from Figure 1. This high variation in co-production of water depends on the type and location of geological basin and coal seam targeted, and the cumulative effects over time in a CSG extraction basin. APPEA observed that during 2015, the Australian coal seam gas industry produced around 60 GL (gigalitre) of co-produced water from over 170 wells.[13]

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[11] Undershultz J., 2016, Unconventional gas. In: Sustainability in the Mineral and Energy Sectors, Editors Sheila Devasahayam, Kim Dowling, Manoj K. Mahapatra, Chapter 28, pp. 545-560.

[12] Australian Energy Resources Assessment, 2018. Available at https://aera.ga.gov.au/#!/executive-summary

[13] APPEA, 2018. Coal seam gas –industry statistics – water production. Australian Petroleum Production and Exploration Association, Canberra, https://www.appea.com.au/wp-content/uploads/2015/05/Q1-2015-Total-CSG-Industry-Data_Final.pdf

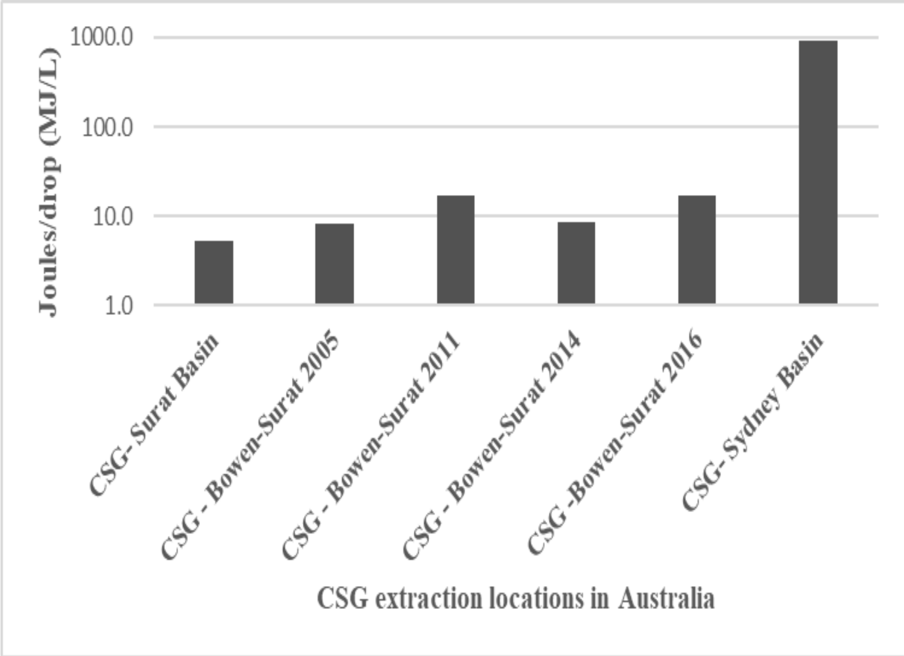

Figure 1. Joules per drop for CSG extraction in various sites in Australia. Data sources are discussed in the text.

Joules per drop from the Camden CSG project, located in south-western Sydney, is highest for any Australian primary energy source in the data base to date (Figure 1). In other words, this CSG project extracted less water per unit of energy[13] than reported for any other primary energy source, and can thus be considered relatively favorably in regards to water.

A comparison of joules per drop of various primary energy sources is depicted in Figure 2 based on Australian and international data. The upper and lower caps in the figure show the maximum and minimum values respectively and where the range is not available, only one data point is shown.

[13] RPS, 2011. Onshore co-produced water: extent and management. RPS report for National Water Commission, Canberra.

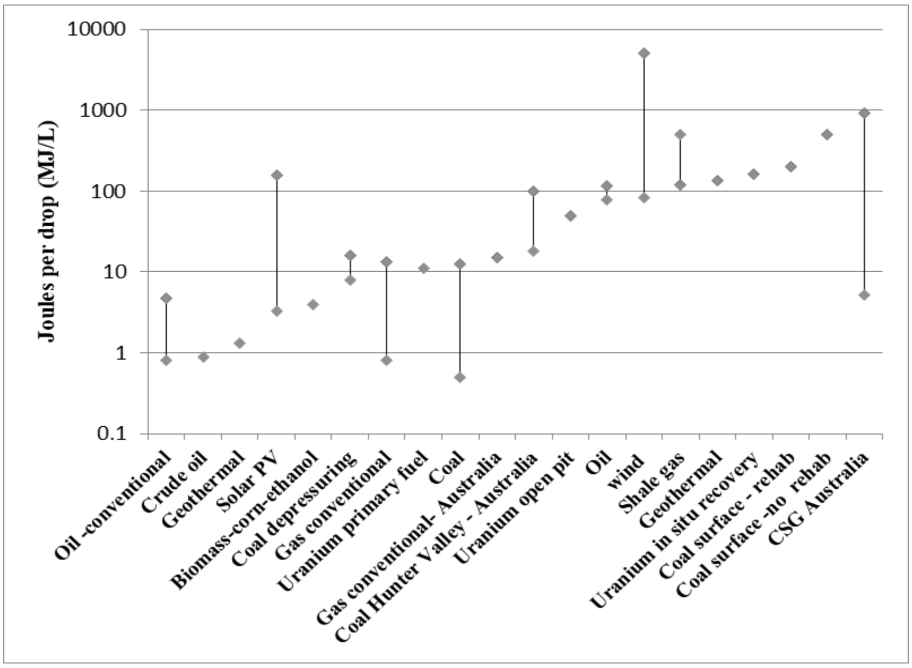

Figure 2. Joules per drop for primary energy sources locally and internationally (updated from Timms, 2018). Data sources are discussed in the text.

Based on the comparison, only wind energy can produce more joules per drop than the Camden CSG project in Sydney.[14] Since the RPS[13] report for the National Water Commission comparing co-produced water across several basins including the Sydney Basin, the company operating this project has reported significantly decreased water use[15] as gas wells are progressively shut down and rehabilitated prior to production ceasing by 2023.[16]

Joules per drop varies over time, and in different basins of Eastern Australia (Figure 2). The water efficiency of CSG projects, converted from data in RPS[14], were from lowest to highest: Surat Basin (5 MJ/L), Bowen Basin (20 MJ/L), and the Sydney Basin at Camden (909 MJ/L). These differences are largely attributed to differences in coal seam permeability, coal age and rank, hydraulic connectivity to recharge sources, and other geotechnical and geological factors. By comparison, water use efficiency of shale gas operations in the

[14] Mekonnen, MM, Gerbens-Leenes, PW, Hoekstra, AY, 2015. The consumptive water footprint of electricity and heat: A global assessment. *Environ. Sci. Water Res. Technol*. Vol. 1, pp. 285–297.

