The water impacts of climate change mitigation measures

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Abstract

A variety of proposed activities to mitigate greenhouse gas emissions will impact on scarce water resources, which are coming under increasing pressure in many countries due to population growth and shifting weather patterns. However, the integrated analysis of water and carbon impacts has been given limited attention in greenhouse mitigation planning. In this Australian case study, we analyse a suite of 74 mitigation measures ranked as highest priority by one influential analysis, and we find that they have highly variable consequences for water quantity. We find: (1) The largest impacts result from land-based sequestration, which has the potential to intercept large quantities of water and reduce catchment yields, estimated to exceed 100 $Mm^3/MtCO_2$-e of carbon mitigated (100,000 litres per tonne CO_2-e). (2) Moderate impacts result from some renewable power options, including solar thermal power with a water cost estimated at nearly 4 $Mm^3/MtCO_2$-e. However, the water impacts of solar thermal power facilities could be reduced by designing them to use existing power-related water supplies or to use air or salt-water cooling. (3) Wind power, biogas, solar photovoltaics, energy efficiency and operational improvements to existing power sources can reduce water demand through offsetting the water used to cool thermal power generation, with minor savings estimated at 2 $Mm^3/MtCO_2$-e and amounting to nearly 100 Mm^3 of water saved in Australia per annum in 2020. This integrated analysis significantly changes the attractiveness of some mitigation options, compared to this case where water impacts are not considered.

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Introduction

In the challenging political environment of climate change policy, frameworks that focus on the mitigation of greenhouse gas emissions rarely consider the consequences for other policy areas, such as the governance of water resources (Pittock 2011). Water impacts are of concern in much of the world, and especially so in the case of Australia, a largely arid country that has recently made enormous investments in water security, such as desalination plants in the major cities. However, despite the global need for climate, energy and water policies and analyses that are integrated (Hightower and Pierce 2008; Howells et al. 2013), the water impacts of carbon mitigation and energy development strategies, as yet, have received limited consideration. In this paper we provide an integrated analysis of the water impacts of climate change mitigation strategies for Australia in three major sectors: land-based sequestration, renewable power generation, and energy efficiency. Throughout this paper, water impacts refer to water consumption rather than withdrawal.

Mitigation prioritisation tools, such as marginal carbon abatement cost curves, are one method to present options for reducing greenhouse gas emissions or sequestering carbon. Prioritising mitigation options across multiple sectors from low to high marginal abatement cost has a strong economic logic, so long as the information underpinning the cost curve is comprehensive and correct. However, it is important to include indirect and social costs, such as those associated with water impacts, which are often ignored.

In Australia, the ClimateWorks 2020 greenhouse gas emissions reduction societal cost curve (based on the McKinsey & Company methodology; ClimateWorks Australia, 2010; p.10) presents 74 opportunities to reduce emissions by 249 $MtCO_2$-e per annum in 2020; a 25 per cent reduction on 2000 emissions. Of the 74 mitigation measures assessed, 64 are estimated to have a water benefit or are water neutral. These account for approximately 145 Mm^3 of water savings per annum in 2020 associated with 178 $MtCO_2$-e (~70 per cent) of a possible 249 $MtCO_2$-e of the total mitigation volume possible in the abatement cost curve. Of the remaining eight measures, five collectively have a water cost of 34 Mm^3 per annum in 2020 associated with 22 $MtCO_2$-e (~10 per cent) of the total mitigation volume. Three reforestation measures have a potential estimated water cost of 6,000 Mm^3 in 2020 associated with 49 $MtCO_2$-e (~20 per cent) of the total mitigation volume. We find that properly accounting for these water impacts would significantly change the ordering in which some mitigation policies would be prioritised, especially these water-intensive afforestation options. Moreover, water savings resulting from some already attractive mitigation options, especially in energy efficiency, would further enhance the case for these.

