A framework for assessing integrated water and energy management scenarios

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Abstract

Water and energy management strategies in Australia have undergone unprecedented change over the last two decades, as a result of reforms initiated by State and Federal governments. These reforms brought about changes to the structure, ownership and regulatory arrangements of the sectors. While the dominant focus of reform has been economic, developments in the recent past, for example, the prevalence of drought, and recognition of the climate change impact of water and energy use, have added a strong environmental focus to reform. This focus has prompted a debate on the nature of the link between water and energy. It appears, however, that debate is not presently informed by any coherent analysis of the relationship between the two sectors. To address this shortcoming, this paper presents an integrated framework based on water- and energy-oriented input-output analysis. This framework could be employed to assess the economy-wide impacts of possible future water and energy developments and builds upon earlier research into the nature of the nexus undertaken by the authors. Outcomes from this assessment would offer valuable inputs for the development of future water and energy management strategies.

1 Introduction

Water and energy management strategies in Australia have changed significantly over the last two decades as a result of reforms initiated by State and Federal governments. These reforms brought about changes to the structure, ownership and regulatory arrangements of the sectors. While the dominant focus of reform has been economic, the prevalence of drought, and recognition of the climate change impact of water and energy use, have added a strong environmental focus to reform. This focus has increased awareness of the links between water and energy, termed water-energy nexus in this paper. It appears, however, that water and energy management strategies are being developed with little understanding of the nature of the nexus. This paper seeks to contribute to a greater understanding of the nature of the nexus by developing a framework that could allow for the assessment of the implications for future water and energy scenarios for New South Wales for the year 2030-31. It begins by reviewing the evolution of water and energy management strategies in Australia, with a view to determine the main drivers influencing their development. The paper then discusses how recent water and energy management strategies, in the context of drought and climate change, have contributed to greater uncertainties and challenges for both sectors, due to the inherent links between water and energy. The paper argues that there is a need to improve current understanding of these links, to ensure that future water and energy management strategies are appropriately integrated in order to handle the challenges, as well as to take advantage of opportunities that these links present. An assessment framework that integrates future water and energy scenarios for New South Wales is then introduced. Each scenario within the framework comprises a combination of social values and governance systems that underpins the selection of technologies to meet water and energy needs. This paper finishes by describing the development of these models for the year 2030-31, which are based on input-output analysis. Outcomes from this assessment would offer valuable inputs for future development of water and energy management strategies.

2 Developments in water and energy management strategies

Water and energy management strategies in Australia have changed significantly since the mid 1900s. During this time, state and/or local governments were responsible for water and electricity utilities and many utilities were vertically-integrated (Johnson & Rix 1993; Smith 1998). Operational and infrastructure planning decisions were largely an engineering exercise, as both sectors focused on meeting the needs of Australia's growing population in the aftermath of World War 2. Indeed, water and electricity infrastructure projects were viewed as critical to national development and received strong social and political support. Cost recovery and environmental considerations were therefore accorded low priority (Department of Resources and Energy 1983).

The Snowy Mountains Hydroelectric Scheme became the first water and electricity project to harness Federal government resources, in cooperation with the state governments of New South Wales and Victoria. Located near the border of both states, construction of the Scheme began in 1947 and was completed in 1974 (Australian Government). By default it became the first inter-state electricity connection in Australia. To this day the Scheme serves a dual role of generating hydropower - providing 6%[1] of Australia's electricity - and of diverting water for irrigation systems downstream.

Towards the end of the 20th century, changes were afoot in both sectors. Concerns were being raised about their financial, service and environmental performance. In terms of financial, assumptions underpinning investment and pricing regimes were queried. Government involvement – which had previously been considered important for economic growth and encouraging private investment in other sectors of the economy – was viewed as inefficient (Booth 2000; Broughton 1999; Smith 1998). Both sectors had also established subsidy patterns to fulfill social and political objectives. In the electricity sector for example, domestic customers in rural areas were heavily subsidised by other customer groups (Rosenthal & Russ 1988). Cross subsidies also occurred between the two sectors. In the case of the Snowy Mountains Hydroelectric Scheme, electricity sales subsidized the irrigation diversion works that would otherwise not have been possible (New South Wales Water Resources Commission 1984).