[15] AGL, 2018. Sustainability report. https://www.agl.com.au/about-agl/sustainability/sustainability-report

[16] AGL, 2017. Fact sheet: Camden gas project. https://www.agl.com.au/-/media/aglmedia/documents/about-agl/how-we-source-energy/camden/camden-document-repository/fact-sheets/camden_factsheet_a4_final.pdf?la=en&hash=047ED116FBB8AC95F9E75180F487954E

US varies from 96 MJ/L in the Texas shale, 208 MJ/L in the Barnett shale, and 435 MJ/L in the Tx-Haynesville Shale (converted from data reported by Nicot and Scanlon[17]).

Fortunately, the actual volume of co-produced water in at least one Australian Basin is significantly less than predicted.[18] Water produced by CSG operations in the Surat-Bowen Basin peaked at 120 ML/PJ in 2005, and reduced to 60 ML/PJ in 2011 and 2016. The corresponding increase in joules per drop is shown in Figure 1. Actual water use is approximately 25% of estimates made by government and academia prior to CSG expansion, and about 70% of an early estimate made by the CSG industry. Lower actual water production values occurred when a dynamic equilibrium of groundwater drawdown was achieved. Increased co-produced water between 2011 and 2016 was related to a significant increase in gas production. Predicted water use was overestimated due to several factors including operational design requirements and simplifications in groundwater modeling (eg. not including multi-phase flow effects or cumulative drawdown effects).

The Northern Territory fracking inquiry[19] recognized rapid technological changes for conventional gas in recent years and implications for water use. For example, water use per well benchmarked by early studies[18, 20, 21], has typically increased in proportion to the increasing length of horizontal wells. Water use is currently 1-2 ML for well drilling, and approximately 1-2 ML for each hydraulic fracturing stage, with 30-40 fracturing stages in the longest wells[20]

The gas industry has proposed a 25 year development scenario of between 1,000 and 1,200 wells in the NT's Beetaloo sub-basin, associated with around 150 well pads, which would require an average of 2,500 ML/year of water for well drilling and hydraulic fracturing. A peak water demand of 5,000 ML/year is predicted between year five to nine. It is unclear how much gas would be produced in this scenario. However, an alternative scenario is considered for 6,260 wells producing 53,250 PJ of gas over 40 years and a total use of 125,000 ML given various assumptions.[20] If this occurs, the equivalent water use efficiency would be ~0.4 MJ/L, at the very low end of the range of values presented in Figure 2. On this basis, it appears that more energy can be produced with less water from CSG in Eastern Australia compared with shale gas in the NT. Importantly however, the NT inquiry considered the sustainability of local water sources for shale gas production, and made a number of recommendations to address concerns.[20] In common with other areas of Australia, further work is required to consider the local catchment context and potential

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[17] Nicot, JP, Scanlon, BR, 2012. Water Use for Shale-Gas Production in Texas, US. *Environ. Sci. Technol.* 46 (6), 3580−3586.

[18] Undershultz J., Vink S, Garnett, A, 2018, Coal seam gas associated water production in Queensland: Actual vs predicted *Journal of Natural Gas Science and Engineering*, vol. 52, pp. 410-422

[19] NT government, 2018. *Final Report of the Scientific Inquiry into Hydraulic Fracturing in the Northern Territory.* https://frackinginquiry.nt.gov.au/inquiry-reports/final-report

[20] Cook P, Beck V, Brereton D, Clark R, Fisher B, Kentish S, J Toomey and Williams J., 2013. *Engineering Energy: Unconventional Gas Production.* Report for the Australian Council of Learned Academies (ACOLA

[21] US EPA, 2016. Hydraulic fracturing for oil and gas: Impacts from the hydraulic fracturing water cycle on drinking water resources in the United States. US Environmental Protection Agency https://cfpub.epa.gov/ncea/hfstudy/recordisplay.cfm?deid=332990

environment impacts of the relatively small volume of water used for energy extraction, compared to, and considered in the aggregate with, other water users.

In the US and Canada, unconventional oil and gas is extracted from Permian Basins, enhanced by horizontal drilling and hydraulic fracturing technologies. Available data indicated that water produced per unit of oil and gas is much lower for unconventional wells, than conventional wells.[22] However, unconventional horizontal wells use large volumes of water for hydraulic fracturing that increase by a factor of ∼10−16 per well and ∼7−10 if normalized by lateral well length. The International Association of Hydrogeologists Energy Commission is currently compiling information for comparison across a number of basins around the world, considering in more detail the implications of energy extraction on groundwater systems and potential environmental impacts.

Coal

A water use curve for a major coal mining area in Australia is presented as a benchmarking tool (Figure 3), analogous to a cost curve for mining operations.[23] This new water use curve for the Hunter Valley coal mines indicates water use variation from 230 to 2075 L/tonne of product coal (average 771, n=10). The water use normalized to energy of product coal was calculated as 10 to 56 MJ/L as shown in Figure 2.

Mine water use was generally unrelated to the magnitude of production or the type of mining as underground or open cut, however, the largest water use appears to be more likely associated with open cut mines. Further analysis is required to understand the relationship between water use and the proximity of the mine to surface water sources such as the Hunter River, and the depth and type of underground mining (eg. longwall or bord and pillar methods). It is evident, however, that mine site-specific factors are important to water use, including the extent of surface diversions, aquifer interception and leading water management practices to replace fresh water with alternative sources. Distinguishing between total water intake and net fresh water (NFW), excluding water reuse and beneficial water discharge, provides important insights.

The source of water intake was found to vary from exclusively groundwater to dominantly surface water at the 10 mine sites.[24] Groundwater was the largest licensed water take from the environment for most of the sites, yet was on average less than half the allocations that these mines were licensed to access. However, groundwater flows are inherently difficult to quantify due to natural subsurface variability, and the Water Accounting Framework[2] requires differentiation of groundwater as inputs or diversions. Inputs such as seepage to a pit that is subsequently used for a task such as dust suppression would be accounted for as an input, whereas that seepage that is directly discharged to surface water or re-injected into a different aquifer without being used would be accounted as a diversion. Also, by excluding evaporation and entrainment losses, a lower average water-use productivity value of 580 L/tonne was estimated for these mine sites. In areas of water stress, technologies to decrease evaporation losses and recover water from waste could thus be beneficial.

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[22] Scanlon BR, RC Reedy, F Male, M Walsh, 2017. Water issues related to transitioning from conventional to unconventional oil production in the Permian Basin, *Environmental science & technology* 51 (18), 10903-10912.

[23] Updated from Timms W, Holley C, 2016, 'Mine site water-reporting practices, groundwater take and governance frameworks in the Hunter Valley coalfield, Australia', *Water International*, vol. 41, pp. 351 – 370.