1 Policy Context

Australia has a commitment to reduce emissions by 5 per cent compared to 2000 levels by 2020 and 80 per cent by 2050. Under business as usual, emissions are projected to increase to 24 per cent above 2000 levels,by 2020 (Department of the Environment 2014). While the climate change policy context in Australia is complex and evolving, policies direct a range of activities in the land, power and energy efficiency 'sectors', detailed below, that align with the abatement opportunities identified in the cost curve, but which mostly do not consider water impacts.

The importance of water is highlighted by the fact that Australia has the most variable arid climate in the world, with about 80 per cent of the country receiving rainfall of less than 600 mm per year (Mushtaq et al. 2013). This variability in rainfall poses challenges for both urban and rural water provision. Australia's major cities are primarily located on the coast and rely extensively on surface-water extraction and storage to meet urban needs. Urban water supplies in Australia were severely affected by a decade of drought spanning from the late 1990s until the late 2000s resulting in widespread and costly water restrictions, which highlighted the vulnerability of rainfall dependent urban water supplies (Grafton and Ward 2008). Subsequently, governments invested heavily in new 'rainfall independent' infrastructure such as desalination plants in most major cities (Cook et al. 2012). This shift in water supply sources has increased both the cost and energy consumption associated with urban water provision (Retamal et al. 2009; Cook et al. 2012). In rural settings, such as Australia's Murray-Darling Basin, water is over-allocated and entitlement to use it can cost upward of \$1,000 per ML depending on location, seasonal climate, and type of entitlement.

1.1. Land-based sequestration

In the land sector, the Australian *Carbon Farming Initiative* established in 2011 is designed to provide incentives for land-based mitigation. Modelled on the international *Clean Development Mechanism,* this policy enables owners to sell credits from carbon sequestered on their land using approved methodologies for additional activities (Australian Government 2011). However, afforestation may significantly reduce water availability in many catchments with already stressed water supplies (van Dijk and Keenan 2007), though estimates vary (Herron et al. 2002; Brown et al. 2007). In an attempt to manage this carbon sequestration and water trade-off, complex regulations were adopted (DCCEE 2011). In the areas of Australia that receive enough rainfall to generate run-off, above 600 mm average annual rainfall, plantings are only eligible for carbon credits if: a) they are in regionally approved areas, and b) established for biodiversity conservation rather than production of commercial products. However the regional planning process is in its infancy, while government and carbon credit income may see significant areas of land afforested for biodiversity.

Agriculture absorbs 60 per cent of water consumption, but due to persistent droughts this reduced from 16,000 Mm^3 (2001/2002) to 7,000 Mm^3 (2007/2008) within the Murray-Darling Basin. During drought periods, irrigation water demand exceeds the water supply thus creating potential for water trade. Based on spot water market prices for the periods from 2001 to 2009, the annual opportunity cost of water in the Murray-Darling Basin ranges up to A\$1,100 per ML (A\$1,100,000 / Mm^3), depending on region, year, and priority of use; see e.g. Psi Delta (2012). There are national targets for water use, but these are more qualitative than quantitative; for example, a commitment to restore sustainable levels of diversion in over-allocated water systems (NWC 2011). Looking to the future, there are significant concerns about the longer-term impact of climate change and climate variability on water availability in Australia. It is expected that, with climate change, future average water availability will decline and that the frequency of extreme events such as drought will increase (Sanders et al. 2010).

1.2. Power generation sector

The 2010-11 water account for Australia reports that the electricity and gas sector consumed 298 Mm^3 of water during that 12-month span, excluding once-through use, comprising 2.2 per cent of total water consumption (ABS 2011). While this is a small proportion, energy generation is often focused in localised areas where water creates competition with other users and ecosystems (Marsh 2009). In nations that experience severe and prolonged water shortages, such as Australia, water and energy policies need to be integrated.

1.3. Energy efficiency measures

As most of the opportunity for energy efficiency improvements is associated with privately-owned infrastructure, much of the government-supported activity has focused on information provision. In 2009, the Council of Australian Governments (COAG) released a *National Strategy on Energy Efficiency* that set out broad areas for enhancing uptake of energy efficiency: (1) household and industry assistance, (2) addressing impediments (mainly in markets), (3) increasing building efficiency standards, and (4) improving the energy efficiency of government operations.