Environmentally, there was greater evidence and awareness of degradation resulting from the sector' activities. In the water sector, poor management of water resources caused reduction in river water quality and river health (High Level Steering Group on Water 1999). In both sectors, infrastructure projects - particularly dam construction - came under closer environmental scrutiny. The Franklin Dam in Tasmania, for example, became a landmark case in 1983, whereby environmental interests and political will overturned the decision to construct a hydro-electric power station in a pristine area of south west Tasmania (Dovers 2001).

[1] Calculated from data in (Energy Supply Association of Australia 2006)

To address these and other concerns, State governments began to review their water and electricity sectors in the 1980s, which constituted the first phase of reform. Despite these early reforms, the sectors became subsumed under the widespread micro-economic reforms initiated by the Federal governments in the early to mid 1990s, which were aimed at improving the competitiveness of the Australian economy overall. Similar changes were made to the structure, ownership and regulatory arrangements of both sectors. The functions were unbundled; competition was introduced into the competitive segments and the monopoly segments were open to third-party access.

The reforms introduced significant changes to the management strategies in both sectors. In particular, decisions moved away from the domain of engineering, to that of economics, particularly market mechanisms. Under the direction of the Federal government, the water and electricity sectors established a pilot rural water market and a national wholesale market, respectively. By the early 2000s, there was a perceptible slowdown in the pace of reforms. Supporters of reform reasoned that additional efficiency gains were possible, leading to a reinvigoration of the reform agenda for both sectors in the mid 2000s (Council of Australian Governments).

Unlike previous rounds, however, this latest round of reform has occurred at a time of widespread drought along Australia's east-coast, which continues to today. Droughts are a natural part of Australia's water landscape and indeed many storage projects in the 1900s were constructed to safeguard Australia's water supplies against the reoccurrence of drought (Beasley 1988). Unlike earlier episodes, the current drought was preceded by a prolonged dry period, causing water storage levels and river flows to fall considerably in the absence of rain.

In addition to drought, climate change is introducing further uncertainties to both sectors. Historical data is no longer viewed as an accurate predictor of future weather patterns, prompting a shift towards adaptive management strategies in the water sector. One such example is the New South Wales Metropolitan Water Plan (2006), which comprises a mix of efficiency and supply measures, including water recycling and desalination. Moreover, recent studies by the IPCC have linked climate change with human activities, such as the burning of fossil fuels for electricity generation (Houghton et al. 2001; IPCC Secretariat 2004). In order to reduce its greenhouse gas emissions, the electricity sector in Australia has implemented a range of strategies, including efficiency programs, renewable energy targets and promotion of generation technologies, such as 'clean' coal and nuclear power (ABARE; Energy Task Force 2004).

Environmental pressures of drought and climate change are bringing to light the critical link between water and electricity. This link presents potential challenges and uncertainties to both sectors, to which we now turn our attention.

3 Water-energy nexus: an unfolding uncertainty

The potential impact on the nexus is significant, particularly in the context of reform. The market mechanism has already resulted in potentially alarming trade offs, because of the lack integration between the water and energy management strategies.

The Snowy Mountains Scheme offers an interesting insight into this phenomenon. Water allocations are generally defined under Snowy Hydro's water licence, however the company has reduced water releases to irrigators downstream, due to water shortages. Whilst Snowy Hydro maintains that it is acting in accordance with its licence, others argue that the company is reserving water to power lucrative peak summer demand – thereby maximising profits - at the expense of irrigators (Wahlquist & Mitchell 18 November 2006). Water shortages are also affecting Snowy Hydro's investment strategy. It has recently acquired two gas-fired power stations in Victoria to buffer against the effects of water shortages. As part of Snowy Hydro's EPA licence, generation from the gas-fired stations is restricted in order to control emissions. It is reported that Snowy Hydro has requested that this restriction be laxed, due to low water levels in its dams (Gordon 2007)

Water shortages have impacted generators elsewhere. In New South Wales, smaller hydropower plants have reduced generation output (S. Gough, pers com). In Victoria, similar reductions in hydropower output has forced the use of more expensive and more greenhouse-gas intensive generation options to meet demand, reportedly pushing up the price of electricity in the wholesale market by more than 80 per cent in peak times (Gordon & Kleinman 2007).

