THE WATER-ENERGY NEXUS: A COMPREHENSIVE ANALYSIS IN THE CONTEXT OF NEW SOUTH WALES

Debborah Marie Marsh

Faculty of Engineering and Information Technology

University of Technology, Sydney

A dissertation submitted to the University of Technology, Sydney in fulfilment of the requirements for the degree of Doctor of Philosophy (Engineering).

2008

Certificate of Authorship/ Originality

I certify that the work in this thesis has not previously been submitted for a degree, nor has it been submitted as part of the requirements for a degree, except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

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Acknowledgements

I am extremely grateful for the people who have supported me over the course of my PhD. Whilst only I could have completed this journey, your collective support greatly helped me in reaching the final destination. Firstly, I sincerely thank my supervisor Associate Prof. Deepak Sharma for his insightful feedback, for opening my eyes to the world of philosophy, and for always encouraging me to look for the positive in situations that would appear otherwise. I thank Dr Chris Riedy from the Institute for Sustainable Futures for providing valuable input at critical times, Dr Katrina Proust from the Australian National University for useful comments on Chapter 4, and Sue Felix for proofreading the entire thesis.

The Faculty of Engineering and the Institute for Water and Environmental Resource Management provided the financial support for this research, for which I am grateful. I would also like to acknowledge the assistance from the Research Degrees Office of the Faculty of Engineering and IT, and in particular the Associate Dean for Research, Prof. Hung Nguyen.

The data requirements for this research were substantial. Numerous individuals and organisations gave willingly of their time to assist with my data requests. I also thank the Centre for Agricultural and Regional Economics at the University of New England for providing the original input-output data used in this research.

To the former PhD researchers in the Energy Planning and Policy Program, I really appreciated your companionship, wisdom and the support network we formed. To other PhD researchers in the faculty, I really enjoyed sharing the numerous lunches and chai lattes over the past few years - you know who you are! To my 'older' friends, a heartfelt thank you for your patience, particularly towards the end of my candidature.

To my family, I thank you so much for the incredible support you have given me whilst I focused on my scholarly pursuits. I am sincerely grateful to my mother Joan and sister Michele for their words of encouragement throughout my candidature and for casting their editorial eye over various chapters of my thesis towards the end.

To my partner, Chris, words cannot describe how grateful I am for your support and love. I am extremely fortunate to have met you during this journey and look forward to sharing many more experiences with you.

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Marsh, D. & Sharma, D. 2007, *Energy-water nexus: an integrated modelling approach*, International Energy Journal Vol 8, pp235-242 (full peer reviewed)

Marsh, D. & Sharma, D. 2006, *A framework to enhance the effectiveness of water management strategies*, Proceedings of the 3rd International Young Water Researchers Conference, Singapore (peer reviewed abstract)

Marsh, D. & Sharma, D. 2006, *Water-energy nexus: a review of existing models*, Proceedings of the 1st Australian Young Water Professionals Conference, Sydney Australia (peer reviewed abstract)

Marsh, D. & Sharma, D. 2005, *Water-energy nexus: identifying the issues*, Proceedings of the Environmental Research Event Conference, Hobart Australia (full peer reviewed)

Marsh, D. & Sharma, D. 2003, *Water industry reform: some performance issues*, Proceedings of the Global Developments in Water Industry Performance Benchmarking Conference, Perth Australia

List of Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics;
ABS	Australian Bureau of Statistics
AC	Alternating current
ACA	Australian Coal Association
ACCC	Australian Competition and Consumer Commission
AEMO	Australian Energy Market Operator
AES	Allen partial elasticity of substitution
AG	Agriculture
AGA	Australian Gas Association
ANCID	Australian National Committee on Irrigation and Drainage
ANZSIC	Australian and New Zealand Standard Industrial Classification
AP6	Asia-Pacific Partnership on Clean Development and Climate
AQAL	All quadrants all levels
AWEA	American Wind Energy Association
AWRC	Australian Water Resources Council
BIGCC	Biomass integrated gasification combined cycle
BMP	Basic metals & products
BRW	Bulk & retail water
BWR	Boiling water reactor
CAEP	Central Asian Energy Pool
CARE	Centre for Agricultural and Regional Economics, University of New England
CAS	Conventional activated sludge
(CC)GT	(Combined cycle) gas turbine
CF	Coal fired
CG	Cogeneration
CHEM	Chemicals
CHP	Combined heat and power
COAG	Council of Australian Governments
COAL	Coal mining
COD	Chemical oxygen demand
CONST	Construction
CoV	Coefficient of variation
CCSD	Cooperative Research Centre for Coal in Sustainable Development
CSG	Coal seam gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DC	Direct current
DECC	NSW Department of Environment and Climate Change
DEEP	Desalination Economic Evaluation Program
DESAL	Desalination
DLWC	NSW Department of Land and Water Conservation
DWE	NSW Department of Water and Energy