2 Methodology

The aim of this analysis is to demonstrate how various mitigation options would impact on water resources, and the extent to which water considerations would change the relative attractiveness of mitigation options. To provide a baseline reference point, we use the potential mitigation measures described in the ClimateWorks Australia (2010) *Low Carbon Growth Plan for Australia,* which has been influential in Australian policy debates.

For the purpose of this analysis, the ClimateWorks Australia analysis provides a cross-section of possible mitigation measures in the Australian context, which are considered plausible by policymakers. In this paper, we add another layer of analysis for water volumes on the carbon mitigation volumes published in this particular cost curve. The true costs of abatement are contested and not peer-reviewed (Kesicki and Ekins 2012). Specific criticisms made include the partial equilibrium nature of the economic analysis, capturing only 'techno-engineering costs', and omitting some carbon mitigation that would have happened in business as usual (ITS Global 2013). However, the purpose of this paper is not to validate or invalidate these specific cost estimates. The purpose is to understand the water cost added to carbon mitigation options, and we use mitigation priorities identified in the ClimateWorks cost curve as a springboard for investigating the water needs and costs for these options. Information on the potential volume ($MtCO_2$-e) of mitigation measures from different policy sectors are taken as given for our analysis of the water consequences.

2.1. Calculating water consumption from electricity demand reduction

To estimate the potential water savings resulting from thermal power offsetting, a comparison of the 2020 'business as usual' case and the 2020 'carbon abatement case' (ClimateWorks Australia 2010; p.38) was conducted and the results are presented in Table 1. From this analysis, we derived the following calculations. Coal/lignite-based power generation reduced from 184 TWh in business as usual case to 65 TWh in the emissions reduction case in 2020 through electricity demand reduction. Following Table 1, this relates to a 179 Mm^3 saving in water volume from lignite/coal reduction. According to supplied data from ClimateWorks Australia (see Supplementary Information), 122 $MtCO_2$-e pa in 2020 of mitigation is due to electricity reduction. Therefore, an average water saving of 1.46 $Mm^3/MtCO_2$-e was calculated as resulting from thermal power offsetting.

2.2. Calculating water consumption from solar thermal power

Solar thermal power accounts for an additional 13 TWh of power in the 2020 emissions reduction case, with a water footprint of 3.18 Mm^3/TWh (mid-point value from US data; Carter 2010; p.32), equalling 38.16 Mm^3 of extra water consumption. Solar thermal accounts for 10.2 $MtCO_2$-e pa in 2020 of mitigation and thus corresponds to a water cost of 3.74 $Mm^3/MtCO_2$-e.

2.3. Calculating water consumption from geothermal power

Geothermal power accounts for an additional 2 TWh of power in the 2020 emissions reduction case, with a water footprint of 2.21 Mm^3/TWh (average value from US data; Carter 2010; p.31), equalling 4.42 Mm^3 of extra water consumption. Geothermal power accounts for 2.3 $MtCO_2$-e pa in 2020 of mitigation and thus corresponds to a water cost of 1.92 $Mm^3/MtCO_2$-e.

2.4. Calculating water consumption from carbon capture and storage

Carbon capture and storage (assumed to be the same for coal and gas CCS) accounts for an extra 11 TWh of power in the 2020 emissions reduction case, with a water footprint of 2.11 Mm^3/TWh (average value for conventional coal from US data; Carter 2010; p.31), equalling 23.21 Mm^3 of extra water consumption. CCS accounts for 9.5 $MtCO_2$-e pa in 2020 of mitigation and thus corresponds to a water cost of 2.49 $Mm^3/MtCO_2$-e.