In Queensland, cheap electricity is being imported from Swanbank and Tarong Power Stations to New South Wales via the national electricity grid (Roberts 2007b). Both power stations are sourcing cooling water from Brisbane's main drinking water supply, Wivenhoe Dam, despite the imposition of water restrictions in the region. Further, New South Wales has sufficient capacity to meet its own demand, without needing to rely on electricity imports from Queensland. Swanbank and Tarong Power Stations are set to cut back production by 20 per cent and 70 per cent respectively due to water restrictions, at a cost of potentially $1 million a day for the QLD government (Ludlow & Wisenthal 2007). These power stations will receive recycled water from the Western Corridor Recycling Project in the coming year, at a cost that is estimated to be several times the $200-300/ ML now being paid for water from Wivenhoe Dam. It is estimated that this move will add $5-10 to the current generation cost of $35 per MWh (Roberts 2007a). A newer power station at Kogan Creek is air cooled, and will assist in reducing the dependence on water supplies in the state (Orchison 2007).

In the water sector, governments are implementing a range of adaptive measures to cope with water shortages, including desalination and water recycling. Both technologies use membrane technology. Desalination, however, requires more intensive processes and therefore consumes up to five times the amount of energy than water recycling (refer to Table 1 below). Further, continuation of water shortages may result in increased reliance on groundwater that would require energy for pumping (NSW Government 2006).

Table 1: Energy consumption of different water treatment technologies.

Water source	Energy consumption (kWh/m^3)
Conventional surface water treatment	0.4 – 0.6
Brackish water desalination	0.7 – 1.2
Reclamation of municipal wastewater	0.8 – 1.0
Seawater desalination	3.0 – 5.0

Source: (Voutchkov 2005)

The above mentioned discussion demonstrates the significance of contemporary challenges imposed by the links between water and energy. These challenges are occurring at a time when important decisions are being made regarding future supply options in both sectors. The New South Wales government, for example, recently commissioned the “Owen Inquiry into Electricity Supply in New South Wales” to examine the need and timing for baseload generation options. There appears, however, to be an absence of modeling frameworks for the Australian context that can comprehensively quantify these links and the implications for the Australian economy (see Marsh & Sharma 2006 for a review of existing water-energy research). Such a framework is needed to ensure that future water and energy policies are appropriately integrated in order to handle the challenges, as well as take advantage of opportunities presented by the water-energy nexus.

4 An integrated water and energy scenario framework

The research framework presented in this paper is useful for examining the implications of the nexus on future water and energy pathways in New South Wales. The framework builds on existing research undertaken by the authors to quantify the links for 1995-96 and 2000-01 and is based in input-output analysis, a widely used policy modeling tool (Marsh & Sharma accepted for publication 2007).

An important strength of input output analysis is its ability to quantify interdependencies between sectors in an economy (refer to Miller & Blair 1985 for a comprehensive introduction to input-output analysis). In this way, the links between water, electricity and other economic sectors may be explored. Specifically, input output analysis will be used to develop models of the New South Wales economy for 2030-31 under different water and energy scenarios, with a view to determine the following:

- Direct and indirect water requirements to meet energy demand
- Direct and indirect energy requirments to meet water demand
- Water-energy indices for non-water and non-energy sectors

The following sections describe the water and energy scenarios adopted in this research, and provides a theoretical background into the use of input-output analysis for this purpose.

4.1 Water and energy scenarios for New South Wales

Several options exist to meet future water and energy needs in New South Wales. For the water sector, these options, as mentioned previously, include desalination and water recycling, among others (NSW Government 2006). In the electricity sector, the recent Owen Inquiry identified ultra-supercritical pulverized fuel coal-fired generation (USC), combined cycle gas turbine (CCGT), wind, biomass, and geothermal hot rock technology as potential options to increase baseload capacity (Owen September 2007). CCGT and open cycle gas turbine plants (OCGT) are also suitable as intermediate load plants. A recent study commissioned by the Federal Government supported the development of nuclear power plants in Australia (Commonwealth of Australia 2006). This technology, however, is currently against New South Wales government policy (Owen September 2007).