E	Employment
EEI	Energy efficiency improvement
ELCOM	Electricity Commission of NSW
EPA	Environment Protection Authority
EPRI	Electric Power Institute
ESAA	Energy Supply Association of Australia (previously Electricity Supply Association of Australia)
EU	European Union
FBT	Food, beverages & tobacco
FEMP	Federal Energy Management Program
FMP	Fabricated metal products
GAD	Government administration & defence
GAMS	General Algebraic Modelling System
GAS	Retail gas supply
GDP	Gross domestic product
GGAS	Greenhouse Gas Emissions Trading Scheme
GRIT	Generation of Regional Input-Output Tables
GT	Gas turbine
GWh	Gigawatt hour
HDR	Hot dry rock
HEC	Hydro-Electric Commission
HWR	Heavy water reactors
HYDRO	Hydropower
IAEA	International Atomic Energy Agency
IC	Internal combustion
ICT	Information, communication and technology
IDW	Irrigation & drainage water
IGCC	Integrated Gasification Combined Cycle
IMP	Integral Methodological Pluralism
IPART	Independent Pricing and Regulatory Tribunal
IPCC	Intergovernmental Panel on Climate Change
ISU	Instream Use
kL	Kilolitre
LCA	Life cycle assessment
LWR	Light water reactor
MBR	Membrane bioreactors
MCE	Ministerial Council on Energy
MES	Morishima elasticities of substitution
ML	Megalitre
MM	Miscellaneous manufacturing
MMS	Modular modelling system
MRET	Mandatory Renewable Energy Target
MWh	Megawatt hour
MWSDB	Metropolitan Water Sewerage and Drainage Board

N	Income
NCC	National Competition Council
NCP	National Competition Policy
NEC	National Electricity Code
NECA	National Electricity Code Administrator
NEM	National Electricity Market
NEMMCO	National Electricity Market Management Company
NETS	National Emissions Trading Scheme
NETT	National Emissions Trading Taskforce
NGMC	National Grid Management Council
NIEIR	National Institute of Economic and Industry Research
NMMP	Non-metallic mineral products
NSW	New South Wales
NWC	National Water Commission
NWI	National Water Initiative

O	Economic output
OCGT	Open cycle gas turbine
OCS	Other commercial services
OLS	Ordinary least square
OME	Other machinery & equipment
OMS	Other mining & services to mining
OR	Other renewables
OXY-CF	Oxygen fired pulverised fuel

PCP	Petroleum & coal products NEC
PE	Primary Energy
PFW	Produced formation water
PIU	Performance and Innovation Unit, Cabinet Office, UK Government
PJ	Petajoule
PR	Petroleum refining
PRS	Power reservoir system
PV	Photovoltaics
PWR	Pressurised water reactor

RAS	Rows and Sums
RECYCLE	Recycled water
RO	Reverse osmosis
RW	Raw Water

SBP	Supply based pricing
SBR	Sequencing batch reactor
SC	Supercritical
SEEG	Société d’Eau et d’Electricité du Gabon
SEW	Sewerage

TCFL	Textile, clothing, footwear & leather
TE	Transport equipment
TGET	Task Group on Emissions Trading
TS	Transport & storage

UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USC	Ultrasupercritical
USAID	U.S. Agency for International Development
VFP	Voluntary fallowing program
WEST	Water-Energy Sustainability Tool
WPP	Wood, paper & printing products
WRT	Wholesale & retail trade
WSAA	Water Services Association of Australia

Abstract

Water and electricity are fundamentally linked. Policy reforms in both industries, however, do not appear to acknowledge the links nor consider their wider implications. This is clearly unhelpful, particularly as policy makers attempt to develop effective responses to water and energy issues, underpinned by prevailing drought conditions and impending climate change. Against this backdrop, this research has comprehensively analysed the links between water and electricity – termed water-energy nexus – in the context of New South Wales. For this purpose, this research has developed an integrated methodological framework. The philosophical guidance for the development of this framework is provided by Integral Theory, and its analytical foundations rest on a suite of research methods including historical analysis, input-output analysis, analysis of price elasticities, and long-term scenario analysis.

This research suggests that the historical and inextricable links between water and electricity, in the absence of integrated policies, has given rise to water-energy trade-offs. In the electricity industry, water-intensive coal-fired power stations that dominate base-load capacity in the National Electricity Market has resulted in intra- and inter-jurisdictional water sharing trade-offs. Intermediate and peak demand technologies, suchas gas-fired, cogeneration and renewables, however, would significantly reduce the industry's water consumption and carbon emissions. Drought and climate change adaptation responses in the water industry are likely to further increase electricity demand andpotentially contribute to climate change, due to policies that encourage investment in energy-intensive technologies, such as desalination, advanced wastewater treatment and rainwater tanks. Increasing electricity costs due to water shortages and the introduction of emissions trading will futher increase water and electricity prices for end users. Demand management strategies in both industries will assist in curbing price increases, however, their effectiveness is lessened by investment in water- and energy-intensive technologies in both industries.

The analysis also demonstrates that strategies to reduce water and electricity consumption of 'other' production sectors in New South Wales is overwhelmingly dependent on how deeply a particular sector is embedded in the economy, in terms of its contribution to economic output, income generation and employment growth. Regulation, demand management programs, and water pricing policies, for example, that reduce the water and energy intensity of agriculture and key manufacturing sectors are likely to benefit the wider economy and the Environment.