2.5. Calculating water consumption from increased gas utilisation

Increased gas consumption for electricity generation accounts for an extra 12 TWh of power in the 2020 emissions reduction case, with a water footprint of 0.56 Mm^3/TWh (Smart and Aspinall 2009; p.1), equalling 6.72 Mm^3 of extra water consumption. We have assumed that this modelled increase in domestic gas consumption is feasible and can occur without additional water impacts (e.g. on coal seam aquifers). Coal-to-gas shift accounts for 24.3 $MtCO_2$-e pa in 2020 of mitigation. The water impact of increased gas use corresponds to cost of 0.28 $Mm^3/MtCO_2$-e, which is offset by the water saving from decreased coal use of 1.46 $Mm^3/MtCO_2$-e. Therefore, the overall water impact of coal-to-gas shift was calculated to be a saving of 1.18 $Mm^3/MtCO_2$-e.

2.6. Calculating water volume reduction from transport fuel efficiency

Gasoline and diesel have an averaged emissions factor of 2,400 $kgCO_2/m^3$ of liquid fuel, used here as 2.4 $MtCO_2$-e/Mm^3 (averaged for CO_2 only from US data; US EPA 2011; p.2). Each $MtCO_2$-e of mitigation from fuel efficiency then roughly equates to 0.42 Mm^3 of fuel. The water footprint of fuel is taken as 1.75 m^3_{water}/m^3_{fuel} (mid-point value for conventional petroleum gasoline and diesel from

US data; Gleick 1994 cited in King and Webber 2008; p.7867), corresponding to a water saving of 0.73 $MtCO_2$-e/Mm^3.

2.7. Calculating catchment water yield reduction from forestry

The volume of water that is intercepted or withdrawn through these mechanisms varies depending on the location. A value of at least 0.1 Mm^3/km^2 (Zhang et al. 2001; NWC 2012; p.144) is estimated for runoff reduction due to the conversion of agricultural crop/pasture land to forestry. Water impact can be calculated with provided values of sequestration rates of between 7.0-10.0 tCO_2-e/ha/yr and planting rates of 50,000-350,000 ha/yr (ClimateWorks Australia 2010; p.116; based on Polglase 2008; see also Polglase 2013). For example, the measure 'reforestation of marginal land with timber plantation' is planted at 50,000 ha/yr (500 km^2/yr). At this planting rate, over ten years, there would be a total area of 5,000 km^2 planted by 2020. The provided value of 8.8 tCO_2-e/ha/yr (8.8×10^{-4} $MtCO_2$-e/km^2/yr) results in a total mitigation of 4.4 $MtCO_2$-e pa in 2020. The water footprint, calculated at 0.1 Mm^3/km^2, would equal 500 Mm^3 in 2020, divided by 4.4 $MtCO_2$-e of mitigation, and thus corresponds to a water cost of 114 Mm^3/$MtCO_2$-e. Note that this value assumes a constant water impact across different sequestration rates per ha.

3 Results

The results of this analysis are presented in Fig. 1, which shows three clear regions of interest. (1) The most striking element is shown in Fig. 1 (inset), which represents three afforestation measures that have significantly higher water costs to the point that they are off the main chart. (2) The top half of Fig. 1 represents lower-priority measures that have variable water costs and savings, and could be reprioritised if water costs and savings were taken into account. (3) The measures in the bottom-left quarter of Fig. 1 are those that are already high-priority activities that would be even more attractive when water savings are taken into account. In the following we discuss these three areas of the results in more detail.

3.1. Mitigation measures with major negative water impacts

The three green circles to the far right in Fig. 1 (inset) represent afforestation measures that have major impacts on water. The afforestation of cleared land intercepts substantial volumes of water, estimated at 0.1 Mm^3/km^2 (NWC 2012; p.144). The change in land use is also important, from both water and economic perspectives, as going from marginal or non-marginal land to either well-managed or poorly managed forests will give different outcomes (Herron et al. 2002).