In order to explore various technological options available to meet future water and energy needs in New South Wales, this research has developed a set of four scenarios. These scenarios are based on the UK Foresight Programme's Environmental Futures scenarios and the

Intergovernmental Panel on Climate Change scenario framework, as well as the IPCC study into emissions scenarios. Both drew significantly on work undertaken by Shell Group Planning, which is in turn underpinned by grid-group cultural theory (Eames & Skea 2002; Nakicenovic & Swart 2000).

Grid-group cultural theory postulates that there are two essential dimensions in any culture: (a) degree of social regulation or prescription, represented by 'grid'; and (b) degree of social integration, represented by 'group'. The 'group' dimension largely corresponds to social values, whereas the 'grid' dimension refers to the degree to which decision-making in a society is autonomous. In some studies, 'grid' represents the level at which power or authority is exerted (Eames & Skea 2002). This research adopts the latter interpretation.

The two dimensions of 'grid' and 'group', hereafter referred to as 'governance systems' and 'social values' respectively, form the two axes that intersect at 90 degrees to form the four quadrants of the scenario framework (refer to Fig. 1 below). The 'social values' axis describes patterns of economic activity, consumption, and policy-making. At one end is consumerism and short-termism. The other end comprises community values of social equity and long-term sustainability. The 'governance systems' axis describes the structure and scale of political authority, from globalization at one end, to regionalization at the other.

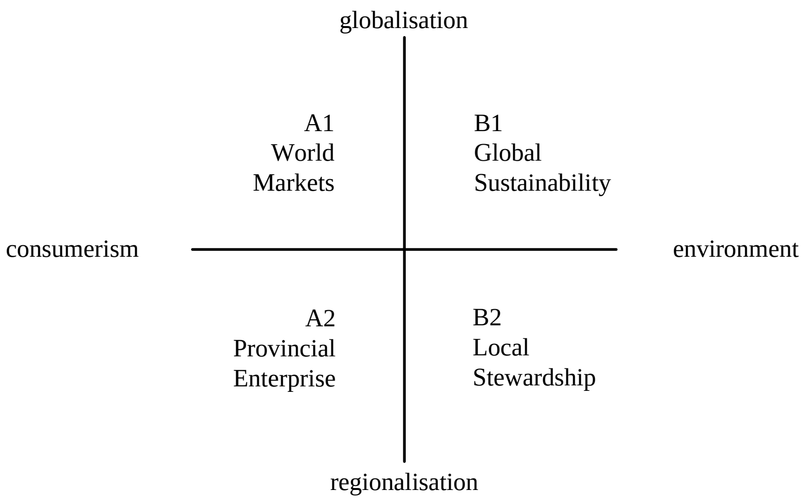

Fig. 1 Scenario assessment framework.

As identified in Fig. 1 above, the four scenarios include: A1 – World Markets; A2 – Provincial Enterprise; B1 – Global Sustainability; and B2 – Local Stewardship.

Scenario A1 – World Markets: low cost technologies and efficiency improvements

The World Markets scenario is underpinned by consumerist values. The main drivers in the water and energy sectors are efficiency and cost reduction, and therefore the environment is accorded a low priority. There is a tendency towards free markets and international trade under this scenario, which facilitates technology transfer and fosters a high degree of innovation. Energy options include demand reductions, and OCGT and CCGT for intermediate demand. Existing coal-fired power station upgrades[2], and new coal-fired power using USC technology provides additional baseload capacity. For the water sector, efficiency measures reduce demand growth. Water recycling, desalination and water harvesting provide new supply capacity.

Scenario A2 – Provincial Enterprises - maintaining security of water and energy supply

The Provincial Enterprise scenario is underpinned by individualist values. The main driver in the sectors is security of supply. The priority is resource independence rather than environmental issues, except for those of local or national significance, such as water shortages. Technological diversity is favoured in order to provide security of supply, although the regional focus hampers some technology transfer. Energy options include OCGT, CCGT for intermediate demand, and existing coal-fired power station upgrades and SC for baseload demand. SC is adopted instead of the more advanced USC, because of the limits to technology transfer. Nuclear power is considered in this scenario, despite current policies banning its development in the state, because of the long-term nature of this study. New SC and nuclear power plants are located in coastal areas or use recycled water for cooling, because of regional water shortages. Desalination and to a lesser extent water recycling provides new supply capacity. Both technologies also encourage rainfall independence.