The future implications of the water-energy nexus are examined through long-term scenario analysis for New South Wales for 2031. The analysis demonstrates how policy decisions shape the domain for making philosophical choices by society - in terms of the balance between relying on alternative technologies and market arrangements, with differing implications for water and electricity use, and for instigating behavioural change. Based on these findings, this research puts forward a range of recommendations, essentially arguing for reorienting existing institutional arrangements, government measures and industry activities in a way that would encourage integration between the water and energy policies.

Although the context of this research is New South Wales, the findings are equally relevant for other Australian states, which share the same national water and energy policy frameworks. Further, the concepts and frameworks developed in this research are also of value to other countries and regions that are faced with the task of designing appropriate policy responses to redress their water and energy challenges.

Chapter 1

Introduction

A journey of a thousand miles begins with a single step

Lao Tzu

Water and energy are fundamental to humanity's existence. Both resources have shaped the development of societies during the course of history: water resources have influenced human settlement patterns; and energy has been an important enabler of work, from the early use of animal and waterpower, to more technically advanced forms such as steam power and later electricity. In a modern society, water and electricity are interdependent. Water is critical for electricity generation, and electricity is critical for water treatment and transportation. For example, over 41 per cent of world electricity generation relies on water-intensive coal-fired power stations and water transportation consumes approximately seven per cent of the energy produced worldwide (James, Campbell & Godlove 2002; US Government 2008). The fundamental role of both infrastructure industries for general economic development and social wellbeing further strengthens the importance of the interdependency between the two.

As humanity embraces the 21st century, the interdependency between water and electricity – termed the water-energy nexus in this thesis – is becoming more apparent in Australia, and indeed the world over, due to industry reforms, drought and more recently climate change.

Industry reforms

The water and electricity industries in Australia have undergone a period of immense reform over the past two decades, beginning with state-level reforms in the 1980s. The New South Wales (NSW) Government, for example, began reforming its water and electricity industries in the 1980s, in response to the public perception that the industries were hampered by poor financial and environmental performance (Dovers 1994). By the mid 1990s, this first phase of reform was subsumed into economy-wide reforms that sought to improve the competitiveness of the Australian economy through improvements to the productivity of infrastructure industries, including water and electricity. These wider reforms were guided by national policy frameworks that were overseen by the Council of Australian Governments (COAG). These frameworks called for the separation of various industry functions, the introduction of commercial principles to competitive functions, and the granting of third party access to monopoly segments. The reforms led to the establishment of a national electricity market (NEM) and a rural water market in the late 1990s in order to promote competition. The reforms also introduced independent regulatory arrangements for price and service delivery, and in the case of the water industry, environmental management and water quality (Industry Commission 1995; Shadwick 2002). In the early 2000s, COAG reasoned that additional efficiency and productivity gains were possible in the water and electricity industries and set about reinvigorating the reforms which continue to this day (Council of Australian Governments (COAG) 2001, 2003).

An increase in awareness of environmental issues has also accompanied the reforms. By the 1980s, society had begun to question the impact of development – including water and electricity infrastructure projects – on the local Environment, such as water and air pollution and salinity. By the 1990s, environmental issues had become more global in nature; the state of the world's water resources, ozone depletion, and global warming received significant attention in mainstream debate. The Earth, it was deemed, could not sustain the past pattern of development into the future. The shift in attitude culminated in the formation of the sustainable development principle in 1987, which places social, environmental and economic considerations on equal footings (World Commission on Environment and Development 1987). These principles have permeated the reforms, particularly since the 2000s.

Climate change

Climate change is one of the most pressing environmental issues of the time. In 2006, the documentary film *An Inconvenient Truth* (2006) assisted in mainstreaming climate change for the public. In the same year, the Government of the United Kingdom (UK) released the Stern Review on the Economics of Climate Change. The Garnaut Climate Change Review (2008c) has similarly reviewed the implications of climate change on the Australian economy.

There is general scientific consensus that carbon emissions from human activity – particularly since the Industrial Revolution – have artificially enhanced changes to the Earth's climate (Working Group 1 IPCC 2007). That is, whilst climate change is caused by some natural phenomena, human-induced climate change, largely through greenhouses gases emitted by the burning of fossil fuels is one of the main causes.

In Australia, fossil fuel-based energy consumption is one of the main sources of carbon emissions, contributing to 69.9 per cent (409 Mt CO_2-e) of emissions in 2006. Electricity comprises the bulk of the emissions from energy consumption, due to the high reliance on coal-fired power stations (Commonwealth of Australia 2008b). Figure 1-1 clearly illustrates the importance of coal to the Australian electricity industry.