The water impact also depends on where land is afforested, the tree species used, the pattern, scale and density of planting and the harvesting period (van Dijk and Keenan 2007). Careful selection of planting type and location can ameliorate the water impact; for instance, the Mallee sands regions of southern Australia that have little or no connected surface drainage might have less impact than planting in the uplands of the Murray River. The total area planted is also a factor in estimating the impact on catchment water yields. Estimates of the area of total afforestation viable under various carbon pricing scenarios range from 0 MHa up to 104 MHa (Mitchell et al. 2012; Polglase et al. 2011), compared to a relatively conservative 6 MHa by 2020 proposed in the ClimateWorks Australia (2010) analysis. Polglase et al. (2013) published a detailed analysis of afforestation for carbon offsetting in Australia, considering a range of economic and social factors, finding that for the most plausible set of assumptions a carbon price of AUD\$40 t CO_2^{-1} would be required for profitability.

Using an indicative price of A\$500,000/Mm^3 (\$500/ML) in water trading, in line with Polglase et al. 2011 and Psi Delta 2012, the intercepted water would incur an additional A\$50-70/tCO_2-e per annum in 2020. Given that the marginal cost of abatement was calculated to be A\$27/tCO_2-e at most for afforestation, then the cost of water adds substantially to this cost. However, unless the water use is in a regulated catchment and a water use license is required to be purchased, then this cost is not borne by the mitigator.

3.2. Low-priority mitigation measures that might be reprioritised due to water impacts

The top half of Fig. 1 depicts mitigation measures that were assessed as lower priority in the original cost curve. Those in the top-left quarter generate water savings, while those in the top-right quarter impose a water cost. This section of the graph is particularly important from a policy perspective, because it captures mitigation options that are sufficiently high cost that some may not be pursued. If the difference between water costs and savings was taken into account, then some of these similar-priority measures might be reprioritised, such that a water-saving measure previously above the cost cut-off would be pursued in place of a water-using measure.

For example, while solar photovoltaics generate water savings of 1.46 $Mm^3/MtCO_2$-e, current solar thermal power generation technology, assumed to consume water through the use of wet cooling towers or once-through cooling, has a water cost of 2.28 $Mm^3/MtCO_2$-e. This adds up to a difference in water use of 3.74 $Mm^3/MtCO_2$-e, which given the same indicative water price of A\$500,000/Mm^3 would alter the cost difference between the two measures by about A\$2/$MtCO_2$-e, close to 10 per cent of the current price of carbon in Australia. Potentially compounding this water footprint is the potential location of these facilities in sunny, yet dry regions of Australia.

The water footprint of carbon capture and storage varies, depending on the technology used for power generation and CO_2 capture. The operation of post-combustion CO_2 capture on existing power plants would increase specific water consumption due to losses in net power plant energy efficiency. Pre-combustion CO_2 capture techniques, including integrated gasification combined cycle (IGCC), are estimated to have lower specific water consumption (e.g. m^3/MWh_{net}) compared to post-combustion CO_2 capture (Usher et al. 2010). It is important to note that the water consumption increases both per gross MWh generated, but more so per net MWh generated, since fewer MWh are sent to the electricity grid after using internal heat and power for CO_2 capture and compression. For example, the U.S. Department of Energy estimates that supercritical pulverised coal with CO_2 capture consumes 3.2 Mm^3/TWh_{net} (2.7 Mm^3/TWh_{gross}) compared to the same power plant without CO_2 capture at 1.8 Mm^3/TWh_{net} (1.7 Mm^3/TWh_{gross}) (NETL 2010).

Carbon mitigation measures in the transport sector would reduce liquid fuel consumption through fuel efficiency improvements, causing a corresponding reduction in water consumption. While electric vehicles were excluded from the Australian analysis, one analysis highlighted electric vehicles drawing power from the US grid would have a water footprint (L H_2O/km) two to three times that of driving on conventional gasoline (King and Webber 2008) due to the higher water impact of electricity generation. Additional transport water impacts could result from the use of liquid biofuels from irrigated or rain-fed energy crops. However, electric vehicles and biofuels are typically forecast to provide very small mitigation potential before 2020 in the cost curve, so we have not attempted to quantify their impact.