[2] Plans to upgrade of existing coal-fired power stations in New South Wales are in advanced stages implementation. This option has therefore been included in all options.

Scenario B1 – Global Sustainability - climate change and water shortages influence technology choice

The Global Sustainability scenario is characterised by strong international coorporation in dealing with environmental issues, particularly greenhouse gas emissions. Technological innovation is high, due to the open exchange of ideas. This innovation is focused on reducing reliance on coal and oil and maximising use of water resources. Energy options include demand reductions, as well as OCGT and CCGT and wind power for intermediate demand. Baseload capacity is met by upgrade of existing coal-fired power stations, additional CCGT plants, and geothermal power. In this scenario, New South Wales relies heavily on gas imports, however this does not pose a threat to energy security, due to the very stable political environment. For the water sector, options include demand reductions, water recycling, and water harvesting.

Scenario B2 – Local Stewardship: maximising use of regional resources in order to protect environment

The main focus of this scenario is maximum utilisation of natural resources, with minimum environmental impact. There is a tendancy towards self-reliance - due to strong local and regional governance - and conservation. The regional focus, however, limits technological innovation, although there is a willingness to invest in local technologies. Technology is geared towards more sustainable and distributed systems. For energy, this includes demand reductions, and wind power, OCGT and CCGT for intermediate demand. Upgrade of existing coal-fired power stations, additional wind power, additional CCGT plants and bioenergy provide new baseload capacity. Water strategies include demand reductions, water recycling, and water harvesting.

Figs. 2 and 3 below illustrate the water and energy options under the four scenarios.

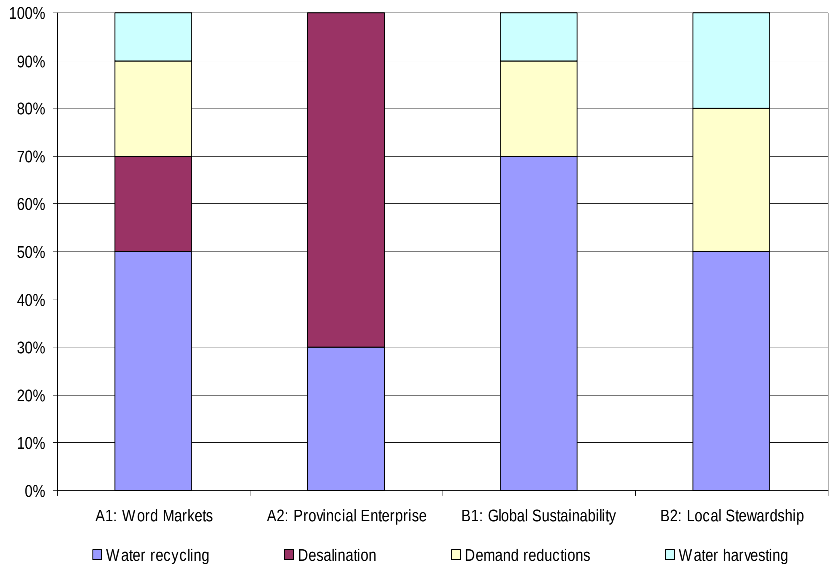

Fig. 2 Mix of water options under the four scenarios.