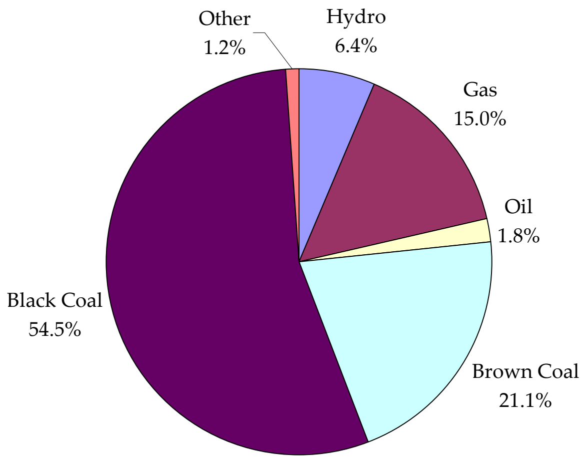

Figure 1-1 Shares in Australian electricity generation by fuel. Source: Commonwealth of Australia (2008b)

The Intergovernmental Panel on Climate Change (IPCC) (2001) reported that without global action to reduce carbon emissions, there is an increased likelihood of greater climate variability and greater frequency of extreme events such as floods and droughts. In Australia, scientists predict up to 20 per cent more months in drought over most of the continent by 2030. Changes to Australia's climate, however, are already observable: twelve of the hottest years in recorded history have occurred in the last thirteen years, and the stream flow supplying Sydney is 40 to 60 per cent below the 100-year average. Furthermore, rainfall intensities and frequencies have sharply increased and decreased across Australia since the 1950s (Commonwealth of Australia 2008a).

Drought

Australia, more so than many other countries in the world, is susceptible to climate change because of its naturally erratic weather patterns. The Australian continent is drought- and flood-prone, a condition that Australia's Aborigines adapted to many thousands of years prior to European Settlement in 1788 (Blainey 1976; Sveiby & Skuthorpe 2006). Since then, Australia's inhabitants have coped with drought by building vast numbers of storage dams, resulting in the highest storage per capita in the world, which is in excess of 4 million litres per person (National Heritage Trust 2005). However, the extended dry period that preceded the most recent drought (from 2001 to 2007) left little opportunity for the replenishment of the storage dams (ABS 2007). Australia is also highly reliant on river systems that have been considerably modified since European Settlement. Many of these river systems – the largest of which is the Murray Darling Basin – have been overallocated and are therefore highly susceptible to the changes in precipitation that will be an inevitable consequence of climate change (Council of Australian Governments (COAG) 2001).

Apparent links between water and electricity

These recent changes – industry reforms, climate change and drought – are reinforcing the historical interdependencies between water and electricity, and highlighting the current and future impacts of the nature of the nexus on water and electricity security. Climate change may affect water availability in the future; and water is a critical input to electricity generation, both for hydropower stations and for cooling purposes for thermal power stations. Similarly, the water industry is seeking more energy-intensive water sources to drought-proof water supplies. Recent media headlines hint at some of these contemporary nexus issues affecting Australia: 'Cheap power a drain on water supply' (Roberts 2007c)...'Big bills to pump water for power – NSW decides' (Roberts 2007a)…'Cool solutions to hot showers' (Friedlander 2007)…and 'Water enters coal-fired power station debate' (Orchison 2008).

The implications of these recent changes for the water and electricity industries are immense. Garnaut (2008c) reports that the cost of supplying urban water will increase by up to 35 per cent, largely due to the supplementation of existing systems with alternative non-rainfall dependent water sources that are also energy-intensive. The electricity industry will also need to drastically reduce its emissions, as well as adapt its infrastructure to cope with more extreme climatic events and potentially reduced access to water resources. Both industries also need to augment their capacities, in order to meet the increase in demand in the future. The Owen Inquiry into Electricity Supply (2007) examined the need and potential timing for baseload capacity in NSW, and the NSW Metropolitan Plan (2006) outlines strategies to meet the demand for water in the future. Any augmentation of capacity will require additional water (in the case of the electricity industry) and additional electricity (in the case of the water industry).

This research contends that water and electricity industry reforms are being implemented with little regard to the understanding of the nature of the nexus, particularly in the context of drought and climate change. This understanding is critical, in order to minimise further trade-offs that may ensue. In addition, a review of existing research into the water-energy nexus (in Chapter 2) further substantiates the criticality of trade-offs between water and electricity. The implications of the links on the two industries and the wider economy, however, do not appear to be analysed in any indepth manner in existing research, which is clearly unhelpful.

The purpose of this research is to comprehensively analyse the nature of the nexus, and the implications for the water and electricity industries, and the wider economy. The context for this research is the State of New South Wales in south-eastern Australia, which offers a fitting case study into the nature of the nexus for many reasons. The State forms an integral part of the National Electricity Market (NEM) and consumes approximately one third of the electricity generated in Australia (Commonwealth of Australia 2008b). A significant area of the State also forms a vital part of the Murray Darling Basin system, which is considered Australia's food bowl (refer to Figure 1-2). New South Wales also contributes approximately one third of

Australia's Gross Domestic Product and contains one third of Australia's population (ABS 2006b, 2008).