The use of biomass burning for power is complicated. If the biomass feedstock was sourced from waste streams, such as bagasse from sugar crops, or green waste from council waste services, then the impact on water would be negligible. However, if biomass was sourced from purpose-grown crops, then the water impact could potentially be high (Gerbens-Leenes et al. 2008), so too if the crops irrigated or rain-fed, or if they are located in already water-scarce regions or in regions with a high degree of climate variability.

3.3. High-priority mitigation measures with benefits to water and other opportunities

The bottom-left quarter of Fig. 1 depicts mitigation measures where considering water impacts would make these more attractive. The largest water savings (145 Mm^3 from 47 measures totalling 120 $MtCO_2$-e per annum in 2020) result from energy efficiency and power sector measures that reduce the demand for electricity from centralised, water-cooled, non-renewable thermal power plants. The additional cost savings associated with reduced water consumption, while modest at less than A\$1/tCO_2-e, add to the attractiveness of these win-win mitigation measures.

In summary, we found three interesting categories of mitigation measures: (1) measures with large negative water impacts, (2) measures that may be reprioritised after taking water costs or savings into consideration, and (3) measures that are already high-priority but become more attractive when considering water savings. We now examine some of the implications of this integrated analysis for water, energy and carbon policy.

4 Discussion and conclusion

We show the importance of considering water impacts in prioritising greenhouse gas mitigation activities. Our analysis shows that greenhouse gas mitigation measures can both increase and decrease water consumption. Energy efficiency measures reduce water consumption, as do measures in the power sector generally (Fig. 1), although they might change the locations of water consumption and thus its consequences. Land-based mitigation measures are likely to impact on catchment water yields, depending on where planting takes place. However, water and carbon emissions are not necessarily in direct trade-off, because water is location-specific in significance and emissions are not. Some reforestation options may need to be reconsidered, either in the scale of plantings, their location, or the carbon price required for cost effectiveness. However, the possible positive benefits of reforestation – especially environmental plantings – with respect to reducing salinity, erosion, and flooding should also be considered in decision-making (van Dijk and Keenan 2007).

This analysis highlights that the cost-effectiveness of several energy efficiency and renewable power mitigation measures can be improved by accounting for water savings. The analysis underlines the importance in relation to renewable energy, particularly solar thermal power, of identifying technologies and locations that appropriately reflect water constraints. The option of dry cooling of solar thermal power generation can reduce water consumption by 90 per cent, but results in a power efficiency penalty of approximately 10 per cent at peak summer temperatures. In some circumstances, that could in turn lead to higher overall carbon emissions (resulting from the extra generation capacity needed) and an increased cost of electricity (Spies and Dandy 2012).

As a framework assessing the water consequences of mitigation options, this analysis has some general limitations. Firstly, the calculated water consequences presented are based on mechanisms by which mitigation options are known to consume or save water. In some cases, for example mechanisms to sequester carbon in soils, no accurate values for water use could be obtained, or they could plausibly be positive or negative, so the water consequences of these measures have been treated as zero. However, the framework presented allows for the inclusion of these values, as well as revised figures for potential mitigation volumes. Such mechanisms to transparently assess the aggregate costs and benefits across sectors like water, energy and carbon resources are needed to avoid perverse impacts of sectoral decisions. Detailed review of the water quantity and quality impacts associated with carbon mitigation strategies could favour adoption of different measures.

Considering the water-energy-carbon issue from a different perspective, energy is a substantial operational cost in the water industry (Rothausen and Conway 2011). During a decade-long drought in Australia, the energy intensity of water supplies in several major cities doubled or even quadrupled due to increased use of inter-basin transfers and the construction of new desalination plants (Kenway et al. 2008; Retamal et al. 2010). However, an analysis of Australian urban households in 2006/07 revealed that a 15 per cent reduction in the use of residential hot water or an equivalent increase in the efficiency of residential hot water systems would completely offset the total energy used by water utilities providing water to those households (Kenway et al. 2008). Recently, urban water management has been shown to indirectly influence 13 per cent of electricity use plus 18 per cent of Australia’s natural gas uses (Kenway et al. 2011). Reconfiguring cities towards water-efficient and low-energy systems represents both a significant challenge and opportunity.