Water resources in some areas of the Hunter Valley are over-allocated and would not be sustainable if actual water use were equal to allocations. For example, the potential impact of mining on the Pages River, an upper tributary of the Hunter River, was a key factor why a proposed open-cut mine was not given regulatory approval.[24] However, in catchments where water is fully allocated and stressed, it has been questioned why high-security water licences are held by some mining sites. Water licences in this jurisdiction can be either general or high-security, the type of licence having implications for the volumes of water that are allocated during relatively dry periods. High-security water licences are essential in these cases because the flows are constant and may not be possible to eliminate (e.g. incidental seepage from river alluvium to an open-cut pit). Further discussion on solutions to improve sustainability of water use and governance aspects of water used by coal mines is discussed by Timms and Holley.[23]

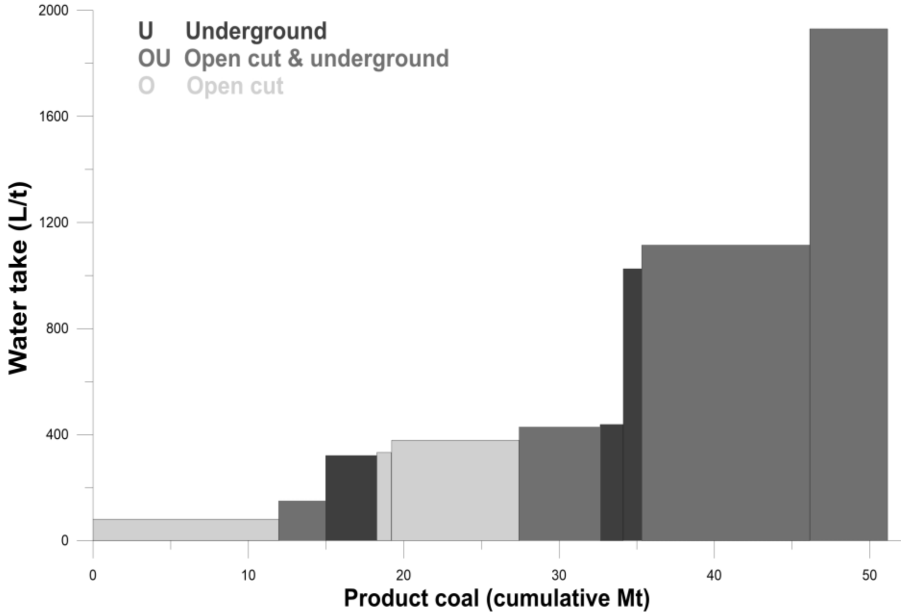

Figure 3. Water use curve for a major coal mining area [23]

JOULES PER DROP – FOR ELECTRICITY GENERATION

Electricity generation uses water during power plant construction and operation phases. The operational phase of electricity generation, such as power plant cooling, contributes to the majority of the water use. Thermo-electric power generation uses around 1.4% of total water consumption in Australia.[25] For example, Figure 3 compares 2017 operational water use data for electricity generation in Eastern Australia, based on information reported by Energy Australia, Alinta, AGL Macquarie and Stanwell. It is evident that generation from coal with evaporative cooling (wet cooling) uses significantly more water (362 to 835 L/GJ) than an open cycle gas plant (18 L/GJ) with air cooling. Considering this data in terms of joules per drop (bubble size in Figure 3 size), electricity generation from gas with air cooling is ~46 times more favorable than generation from coal with evaporative water cooling. While more energy from less water can be achieved by a gas plant using air cooling, there may be a trade off in terms of construction costs and operating efficiency.

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[24] NSW Government, 2010. See, https://www.planning.nsw.gov.au/-/media/Files/DPE/Media-Releases/2010/May/14052010-nsw-government-protects-multi-billion-dollar-nsw-thoroughbred-industry--stops-coal-mine-in-upper-hunter.ashx

[25] Radcliffe, J.C. 2018. The water-energy nexus in Australia – The outcome of two crises. *Water-Energy Nexus,* vol. 1 (1), pp. 66-85.

In electricity generation phase, the water intake (withdrawal and consumption) of a power plant is determined by the cooling technology used. A complete accounting of water for electricity production should consider once-through water use and discharge to a receiving environment versus closed cycled water cooling.[26] The water use figures mentioned above indicate the total water incurred in all unit processes during electricity generation. It includes water withdrawal for power plant cooling, water consumption for producing process water in the boilers, water evaporated during cooling and other consumption within the plant premises. More data is required to give a disaggregated picture of water use in electricity production in terms of withdrawal and consumption, which would be helpful in estimating the net water extracted from the environment.

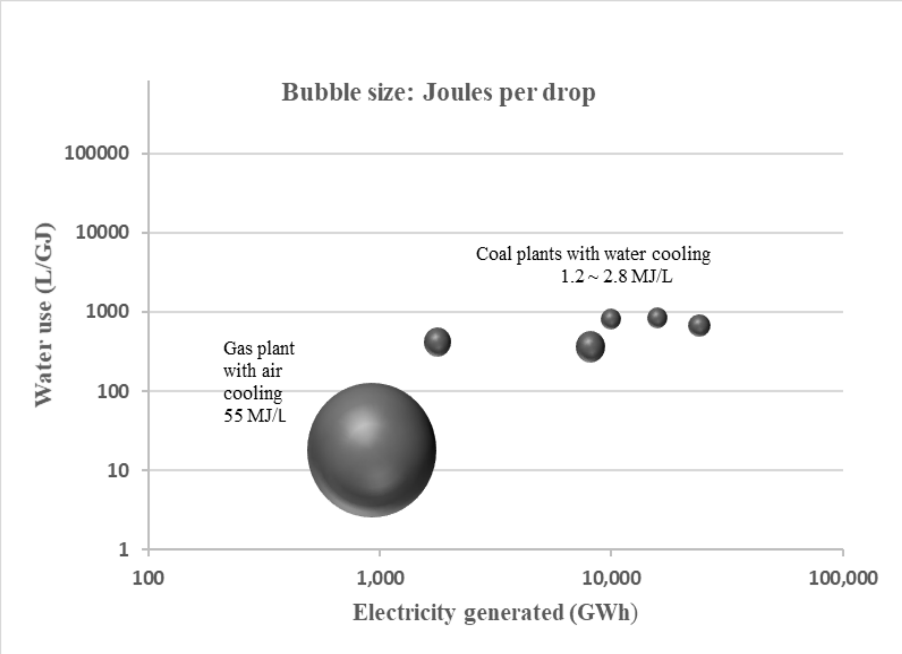

Figure 4. Water use and joules per drop during operation of coal and gas plants generating electricity for Eastern Australia (Timms[27]).

Further work is in progress to compile more local data regarding water use for construction and operation of electricity generation plants, and to consider economic and energy tradeoffs for alternatives to water cooling, and the quality of water that is required. The total direct and indirect water use, including water used during mining or extraction of fuel used in electricity generation and water for cooling, can then be compared on a like-for-like basis.

Table 1 summarizes the proportion of direct water use (operational) during electricity generation compared with indirect water use associated with primary fuel and construction of electricity generation plants. The water use of natural gas, oil and coal is primarily during operations (77-97%), whereas wind energy and solar

[26] Pan, SY, Snyder, SW, Packman AI, Lin YJ, Chiang PC, 2018. Cooling water use in thermoelectric power generation and its associated challenges for addressing water-energy nexus. *Water Energy Nexus*, vol. 1, pp. 26-41.