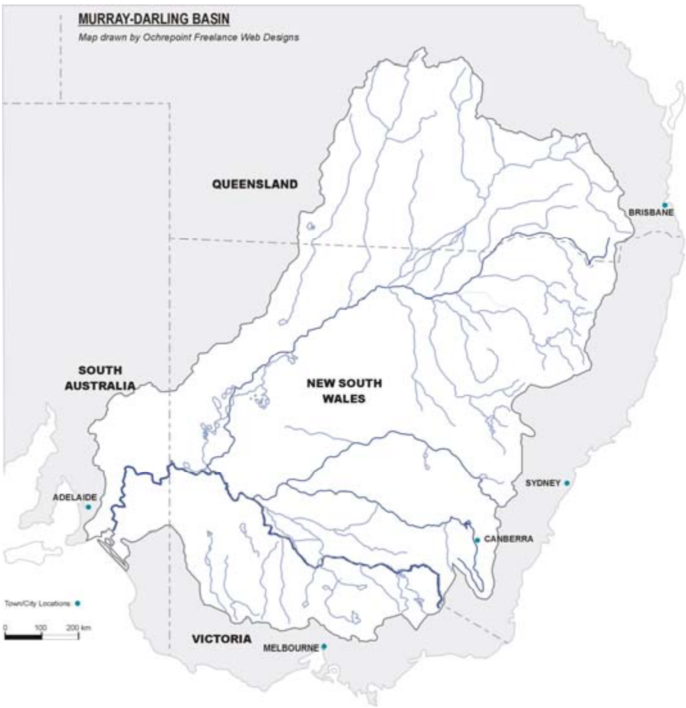

Figure 1-2 Map of the Murray Darling Basin in south-eastern Australia.
Source: Ochrepoint (2008)

The analysis presented in this research focuses on past historical links between water and electricity, existing empirical links in the NSW economy, and the potential for water and energy policy trade-offs in the future. A comprehensive understanding of the nature of the nexus would assist in assessing existing institutional arrangements and government policies in the water and electricity industries, and in developing more integrated water and energy policies.

1.1 Research objectives

The main objective of this research is ***To develop a comprehensive understanding of the nature of the water-energy nexus for New South Wales, with a view to contribute to the development of more integrated water and energy policies.***

This main objective comprises the following five specific objectives:

1. To analyse the evolution of the water-energy nexus in Australia, with a particular focus on New South Wales;
2. To empirically investigate the links between the water, electricity and other economic sectors in New South Wales;
3. To further validate the findings of the empirical investigation by determining the extent of substitution between water and electricity;
4. To identify the potential trade-offs that will need consideration in order to satisfy the future demand for water and electricity;
5. To demonstrate how consideration of the water-energy nexus could assist with effective policy development for the water and electricity industries.

1.2 Research framework

Figure 1-3 depicts the methodological framework developed for this research. The framework comprises a set of research methods drawn from various academic disciplines. This research specifically adopts Integral Theory to guide the development of the methodological framework, and to assess the suitability of individual research methods for developing an understanding about the nature of the nexus. Such specific methods include historical analysis, input-output analysis, measurement of price elasticities of demand, scenario analysis and assessment of policy implications. An overview of the salient features of Integral Theory and the research methods is provided in this section. A more detailed description follows in Chapter 3.