Current economy-wide carbon abatement analyses have not considered the potential for changes in the water supply and waste-water sectors to reduce emissions. An abatement cost curve for the water sector (WSAA 2012) identifies the least-cost opportunities in the water industry emissions, including energy efficiency measures, renewable energy generation, and diversion or localised treatment of different types of waste-water. Operational energy savings can be obtained through the installation of variable-speed water pumps, installation of small-scale hydroelectric plants, and smart water meters. Emissions produced by sewerage treatment are a source of greenhouse gases, some with high warming potential. Energy capture from these waste gases can reduce the emissions profile of the industry and also provide low-cost energy to its operations. Water demand management for hot water end-uses have the potential for simultaneously reducing both water and energy consumption.

From this Australian case, mitigation measures that carry water co-benefits, especially energy efficiency, ought to be pursued. Other measures, especially sequestration in the landscape, warrant close scrutiny in implementation to ensure that any emissions benefits are not offset by unintended, substantial and costly reductions in water availability for other uses. Other instruments could include planning, funding and regulatory mechanisms including reporting, data management and target setting (Hussey and Pittock 2012), provided they are embedded in a systemic governance framework. This study has focussed on the climate, energy and water nexus, but this approach can be applied to embrace other sectors like agriculture or health to maximise benefits for society.