[27] Timms, W, 2018. Increasing productivity with less fresh water in mining and electricity generation in Australia, Abstract presented at Engineers Australia, *Hydrology and Water Resources Symposium*, HWRS2018, 3-8 December 2018, Melbourne.

PV use much less water and mainly during construction (50-83%). Biomass energy sources such as firewood are unique, in that significant water use is associated almost exclusively with growth of the fuel (~100%).

Table 1 Water use for selected energy generation showing percentage of water use associated with primary fuel, construction and operation (modified after Mekonnen et al[14]). Joules per drop data from this reference are also included in Figure 2.

	Water use (L/GJ)		Joules per drop max (MJ/L)	% of water use		
	Min	Max		Primary fuel	Construction	Operations
Firewood biomass	48000	500000	0.02	~100	-	0.1
Solar thermal	118	2180	8	-	71	29
Coal	79	2100	13	22	0.4	77
Oil conventional	214	1190	5	9	0.1	91
Natural gas	76	1240	13	2	0.4	97
Solar PV	6.4	303	156	-	83	17
Wind	0.2	12	5000	-	50	50

Renewables

There are large differences in water use by renewable energy sources that must be recognized in decision-making. Solar PV and wind energy are far better for electricity generation in water stressed areas than biomass and solar thermal with current technologies and information available. It is reported that wind can produce the most joules per drop of water of any renewable option (eg Mekonnen et al[14]) despite the water used to manufacture steel wind turbines, supply metallurgical coal to steel mills, and construct concrete footings for wind turbines. However, it is uncertain whether solar PV could, in the future, become a better renewable option to reduce total water use. Further advances in solar PV, such as thin film technology, could achieve record levels of joules per drop of water. Robotic cleaning of solar panels to increase operational efficiency could reduce very low volumes of direct water use even further. Regardless, a portfolio of electricity sources that optimizes multiple criteria including reliability, affordability and overall sustainability will continue to drive new investments.

Biomass energy sources such as firewood are unique, with potentially significant water use, with orders of magnitude greater than another other renewable or non-renewable energy source (Table 1). However, biomass energy sources are enormously varied, including: traditional crops, algae, and derived energy sources including biofuels and biogas generation and co-generation from landfill and other wastes. Gerbens-Leenes et al[28] compared the water use of biomass generation from fifteen crops grown in four countries. The

[28] Gerbens-Leenes, P.W., Hoekstra, A.Y., van Der Meer. 2008. Water footprint of bio-energy and other primary energy carriers. Value of water: Research report series no. 29. Available at : http://www.danishwaterforum.dk/activities/Water_and_Energy/Report29-WaterFootprintBioenergy.pdf

water use of cropping for biomass depends on the crop type, agricultural systems (eg. irrigation) and climate zone. Maize grown in the Netherlands, for example, can generate forty times the joules per drop of cotton grown in Zimbabwe (0.04 vs. <0.01 MJ/L). Wu et al[29] reported a value for corn grown for ethanol in the US that is equivalent to 4 MJ/L, the highest ranking biomass source shown in Figure 2.

It is apparent that crops for biomass are a poor choice based on water metrics alone, considering that the best joules per drop option for electricity is currently wind turbines (5000 MJ/L). Crops that are rain-fed or irrigated exclusively to grow biomass energy sources (eg. poplar forests) are clearly incompatible with dry areas that are water stressed and/or over allocated. However, if biomass is waste from a crop with food or material benefits (eg. sugar cane, cotton) or provides environmental benefits, such as mitigation of soil erosion, a more complex set of tradeoffs would need to be considered.

Hydrogen, hydropower and nuclear energy

The water that is required at every step of the hydrogen economy depends on the production method, whether from electrolysis of water or coal gasification with carbon capture storage, for example. Limited available information suggests that water requirements for hydrogen production depend primarily on method and vary over a wide range similar to shown in Figure 1 for CSG in Australia.[30]

Importantly, as hydrogen is an energy carrier, the source of energy for hydrogen production and other indirect factors in the supply chain (eg. transport in the form of ammonia) must be factored into the overall efficiency, whether from an economic or environmental perspective. As for all energy systems, decommissioning, waste recycling and disposal of emissions or the infrastructure needed to store and transport energy, will also contribute indirect water use.

Special cases of water use related to hydropower and nuclear energy are beyond the scope of this paper. The range of reported water use in nuclear power is very large[15], and yet generation IV reactor designs reduce or eliminate direct water use, and the water efficiency of in situ leach methods to mine uranium is ranked favourably[18] as shown in Figure 2.

LEGAL RELEVANCE OF A JOULES PER DROP ANALYSIS

The technical ‘joules per drop’ analysis outlined above highlights the significant variation in water use performance of varying energy sources in Australia and internationally. This section briefly outlines the potential legal and policy contexts in which a joules per drop analysis may prove useful as a readily understood measure for comparing energy projects and sources. The relative paucity of legal thinking about the water-energy nexus — which is characterised heavily by scholarship in the scientific, technical and economic fields — has already been noted.[31] It also extends the existing legal literature on the water-energy

[29] Wu, M., Mintz, M., Wang, M., Arora, S. 2009. Water consumption in the production of ethanol and petroleum gasoline. Environmental Management, vol. 44, pp. 981-997.

[30] Mehmeti A, Angelis-Dimakis, A, Arampatzis G, McPhail SJ and Ulgiati S, 2018. Life Cycle Assessment and Water Footprint of Hydrogen Production Methods: From Conventional to Emerging Technologies. *Environments*, 5, 24; doi:10.3390/environments5020024

[31] Rhett B. Larson, Cameron Holley and Diana M. Bowman, ‘The Energy/Water/Food Nexis – An Introduction’ (2018) 59 *Jurimetrics* 1, 4.

nexus, which has yet to substantially investigate the potential of current Australian law to accommodate 'joules per drop' thinking in the context of energy projects.[32]

A wide range of potential law and policy contexts throughout different law-related stages of an energy development might be informed by a joules per drop analysis (see Table 2, below, upon which each of the sections below expands). Early on, public strategists assess potential paths for energy sector development and should consider the water use of various options. Governments and private firms make investment-related decisions about specific energy projects, and decision-makers consider environmental impact assessments (EIAs) and water entitlement applications for individual energy projects. Proponents and their stakeholders consider water-related risks during the operation of the project. The joules per drop analysis continues to be relevant to an entirely different audience even after the energy has been produced, as consumers respond to information about their energy purchase options.