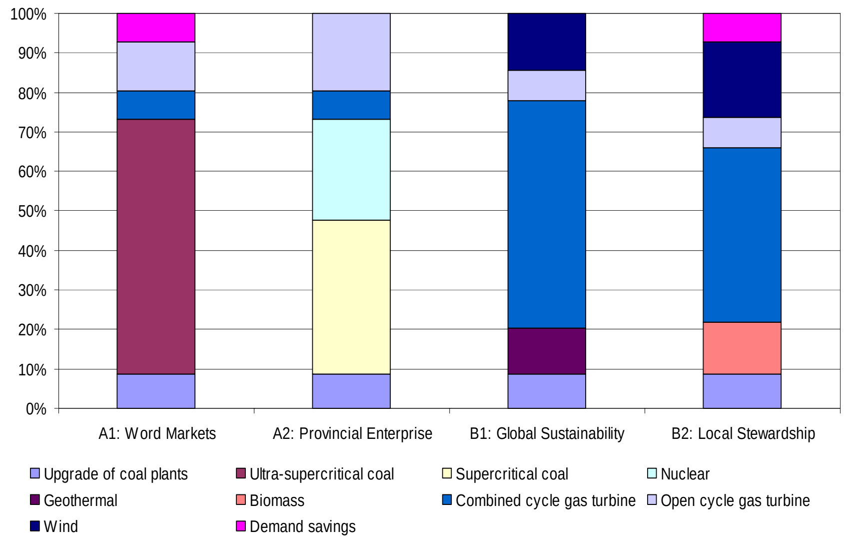

Fig. 3 Mix of electricity options under the four scenarios.

4.2 Use of input output analysis to assess future scenarios

This research uses input output analysis to quantify the links between water and energy for the four scenarios described above for the year 2030-31. As mentioned earlier, this model is based on a model previously developed by the authors for New South Wales for 2000-01. The purpose of this section is to describe how the existing 2000-01 has been modified in order to assess the four scenarios mentioned above.

Background to input output analysis

The input output table and the coefficients derived from it form the basis of input output analysis. Essentially, the table depicts three elements of an economic system: inter-industry table, primary inputs and final sectors. The **inter-industry table s**hows the flow of goods and services between production sectors; outputs from a sector form inputs for other sectors and as such this flow is commonly refered to as intermediate demand. **Primary inputs** are payments to factors of production. In a standard model, primary inputs include compensation to employees, gross operating surplus and mixed income and taxes less subsidies. **Final sectors** typically include household consumption, public expenditure, capital stock, investment and exports. The basic structure of the input output table and these elements are illustrated in Fig. 4 below.

Outputs to sector j / Inputs from sector i	Production sectors (j)	Final sectors	Total output
Production sectors (i)	Inter-industry table (x_{ij}) (intermediate demand)	(Y_i) (final demand)	(X_i)
Primary inputs	(V_j)	GNP	
Total input	(X_j)		

Fig. 4 Basic structure of an input output table.

For an economy with *n* sectors, the relationship between the three elements is represented by the following equation:

$$X_i = \sum_{j=1}^{n} x_{ij} + Y_i \tag{1}$$

where X_i is the total output of sector *i*, x_{ij} represents the flow of outputs from sector *i* to sector *j* where it is used as inputs, and Y_i represents final demand for sector *i* outputs. The input output table is transformed into an analytical model by firstly computing technical coefficients from the inter-industry table. These coefficients- denoted by a_{ij} - quantify the amount of inputs required from sector *i* to produce 1 unit of output in sector *j*:

$$a_{ij} = \frac{x_{ij}}{X_j} \quad \Rightarrow \quad x_{ij} = a_{ij} X_j \tag{2}$$

where X_j is the total input to sector *j*. Substituting x_{ij} in X derives the following:

$$X_i = \sum_{j=1}^{n} a_{ij} X_j + Y_i \tag{3}$$

In matrix form, the above equation becomes:

$$X = AX + Y \quad \Rightarrow \quad X - AX = Y \tag{4}$$

where *X* and *Y* are column vectors of total output and final demand respectively, and *A* is the matrix of technical coefficients. Using an *n*x*n* identity matrix (*I)* and solving for total output (*X)* as a function of final demand (*Y)*, X may also be written as:

$$X = (I - A)^{-1} Y \tag{5}$$

where the inverse matrix $(I - A)^{-1}$ – also known as the Leontief inverse matrix – represents the total (direct and indirect) requirement for sector *i* outputs (*X*) to satisfy one unit of final demand in sector *j (Y)* and therefore is considered demand-driven.