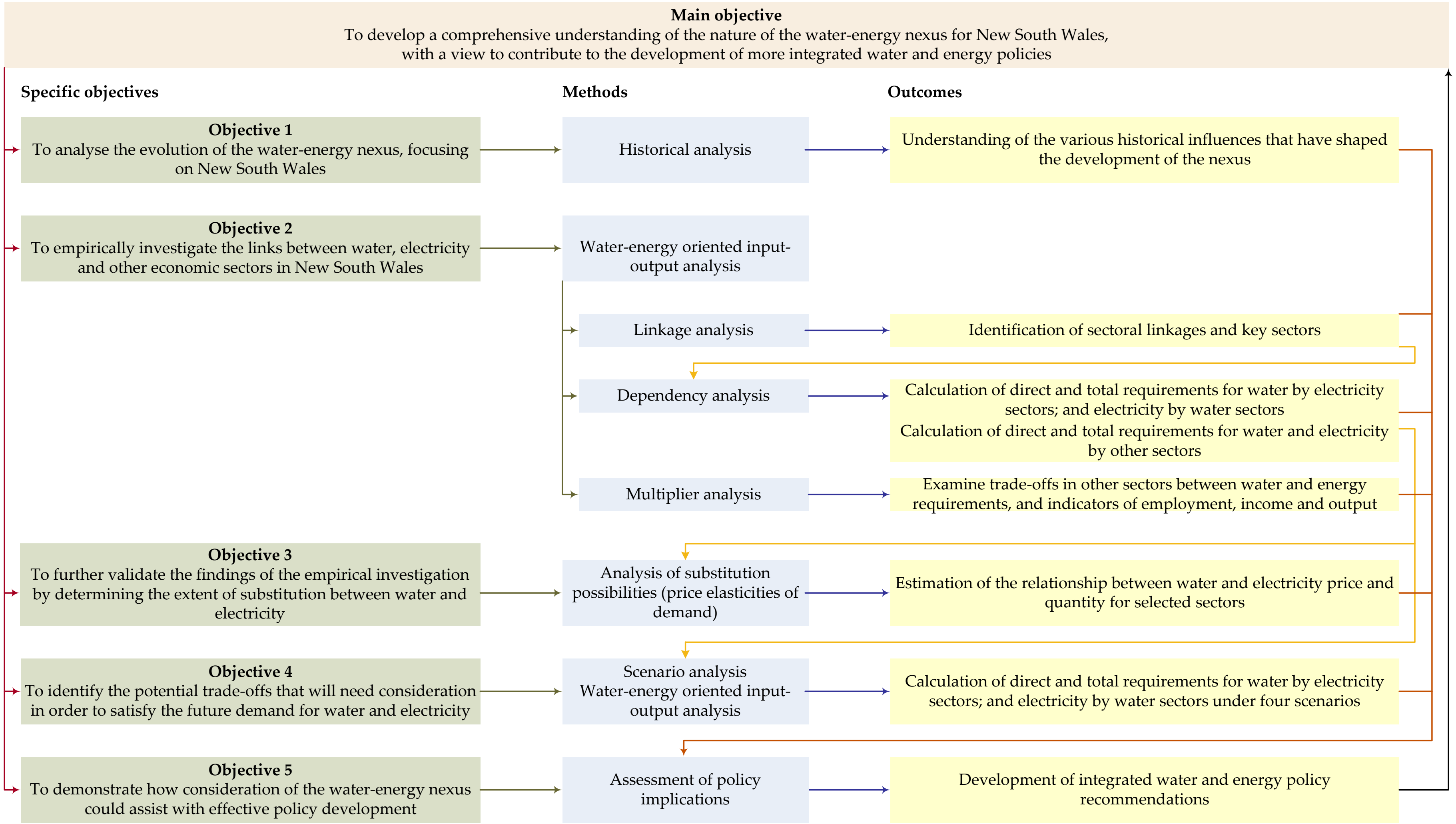

Figure 1-3 Methodological framework for this research

1.2.1 Integral theory – a guiding philosophy

American philosopher Ken Wilber (1949~) developed Integral Theory after years of cross-cultural research into various fields of human knowledge. Through his research, Wilber (2000c) concluded that knowledge has five major elements represented by quadrants, levels, lines, states and types. Wilber's resulting framework – termed 'all quadrants all levels' or AQAL for short – depicts these five major elements. Wilber contends that methodologies from the four quadrants that comprise the AQAL framework are equally valid and necessary to comprehend reality. Wilber later developed the concept of Integral Methodological Pluralism (IMP) to assist with the integration of methodologies (Esbjorn-Hargens 2005).

The concept of IMP has been broadly applied in this research to identify and integrate the perspectives captured by each of the methods. This, this research argues, would provide a suitable platform for comprehensively analysing the nature of the water-energy nexus. Section 3.1 contains a detailed description of IMP and its application to this research.

1.2.2 Research methods

This section introduces the five methods adopted by this research. The methods combine both qualitative and quantitative approaches, in order to develop a comprehensive understanding of the water-energy nexus from various perspectives identified by IMP. A more detailed description of the methods is contained in Chapter 3.

Historical analysis

Historical analysis is used to develop an historical time profile of the nexus for Australia, with a particular focus on NSW. This is undertaken by first constructing separate time profiles for the urban water, rural water and electricity industries. The division of the water industry into its urban and rural components is in recognition of their distinct histories and purposes. That is, rural has a focus on irrigation, whereas the focus of the urban water industry is on town water supply and sewage. A water-energy nexus profile is subsequently developed, based on these three profiles. Further, each profile is divided into four time periods, which represent significant phases in the development of the industries in Australia. These time periods are:

1. Early developments in water and electricity (pre 1890)
2. Building on the foundation (1890 to 1939)
3. Expansion and pressures for change (1940 to 1979)
4. Initial and contemporary reforms (1980 to 2007)

The purpose of the historical analysis is to identify the forces that shaped the development of the nexus in the past. This will provide a deeper appreciation of nexus issues that are prevalent today.

Input-output analysis

Input-output analysis is a widely used analytical tool that identifies the interdependencies between various economic sectors and therefore lends itself well for examining the links between water, electricity and the wider economy. In order to quantitatively examine these links, this research has developed a set of water-energy oriented input-output tables for NSW for 1995-96 and 2000-01. The two years were selected according to the availability of water and energy data and state-based input-output tables. Both years also represent distinct time periods in the process of industry reform, and therefore may provide some additional insights into the changes to the nature of the nexus during this period. As illustrated in Figure 1-3, the techniques associated with input-output analysis include linkage analysis, dependency analysis and multiplier analysis.

Linkage analysis quantifies a sector's contribution to economic activity. It is used in this research to identify the dominant or 'key' sectors in NSW; to understand the contribution of the water and energy sectors to economic activity, and to identify if this contribution has changed between 1996 and 2001.