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Figure 1

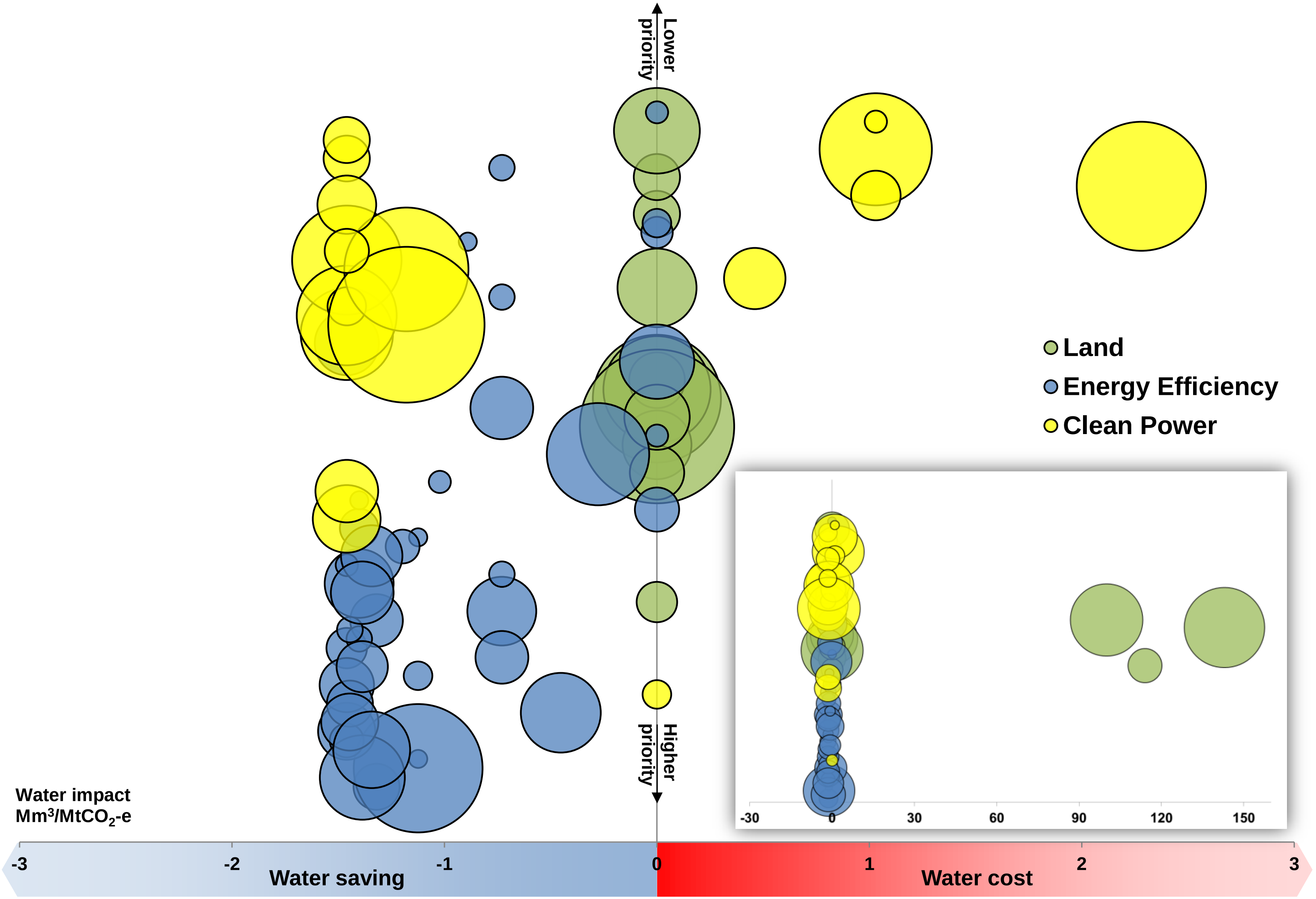

Fig. 1. The water impacts of climate change mitigation measures at a glance.

Each bubble represents a mitigation option, with the size of the bubble proportional to the volume of mitigation opportunity ($MtCO_2$-e). The x-axis represents water impacts ($Mm^3/MtCO_2$-e). The y-axis is the priority of mitigation activity ranked in order of lowest to highest cost, omitting water impacts, per tonne CO_2-e. Inset: Three of the land-based mitigation measures have a much higher water impact, and to preserve detail these are only shown in the inset plot, which is the same information with a full-scale x-axis. Source: y-axis and bubble size from ClimateWorks Australia 2010.

Table 1. Analysis of water consumption for power generation in Australia

		2009-10	**2020 Business as Usual**		**2020 C Abatement Case**		
	Water Intensity	**Current Generation** [d]	**Generation** [e]	**Water Use**	**Generation** [e]	**Water Use**	**Difference**
	Mm^3/TWh	**TWh**	**TWh**	**Mm^3**	**TWh**	**Mm^3**	**Mm^3**
Lignite	1.52 [a]	56	54	82.08	15	22.8	-59.28
Coal	1.50 [a]	125	130	195	50	75	-120
Gas	0.56 [a]	36.2	59	33.04	71	39.76	6.72
Oil	1.48 [b]	2.7	5	7.4	4	5.92	-1.48
CCS	2.11 [b]	0	0	0	11	23.21	23.21
Biomass co-firing	1.59 [b]	0	0	0	1	1.59	1.59
Wind	0.00 [b]	4.8	24	0	37	0	0
Solar	3.18 [b,c]	0.3	2	6.36	14	44.52	38.16
Geothermal	2.21 [b]	0	5	11.05	7	15.47	4.42
Biomass/biogas	1.59 [b]	2.1	9	14.31	14	22.26	7.95
Other	N/A	14	16	N/A	16	N/A	N/A
TOTAL		**241.4**	**304**	**349.24**	**240**	**250.53**	**-98.71**

This table presents a range of power generation sources and their water intensities (Mm^3/TWh). Values for current electricity generation in 2009-10 are given (TWh), as well as generation projected for 2020 under business as usual, and under the carbon abatement case. Water use is calculated using values for water intensity. Sources: [a] Smart and Aspinall 2009; p.1; [b] Carter 2010; pp.31–32; [c] Value for solar-thermal, assuming total installed capacity of 2.9 GW by 2020; [d] ABARES 2011; Table O; [e] ClimateWorks Australia 2010; p.38.