Some of these contexts lend themselves well to adopting a joules per drop analysis as a modest extension of existing policy approaches in current decision-making structures, for example, understanding that intensive water use is a matter of the national interest. This is currently explicitly recognised in federal water law (albeit only in relation to the Murray-Darling Basin),[33] but is not yet recognised in policies about inbound foreign investment in energy projects in Australia. In other contexts, the analysis would pose a more substantial challenge, for example, considering water use productivity (distinct from the broader economic value created by water use) in considering the grant of a water entitlement. Importantly, in no case would a legal change be required to accommodate considering a joules per drop analysis. Some of these options are highly speculative. However, it is worth highlighting that existing levels of public concern about the water use of CSG and information about its water impacts[34] may well set the stage for the broader political acceptability, or even imperative, of incorporating a joules per drop approach in energy-related decision-making contexts more broadly.

As a preliminary matter, it is important to note that the concept of environmental significance is central to many stages of a development: considering the environmental significance of water use when strategically planning an energy portfolio, when considering a particular energy project as a financier or regulator, and when considering consumer support. The water use productivity of an energy project is an important indicator of this significance, which (as discussed above) is also influenced by local circumstances, such as local water scarcity and locally threatened water-dependent ecosystems. Yet even though law and policy

[32] For examples of overseas legal scholarship dealing with the water-energy nexus, see Roberta F Mann, 'Like Water for Energy: The Water-Energy Nexus through the Lens of Tax Policy' (2011) *University of Colorado Law Review* 505; Sarah Ladin, 'Energy-Water Nexus, the Clean Power Plan, and Integration of Water Resource Concerns into Energy Decision-Making' (2017) 7 *Michigan Journal of Environmental and Administrative Law* 205; H. David Gold and Jason Bass, 'The Energy-Water Nexus: Socio-Economic Considerations and Suggested Legal Reforms in the Southwest' (2010) 50 *Natural Resources Journal* 563. For examples of reform-oriented legal scholarship, see Mann, cited here (arguing that tax incentives should be re-structured to take into account the water impacts of different energy sources); Ladin (cited here) argues for a variety of legal duties to consider water resources and new legislative research mandates; Gold and Bass propose various statutory changes, including a priority system in water allocation processes that would favour water-efficient renewable energy projects.

[33] *Water Act 2007* (Cth) s 3(a).

[34] See generally Rebecca Nelson, 'Water Data and the Legitimacy Deficit: A Regulatory Review and Nationwide Survey of Challenges Considering Cumulative Environmental Effects of Coal and Coal Seam Gas Developments' (2019, forthcoming) 23(1) *Australasian Journal of Water Resources*.

contexts are often focused on the local circumstances of a project, a joules per drop analysis signals the ongoing importance of water-related impacts in the context of climate change concerns about energy; it also forms an immediately useful comparator between energy projects and sources.

Table 2 Legal contexts accommodating a joules per drop analysis through key law-related stages of an energy project

Stage	Early – planning production	→	→	→	→	Late – energy consumption
	Strategic planning and strategic environmental assessment	Strategic investment policy	Project-based environmental impact assessment	Water entitlements	Allocations made to water entitlements	Marketing to consumers
Actors	Government	Government finance entities, banks & investors, foreign investment regulator	Environmental regulators	Water regulator	Proponent, stakeholders (eg shareholders)	Energy retailers, consumers
Key questions	How should we structure our energy mix, considering the water use of alternative components?	Should we invest in this project? Should we allow foreign investment in this project (is it in the national interest)?	What are the likely impacts of this project on the environment/ water resources? Are they significant? How do alternatives compare?	Should we grant a water entitlement to this energy project? Are the volume and conditions of a water licence justified for the energy gain?	How much is the energy output of this project likely to be affected by legal risks to water availability or water quality?	Are 'green' claims made about this energy product accurate considering its water use?

Strategic Planning and Strategic Environmental Assessment

Strategic environmental assessment (SEA) analyses the impacts of proposed policies, programs or plans to guide subsequent projects.[35] SEA has not been taken up to a great degree in Australia, although examples of SEA regimes, in name or substance, do exist as both statutory and voluntary, policy-based processes.[36] SEA is the more formal, environmentally-focused cousin of broader strategic planning for energy futures. Internationally, analysing alternatives to a proposed policy, plan or program is recognised to be a central component of SEA.[37] Indeed, SEA has been particularly recommended in the energy context as a way of exploring a wide range of options to reach desirable outcomes when electricity demands outgrow existing

[35] Mandy Elliot, Environment Impact Assessment in Australia: Theory and Practice (6th ed, Federation Press) 67-75.
[36] Ibid 71-74.
[37] Ainhoa Gonzalez and Riki Therivel, 'Alternatives in Strategic Environmental Assessment of Plans and Programs' (2014) FASTIPS (International Association for Impact Assessment, Fargo, ND), http://www.jsia.net/6_assessment/Fastips_7-SE-Alternatives.pdf.

coal-fired electrical generation.[38] Globally, SEA in the energy sector has been used to explore the environmental effects of different mixes of energy sources,[39] and has been used to some degree in the energy sector in Australia.[40] It has as yet-unfulfilled potential to assess more comprehensively the full suite of impacts (including water impacts) of energy developments.[41] A joules per drop analysis could clearly assist in analysing the water-related implications of alternative energy generation scenarios over larger regions, and with a much greater suite of alternative scenarios, than is possible with project-based EIA.

Strategic Investment Policy by Governments and Firms

As well as undertaking strategic planning as an input to policy, government makes strategic decisions about financing specific projects. It does so both indirectly, through decisions to allow foreign finance, and directly, through decisions to approve a project's access to government finance mechanisms. A joules per drop analysis could help elucidate the water/energy tradeoffs in these decisions, including how these tradeoffs compare between energy sources and locations.

At the federal level, one such context is a decision under the *Foreign Acquisitions and Takeovers Act 1975 (Cth)* by the Treasurer to reject certain kinds of proposed investment or acquisition by foreign persons if he or she is satisfied that the investment or acquisition would be 'contrary to the national interest'.[42] Australia's mining industry relies heavily on foreign investment,[43] and a foreign person may require federal clearance to acquire shares in an Australian mining corporation for the purposes of a mining development.[44] Foreign persons also require approval to acquire any interest (of any value) in an Australian mining or production tenement.[45] The relative water efficiency of an energy project is relevant to assessing the national interest (determinants of which are set out in policy, since the term is not defined in the Act) in the consistency of investments 'with the Government's objectives in relation to matters such as environmental impact'.[46] However, a Treasurer would, himself or herself, need to take an enlightened view on the relevance of a joules per drop analysis, since courts are reluctant to interfere with a Treasurer's determination of the national interest.[47] More broadly, generally high levels of public concern have previously led the Treasurer to reject foreign investment on the basis that '[it] could risk undermining public support for the foreign investment regime and ongoing foreign investment more generally, which would not be in the national