Dependency analysis quantifies the direct and total use of water and energy in the economy, which may also be referred to as water and energy 'intensities'. Several types of intensities may be calculated, which this research groups into three sets: i) water intensities for the energy sectors ii) energy intensities for the water sectors; and iii) water and energy intensities for the remaining sectors. The first set is useful for identifying energy sectors that are heavily dependent on water and therefore more exposed to generation restrictions during water shortages. The second set identifies the most energy-intensive water sector and the most dominant forms of energy used. The third set identifies water- and energy-intensive sectors and their implications, which is dependent on their contribution to economic activity. Further, the correlation between water and energy intensities for the remaining sectors is analysed using additional statistical tools, in particular Venn diagrams and the Pearsons Product Moment Correlation Coefficient.

Multiplier analysis examines the impact of policy decisions and other changes to final demand on a range of economic and social indicators. In this research, these indicators are represented by output, income and employment multipliers. The macro-level impact of the water-energy nexus is explored using multiplier analysis, by comparing the water and energy intensities of the sectors, with their economic output, income and employment multipliers. The aim is to determine any possible trade-offs between water and energy use with these wider socio-economic indicators. The analysis focuses on the remaining sectors in the economy, that is, those sectors that do not supply water and energy. In doing so, it recognises that the implications of the water-energy nexus extend beyond the water and energy industries.

Analysis of substitution possibilities (price elasticities of demand)

Price elasticities of demand measure the responsiveness of quantity demanded to an incremental change in price. When applied to one good, it is termed own price elasticity of demand. When applied to two goods, it is termed cross price elasticity of demand. Cross price elasticities quantify the extent of substitution or complementarity between two goods, such as water and electricity.

This research calculates own and cross price elasticities for water and electricity, using the classical arc elasticity formulation. Elasticities are calculated for sectors that have been identified in the dependency analysis as water and/or energy-intensive, as well as Households. This is undertaken for time periods where sufficient historical water and electricity use and price data is available, namely 1993-94 to 1996-97, 2001 and 2004-05. The findings from this method are used to further validate the results from the input-output analysis.

Scenario analysis

This research analyses four alternative scenarios to meet the demand for water and electricity in 2031, with a view to determining: water required to satisfy electricity demand, energy required to satisfy water demand, and the resulting carbon emissions from energy use in the water industry. The scenarios closely align with the scenario matrix developed by the UK Foresight Program on Environmental Futures, which frames plausible futures along governance system and social value dimensions.

The scenarios are modelled using input-output analysis by updating the 2001 model based on projections of economic growth, water demand and electricity demand. The findings will be useful for determining the net water-energy impact of various water and energy policies modelled by the scenarios.

Assessment of policy implications

The previous methods offer various insights into the nature of the water-energy nexus. In order to put forward recommendations for more integrated water and energy policies, it is important to assess these insights in terms of their policy implications, and in particular, policy trade-offs that may ensue. Given the contemporary nature of this topic, this assessment comprises a review of the latest water and energy policy developments. Based on this review, the assessment puts forward recommendations that would assist in strengthening the institutional arrangements in the water and electricity industries, improving the efficacy of existing government measures, and developing additional government measures that would reduce the potential for trade-offs in the future.

1.3 Scope of research

The scope of the research varies for the specific objectives and is dependent on the availability of suitable data. This scope may be defined as temporal, spatial and sectoral, as outlined in Table 1-1 The primary spatial scope of this research is New South Wales. The rationale behind the state-based approach is that whilst water and electricity reforms are initiated at a Federal level, their implementation occurs at a state level. Therefore, it is more insightful to analyse policy implications at this level that reflect state specificities. Chapter 3 and other relevant chapters provide a detailed description of the scope for each objective, a summary of which follows from Table 1-1.

Table 1-1 Scope of the analysis

Specific Objective	Research Method	Temporal	Spatial	Sectoral*
1	Historical analysis	Prior to European Settlement to 2007	Regional (NSW), National (Australia) and Global	Urban water industry Rural water industry Electricity industry
2	Input-output analysis	1995-96 and 2000-01	Regional (NSW)	32 sectors, including 6 electricity generation sectors and 3 water sectors
3	Measurement of price elasticities	1993-94 to 1996-97, 2001 and 2004-05.	Regional (NSW)	8 sectors plus Households
4	Scenario analysis	2031	Regional (NSW)	7-8** electricity sectors, 3-4** water sectors, and 23 other sectors
5	Assessment of policy implications	Longer-term outlook	Regional (NSW) National (Australia)	Water and electricity industries and other key sectors

Note: *Refer to Chapter 3 for the specific sectors considered in each objective; ** the number of sectors vary between the four scenarios.

Objective 1 focuses on the historical evolution of the links between the water and electricity industries in NSW. It begins with European Settlement in Australia in 1788 and concludes in 2007. Whilst the focus is NSW, the analysis incorporates important national and global influences during this time period. The analysis also includes global influences that were prevalent prior to European Settlement, which had significant implications for NSW water and electricity industries, and the development of Australia at large.