The input output table commonly adopts monetary values, obscuring the fact it actually represents quantities. That is, flows of goods and services may be depicted in mixed physical quantities, such as petajoules (PJ) of energy or megalitres (ML) of water. Where both physical and monetary values are used, the model is considered a ‘hybrid’. In this case, total input to sector *j*, (X_j), comprises mixed units and cannot be summed. Technical coefficients (a_{ij}) are therefore calculated using the corresponding row sum of sector *j*.

Steps to modify input output tables for scenario analysis

There are several methods to update input output tables for a future year for the purpose of scenario modeling. These methods include trend analysis, expert judgment, independent forecasting estimates and the RAS method (see for example Duchin & Lange 1994; Faber, Idenburg & Wilting 2007; Leontief & Duchin 1986; Miller & Blair 1985; Stone 1961). This research adopts a combination of these, using a three-step approach. These steps are illustrated in Fig.5 below and described in further detail in the following paragraphs.

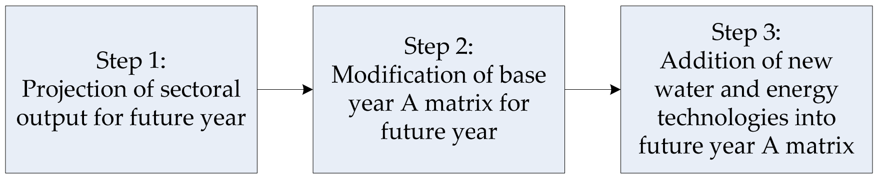

Fig. 5 Steps to update the input output model for scenario analysis.

Step 1: Projection of sectoral output for future year

Economic growth assumptions have been kept consistent for all four scenarios. Sectoral output for water and electricity is based on existing reports on forecasted demand in both sectors (see for example Transgrid 2007; White et al. 2006). For other sectors, output is based on existing studies into economic growth in New South Wales (Cuevas-Cubria & Riwoe 2006; NIEIR 2007). This output is determined by the relative growth rates of different sectors. For example, if economic growth is 2% and relative growth is 0.5 for a particular sector, than sectoral growth is 1% for that year.

Step 2: Modification of the base year A matrix

The technical coefficients in the A matrix represent the amount of inputs required from all sectors in an economy to produce 1 unit of output from a particular sector. The technical coefficients for 2000-01 have been modified in order to represent the structure of the NSW economy in 2030-31 under the four different scenarios.

Water and energy technical coefficients from 2000-01 are transformed by multiplying projected sectoral outputs from Step 1 to estimate water and energy consumption for the different sectors in 2030-31.

For non-water and non-energy sectors, technical coefficients are calculated using the RAS method, which is an iterative process. Stone (1961) first proposed this method as a way to generate an A matrix for years where minimal data is available. This method required three sets of information: total output X (from Step 1), and intermediate supply and demand (both of which can be derived from Step 1). The aim of this method is to develop a set of technical coefficients to satisfy the projected intermediate supply (denoted as *U*) and intermediate demand (denoted as *V*). In the first iteration, the base year *A* matrix is multiplied with the total output for the future year, in order to calculate first estimates of *U* and *V*. The estimate is then compared with the projected future values of *U* and *V*, in order to derive '**R**'ow and '**S**'um coefficients. The *R* and *S* coefficients are then used to modify the *A* matrix. This process is repeated until the calculated and projected values of *U* and *V* converge to within a small margin. A more detailed description of this process may be found in Miller & Blair (1985).

Step 3: Addition of new water and energy technologies
New technologies introduced in the scenarios are modeled by inserting rows and columns into the A matrix. Detailed engineering data and expert judgement are both employed to develop a set of technical coefficients for each of the new technologies for a typical year of operation.

5 Conclusion

It is clear that water and energy management strategies in Australia currently do not take into account the links between the water and electricity sectors. These links, however, are already posing significant challenges and uncertainties for both sectors, due to the occurrence of drought in Australia's east-coast and the acceptance of climate change impacts of water and energy use. These challenges and uncertainties demonstrate the need for frameworks to assess future water and energy management strategies in a more integrated manner. This paper presents such a framework, based on input output analysis. Four scenarios have been developed using this framework, to assess a range of water and energy options for New South Wales for the year 2030-31. Models of each scenario are currently under development and preliminary results are forthcoming. These results would provide important inputs to assist in the development of future water and energy management strategies.

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