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[38] Bram Noble and Kelechi Nwanekezie, 'Conceptualizing strategic environmental assessment: Principles, approaches and research directions' (2017) 62 *Environmental Impact Assessment Review* 165, 167.
[39] Stephen Jay, 'Strategic Environmental Assessment for Energy Production' (2010) 38 *Energy Policy* 3489, 3491.
[40] Simon Marsden, 'The 'Triangle' of Australian Energy Law and Policy: Omissions, Connections and Evaluating Environmental Effects' (2017) 29 Journal of Environmental Law 475, 500-502.
[41] See generally ibid.
[42] *Foreign Acquisitions and Takeovers Act 1975* (Cth) Pt 3.
[43] John Sartori, 'Australia's foreign investment legislation and its application to acquisitions of shares in Australian mining corporations' (2017) 36(2) *Australian Resources and Energy Law Journal* 53, 53.
[44] See generally ibid.
[45] Treasurer (Australia), Australia's Foreign Investment Policy (2019) 4, https://cdn.tspace.gov.au/uploads/sites/82/2018/12/1-January-2019-Policy_.pdf.
[46] Ibid 10.
[47] *Canwest Global Communications Corporation v Treasurer* (1997) 147 ALR 509, 525.

interest'.[48] This might suggest that public outcry or political campaigns about relatively unproductive water use (on a comparative joules per drop basis), particularly in circumstances of water stress and third party effects, might contribute in the same way to reasoning about the national interest in allowing such a foreign investment.

Federal and state governments also provide direct financial support to facilitate investment in the energy sector, for example, through the Clean Energy Finance Corporation (CEFC), which has an investment function in pursuit of a broader object 'to facilitate increased flows of finance into the clean energy sector'.[49] The CEFC may only invest in 'complying investments', which must be 'clean energy technologies' that include low-emission technologies and renewable energy technologies.[50] Its statutory investment policies must deal with investment strategy and risk management.[51] The CEFC's current policy is to assess projects for potential benefits to water quality for investment screening purposes,[52] but there is no mention of the potential for its energy investments to have different (potentially adverse) water *quantity* impacts. This seems anomalous and might be addressed by adopting a joule per drop indicator as one element the CEFC considers, particularly where it is considering applications for finance from multiple projects in the same region. All else being equal, the CEFC may choose to support higher water use productivity clean energy projects, particularly in water stressed areas.

Environmental law scholars have long asked whether environmental investment policies in the financial sector might play a significant role in environmental governance through approaches to corporate social responsibility.[53] Environment-oriented investment policies of private banks[54] might also consider using the joules per drop analysis in a similar way to that suggested above for government finance- and investment-related decisions.

Project-based Environmental Impact Assessment

Project-based EIA is a statutory process that aims to provide information about the likely environmental impacts of a proposed project for use by regulators and the public more broadly. A joules per drop analysis can provide a simple indicator of the tradeoffs between the project's water withdrawal impacts (which must be interpreted in the local context of water stress and ecosystem dependence) and its energy production, and enables comparisons between the environmental impacts of different potential energy projects withdrawing water from the same source.

Some jurisdictions require some degree of description or analysis of alternatives for (or to) a proposed project as part of their project-based EIA legislation and policy—a comparative context in which a joules per drop analysis becomes critically useful. Some form of 'alternatives assessment' is a common feature of EIA

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[48] Treasurer (Australia), 'Foreign Investment Application: Archer Daniels Midland's Proposed Acquisition of GrainCorp Limited' (Press Release, 29 November 2013) http://jbh.ministers.treasury.gov.au/media-release/026-2013/.

[49] Clean Energy Finance Corporation Act 2012 (Cth) ss 3, 9(1)(a), 58.

[50] Clean Energy Finance Corporation Act 2012 (Cth) ss 59, 60.

[51] Clean Energy Finance Corporation Act 2012 (Cth) s 68(1).

[52] Clean Energy Finance Crop, CEFC Investment Policies (Feb 2019) 19, https://www.cefc.com.au/media/402017/cefc-investment-policies-feb-2019.pdf

[53] See, eg, Benjamin J Richardson, 'Can Socially Responsible Investment Provide a Means of Environmental Regulation?' (2009) *Monash University Law Review* 262.

[54] Australian Banking Association, 'Environment', https://www.ausbanking.org.au/banks-in-australia/environment/.

across Australia.[55] Some policy explicitly adopts an 'alternatives *for* the project' approach, differentiating it from requiring analysis of alternatives *to* the project.[56] In the former situation, the alternatives could relate to location, scale or design[57] that may well have a bearing on water use intensity, for example, using water from a different aquifer, using less water-intensive production processes, or analysing how project scale relates to water use intensity. Alternatives *to* the project encompass projects that are entirely different from the proposal, for example, using an entirely different source to produce energy. It is less likely to be viable and expected for private projects in Australia to consider such alternatives, unlike public urban transport projects, for example.[58] Some other jurisdictions do have a practice of considering 'alternatives to' a project even within project-based EIA, and some scholars have even called this 'arguably the most important part of [project-based EIA legislation]'.[59] A joules per drop analysis could assist in analysing the water-related implications of alternatives in both the 'alternatives to' and 'alternatives for' contexts, enabling simple comparison of the water use productivity of each alternative.

A joules per drop analysis may also be relevant to considering the *significance* of a proposed energy project for the purposes of the environmental approvals that are informed by project-based EIA. Under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act), large coal mines and CSG developments (but not other energy developments) require assessment and approval by the Commonwealth Environment Minister if they are likely to have a significant effect on water resources.[60] Among the factors relevant to determining whether a proposed large coal mine or CSG development is likely to have such an impact is whether it will directly or indirectly result in a change to the hydrology or water quality of a water resource 'that is of sufficient scale or intensity as to reduce the current or future utility of the water resource for third party users'.[61] Under current government policy, this 'utility' explicitly includes 'use by other industries'.[62] The amount of energy that can be produced using a given quantity of water in a certain location is a measure of productivity that relates closely to the idea of 'utility'. If a third party could produce more energy from that same quantity of water now or in the future, but the water is instead dedicated to a coal mine or CSG proponent that would produce much less energy using this water, this arguably reduces the current or future utility of that water resource for third party users. This reasoning as to the significance of the impacts of a coal mine or CSG project on a water resource will most plausibly arise in regions with significant alternative energy generation potential where there is high competition for water or other current or future causes of water stress (eg climate change-induced scarcity or dependence on non-renewable groundwater).

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[55] Mandy Elliot, above n 35, 188, 189, 195-196, 259, 260.
[56] Department of Sustainability and Environment (Victoria), Ministerial guidelines for assessment of environmental effects under the Environment Effects Act 1978 (2006) 8, 10, 15, https://www.planning.vic.gov.au/__data/assets/pdf_file/0026/95237/DSE097_EES_FA.pdf.
[57] Ibid 8.
[58] Elliot, above n 35, 195.
[59] Robert V Percival et al, *Environmental Regulation: Law, Science and Policy* (6th ed, Wolters Kluwer, 2009) 911.
[60] *Environment Protection and Biodiversity Conservation Act 1999* (Cth) s 24D.
[61] Department of the Environment (Commonwealth), *Significant Impact Guidelines 1.3: Coal seam gas and large coal mining developments - impacts on water resources* (2013) 16.
[62] Ibid.

Water Entitlements

In addition to project-specific assessment of environmental impacts under environmental laws, an energy project may require a water entitlement issued under a state or territory's water laws in order to take and use water. A joules per drop analysis may be relevant to a decision maker considering an application for a water entitlement where this is required. Some jurisdictions continue the historical practice of exempting mining and petroleum projects from the requirement to hold a water entitlement, or only require a water licence for direct pumping of water,[63] meaning that a development may use water to some degree without an approval under a state or territory water law. Renewable energy projects have not historically benefited from special exemptions. In 2004, when Australian governments signed the National Water Initiative and committed to reform their water laws, they agreed that 'special circumstances' affected the minerals and petroleum sectors, which require 'specific management arrangements outside the scope of this Agreement',[64] rather than requiring these industries to obtain the same water-related approvals as other industries.

This policy position is now changing as public concern about water use by extractive industries increases.[65] The Australian federal Parliament recently scrutinised water use by extractive industries (though not that by renewable energy developments).[66] It supported and re-stated an earlier recommendation of the Productivity Commission that 'state and territory water entitlement and planning frameworks explicitly incorporate extractive industries'.[67] In line with this position, in late 2018, the Northern Territory removed its water licensing exemptions for mining and petroleum.[68] Water licensing is therefore relevant for energy-related projects to differing degrees in different jurisdictions, and this is an area of active legal change.

For energy developments that require a water entitlement, the process of considering an application for a new entitlement may raise considerations to which a joules per drop analysis is relevant. For example, in considering whether to grant a licence to 'take and use' groundwater in Victoria, the Minister must consider broadly worded matters that implicitly relate to efficiency, productivity and comparisons with other water users, for example, 'the conservation policy of the Government', 'government policies concerning the preferred allocation or use of water resources', 'the purposes for which the water is to be used' and 'the needs of other potential applicants'.[69] Though judicial interpretation of these phrases is relatively scarce, they might plausibly encompass a metric such as joules per drop where there is a comparison to be made between competing aspiring energy sector water users in a particular location. In other jurisdictions, the pursuit of broadly worded and often undefined water efficiency objectives[70] may occur in other ways, for

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[63] Productivity Commission, *National Water Reform: Productivity Commission Inquiry Report* (2017) 82-83 https://www.pc.gov.au/__data/assets/pdf_file/0007/228175/water-reform.pdf.

[64] *Intergovernmental Agreement on a National Water Initiative between the Commonwealth of Australia and the Governments of New South Wales, Victoria, Queensland, South Australia, the Australian Capital Territory and the Northern Territory*, 25 June 2004, para 34, pp. 6–7, http://www.agriculture.gov.au/SiteCollectionDocuments/water/Intergovernmental-Agreement-on-a-national-water-initiative.pdf

[65] Productivity Commission, above n 63, 81.

[66] Australian Senate Environment and Communications References Committee, *Adequacy of the regulatory framework governing water use by the extractive industry* (2018).

[67] Ibid [5.40].

[68] *Water Legislation Amendment Act 2018* (NT) s 5 (amending the *Water Act 1992* (NT) s 7).

[69] *Water Act 1989* (Vic) ss 40(1)(i), (j), (l), (m), 51(1)(b), 53(1)(b).

[70] For a general discussion of the lack of legal clarity around the concept of water efficiency in the groundwater context, see Madeleine Hartley, 'Regulating for groundwater-use efficiency: A toolbox approach

example in decision-makers considering statutory objects that relate to efficiency, such as 'promot[ing] the efficient use of water through … the initial allocation of water' (or similar).[71]

It should be noted that considering a joules per drop analysis under legal provisions that deal with efficiency is likely only relevant in the context of water entitlements that are 'bundled' with land (that is, tied to use of the water on a particular parcel of land for a particular purpose), which generally is the case for groundwater. It is likely minimally relevant to the type of 'unbundled' water entitlements that resulted from two decades of water reforms in many jurisdictions.[72] In the latter situation, which generally applies to surface water in many jurisdictions, water may be traded without needing to consider how or where it will be used (because water use is dealt with under a separate site use approval, separate from the water share or water allocation), provided trading rules are met. Water markets are considered inherently to maximise the economic productivity of water use, and in this sense, efficiency.[73]

Allocations Made to Water Entitlements and Risks of Changes to Legal Water Availability

Beyond the issue of entitlements for energy projects, Australia's water law frameworks for allocating water to entitlements mean that a joules per drop analysis provides an important way to understand the water-related risks that a project may face during its operation, which is relevant to both managers and stakeholders. In many Australian jurisdictions, holding a water entitlement is equivalent to having a bank account: the entitlement holder still needs to be allocated water against the entitlement to be able to use it.[74] This process must be consistent with the regionally applicable water plan, and takes into account seasonal conditions and environmental requirements determined in law.[75] Even where a mining or energy development entrant may be granted a water entitlement, or be able to buy an existing water entitlement in a fully allocated system, that entitlement may not mean access to real water if that region's seasonal determination of available water means that limited or no water allocations are made to entitlements—a situation with which irrigators are familiar during drought. Forms of high security entitlements mentioned above mean that allocations are more likely to be higher in dry years, compared to lower security entitlements.

Projects that have high 'drops per joule' during their operation (as opposed to construction) face higher risks in terms of legally-influenced water scarcity, that is, higher risks that the project's operation may be affected by water not being legally available at important times. The risks that water availability poses to mining have long been recognised,[76] including the risk that 'regulatory water shortages' caused by 'increased regulation and reduced water rights' might lead to cuts in production.[77] This concern is arguably heightened in contemporary Australia with policy changes regarding water licensing exemptions for mining. Neither existing water risk disclosure metrics or policies for relevant industries, such as the Minerals Council of Australia's

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based on the experiences of three disparate jurisdictions' (2014) 31 *Environmental and Planning Law Journal* 92, 93-98.

[71] *Water Act 2000* (Qld) s 2(2)(g)(ii). See also *Rights in Water and Irrigation Act 1914* (WA) s 4(1)(b).

[72] Alex Gardner et al, *Water Resources Law* (2d ed, 2017) [12.8]-[12.9].

[73] See generally ibid Ch 23.

[74] Eg Ibid 25.19 (in relation to NSW).

[75] Ibid [12.7], [12.14].

[76] Eg Amanda Sauer and Marta Miranda, *Mine the Gap: Connecting Water Risks and Disclosure in the Mining Sector* (World Resources Institute, 2010), https://www.wri.org/publication/mine-gap.

[77] Ibid 5.

water policy and accounting framework,[78] nor investors' water risk tools such as the Ceres Aqua Gauge,[79] require or facilitate a 'joules per drop' analysis, though they do require measurement of water use. A 'joules per drop' analysis would provide a consistent, standardised way of quantifying how an energy project's key economic output depends on its water inputs in the context of water law-influenced risks to water availability.

Marketing Representations about Sustainability to Energy Consumers

Even after energy has been produced, a joules per drop analysis is relevant to consumers assessing the 'green' credentials of information about energy that they currently receive. A joules per drop analysis might even form the basis of expanded requirements to provide better information. Consumer laws regulate claims made about the 'environmental friendliness' of products.[80] Concerns about environmental claims in marketing have arisen alongside the rise of consumers' environmental awareness. Australian regulators have issued guidance for business to ensure environmental claims in marketing comply with the requirements of the Australian Consumer Law (and its predecessors) for over 25 years.[81] Most importantly, businesses must not engage in any conduct that is likely to mislead or deceive consumers.[82] The Australian Competition and Consumer Commission's (ACCC) current guidance on 'renewable' or 'green' energy does not mention ways in which renewable energy may have environmental impacts other than greenhouse gas emissions,[83] for example through use of scarce water. However, relatively broad claims about 'green-ness' would seem to imply that an energy product is 'completely environmentally benign', which has the potential to deceive consumers, and against which the ACCC specifically warns.[84] Energy businesses that advertise renewable energy as 'green energy' or similar, without further disclosure, might consider the ACCC's recommendation that some types of environmental claims 'should be quantified by comparison to existing benchmarks or rating systems, or otherwise explained in more detail'.[85] The joules per drop analysis could well serve as such a benchmark system in relation to the water use of different energy sources.

Popularising a joules per drop analysis could well have larger benefits than ensuring that consumers are not deceived: an energy-water analysis might also positively influence consumers' behaviour in purchasing energy. A starting point might be to include such information in independent 'star rating' analyses of the environmental performance of Australian energy providers, which, in relevant part, is currently based only on

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78 Minerals Council of Australia, Water Policy (2012) http://minerals.org.au/sites/default/files/MCA%20Water%20Policy%202012.pdf; Minerals Council of Australia, Water Accounting Framework for the Minerals Industry: User Guide V 1.3 (2014) https://minerals.org.au/sites/default/files/WAF_UserGuide_v1.3_%28Jan_2014%29.pdf.
79 Ceres, Ceres Aqua Gauge: A Comprehensive Assessment Tool for Evaluating Corporate Management of Water Risk, https://www.ceres.org/resources/tools/ceres-aqua-gauge-comprehensive-assessment-tool-evaluating-corporate-management
80 For discussion of consumer laws in this specific context, see Australian Competition and Consumer Commission (ACCC), Green Marketing and the Australian Consumer Law (2011), https://www.accc.gov.au/system/files/Green%20marketing%20and%20the%20ACL.pdf.
81 Marine Nehme and Michael Adams, 'Section 18 of the Australian Consumer Law and Environmental Issues' (2012) 24(1) Bond Law Review 30, 53.
82 Competition and Consumer Act 2010 (Cth) Sch 2 s 18.
83 ACCC above n 80, 14.
84 Ibid 23.
85 Ibid 13.

emissions intensity.[86] A more legally formal approach is also worth noting. Australian consumers have become familiar with the 'water star' ratings available on water-using technologies such as dishwashers, toilets and showers. Originally a voluntary scheme operating in Melbourne, this rating system is now established under the *Water Efficiency Labelling and Standards Act 2005* (Cth) and corresponding legislation in the states and territories.[87] It has successfully and cost-effectively generated water savings through changed consumer behaviour.[88]

Might the water star ratings experience suggest that a joules per drop rating could influence energy purchase behaviour, even if consumers do not directly benefit financially from choosing less water-intensive energy production? A recent study of household behaviour in 11 OECD countries, including Australia, found a link between households that engaged in water-saving behaviour and those that engaged in energy-saving behaviour; it also found that labelling and rating schemes for either water or energy appeared to generate 'twin benefits' in influencing the other area.[89] Such behaviour was also correlated with attitudinal factors attributing importance to, and concern about, the environment.[90] While certainly not conclusive, the study confirms a link between water issues, energy issues, and environmental awareness that at least raises the potential of a joules per drop rating to influence consumer behaviour. It also highlights a scholarly and practical gap at the intersection of the water-energy nexus and eco-labelling. However, in investigating the potential value to consumers of water-energy disclosures, reformers should consider the possibility of undesirable backlash against high water-use, renewable energy projects in the context of climate change concerns.

SUMMARY AND ONGOING WORK

The use of electricity involves a hidden flow of water which is often overlooked. The limited attention given to water for energy use is partly attributed to the relatively small total water use by the mining and electricity generation sectors. Yet, the transition to an increasing proportion of unconventional gas and renewable energy sources has implications for water resources, particularly in relatively dry, water stressed and fully allocated catchments. Wind energy, solar PV and CSG from the Sydney Basin near Camden could generate the most joules per drop of water. However, biomass energy, solar thermal and some coal and CSG projects generate relatively few joules per drop of water, or use more water per unit of energy produced.

It is good news that water savings are expected by replacing coal fired and water cooled electricity generation, with air-cooled gas based electricity, wind energy and solar PV. The direct water use of extracting unconventional gas from the ground, appears to be similar in range to other primary energy sources. However, the indirect water used by gas-based electricity generation is significantly less compared to coal-based electricity generation. Australian experience in CSG has indicated that actual volumes of co-

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[86] Alviss Consulting, 2018 Green Electricity Guide: Report on the Methodology and Results (2018) https://www.greenelectricityguide.org.au/wp-content/uploads/2018/03/2018-GEG-Final-13-Feb-2018-V.2.pdf, see also https://www.greenelectricityguide.org.au/.

[87] Chris Guest, *Independent Review of the Water Efficiency Labelling and Standards Scheme* (2010) 8, http://www.waterrating.gov.au/SiteCollectionDocuments/2010-WELS-scheme-review-final-report.pdf.

[88] Ibid 9.

[89] To Dieu-Hang et al, 'Household adoption of energy and water-efficient appliances: An analysis of attitudes, labelling and complementary green behaviours in selected OECD countries' (2017) 197 *Journal of Environmental Management* 140, 147.

[90] Ibid 146.

produced water are less than predicted, and decrease over time. At this early stage of development it is unknown whether similar trends in direct water use occur with other types of unconventional gas extraction in Australia, including shale gas and tight gas.

Collating more baseline data for comparison of these primary energy sources and subsequent use in electricity generation is important. New opportunities can be identified to reduce fresh water diversions (ie a goal of more joules per drop) during extraction and utilization of energy. Future planning could explicitly consider increasing the joules produced per drop of fresh water diverted or consumed during primary energy extraction and electricity production. The sustainability of our energy systems is yet to consider both reduction of greenhouse gas emissions and increasing the energy produced per drop of water, particularly for water stressed areas. Optimizing energy reliability, affordability and sustainability for energy systems in transition is a critical challenge.