Objective 2 broadens the sectoral scope from the water and electricity industries to all sectors in the NSW economy, and also includes the Australian Capital Territory (ACT). Input-output models for 1995-96 and 2000-01 are developed as part of this objective. The two years of analysis represent distinct time periods in the process of reform in both industries and their comparison may give rise to additional insights into the nature of the nexus as a result of reform. Whilst the electricity industry is central to this research, the links between water and energy more broadly are considered in Objective 2, in particular when quantifying water intensities for the energy sectors, energy intensities for the water sectors, and energy intensities for the other production sectors.

Objective 3 analyses substitution possibilities, by calculating the cross-price elasticities of demand for non-water and non-energy sectors, as well as their own-price elasticities. Water use data limited the scope of analysis, in this case the years and sectors for which elasticities are calculated. Elasticities were calculated for the five years of available water data, which were 1993-94 to 1996-97, 2000-01 and 2004-05. Only three of these years occurred consecutively and as such, the research adopted the classic price elasticity formulation in lieu of more complex econometric approaches. In terms of sectoral scope, this research selected those sectors that were deemed by the dependency analysis to be water- and energy-intensive. In addition, due to the changes in the level of aggregation of water use data in the latest Water Account (2004-05), the Services group – which comprises five sectors in the input-output models – were aggregated into one. Elasticities for Households were also calculated.

Objective 4 models four future water and energy scenarios for NSW for the year 2031 that comprise alternative water and electricity industries in NSW. This timeframe was selected because it is sufficiently into the future to consider emerging technologies that are likely to become available in the longer term. Significant policy changes may also be factored into the timeframe, yet it is still within the horizon of the present to have an impact on current policy development. As with Objective 2, this objective uses input-output analysis to model the scenarios and explore the relationships between water and electricity. Therefore, whilst all sectors in the NSW economy are incorporated in the models, the analysis focuses specifically on water intensities for the electricity sectors, energy intensities for the water sectors, and the corresponding carbon emissions for the water sectors.

Objective 5 is similarly focused on NSW, yet the scope is again broadened to consider all sectors in the economy. This objective considers the implications of the nexus in terms of policy trade-offs, and discusses these implications from a short to longer-term perspective.

Throughout the thesis, the terms 'water industry' and 'electricity industry' refer to both industries in general. Where references are made to specific segments of the industries, particularly in the empirical analyses for Objectives 2 to 4, the terms 'water sector' and 'electricity sector' are used. The electricity industry is disaggregated into sectors that represent the different generation technologies, whereas the water industry is disaggregated into broad functions, such as irrigation water supply, water supply and wastewater treatment.

1.4 Data considerations

The methodological framework developed for this research draws upon several disciplines. The data requirements are therefore diverse and reflect the multi-disciplined nature of the framework. In the case of Objective 1, this research represents the first exploration of the water-energy nexus from an historical perspective for Australia. It was therefore necessary to explore in detail the development of both the water and electricity industries, in order to draw out some of the forces and common trends that shaped the development of the nexus. This required an extensive review of literature comprising secondary resources of primarily books, as well as contemporary accounts in the form of books, reports, journal articles, legislation and policy papers. This research also used unstructured interviews and other personal accounts to gain insights into the social impacts of reform, particularly in the electricity industry.

Data significantly influenced the scope of analysis for Objective 2. The availability of input-output tables and water use data for NSW dictated the years of analysis. This research obtained input-output tables from the Centre for Agricultural and Regional Economics from the University of New England, which were heavily modified for the modelling undertaken for Objective 2. The models required three main types of data – water data, energy data, and economic data – for three general sets of sectors – water sectors, energy sectors and other production sectors. Water and energy data sources included the Australian Bureau of Statistic's Water Accounts, the Australian Bureau of Agricultural and Regional Economics, industry associations, irrigators, generators, and water utilities, industry experts, and State and Federal government reports. Economic data was sourced primarily from price determination reports from the NSW Independent Pricing and Regulatory Tribunal (IPART), and again directly from water and energy utilities.

A significant data issue related to Objective 2 was changes to the 2000-01 Water Account by the Australian Bureau of Statistics (ABS). These changes were released as part of the 2004-05 Water Account in late 2006, which was not known to the researcher until mid 2007. The ABS website for the 2000-01 Water Account failed to mention these substantial revisions. This incident highlights the evolving nature of data collection techniques in the water industry, which will undoubtedly continue to improve over time. This would enable better comparisons across years of analysis, and the adoption of more complex research methods that require data at regular time intervals. The data required for Objective 3 were readily sourced from that collected for Objective 2. The main issue was the higher water data aggregation adopted in the 2005 Water Accounts. As described previously, this research adapted to this aggregation by assuming one sector to represent all services sectors in the economy.

Objective 4 data requirements were similarly complex as Objective 2, largely because input-output coefficients were required for new water and electricity sectors considered under each scenario. These sectors were selected after an extensive technological review, to ensure that a good cross section of current and emerging technologies were analysed in the scenarios. This review took into account other technological assessment reports, expert advice, industry reports, research papers and journal articles. Input output coefficients were developed for the new water and electricity sectors considered in the scenarios using detailed engineering data from project specification reports, specialist industry courses, expert advice, Independent Pricing and Regulatory Tribunal (IPART) price determinations, journal articles, construction cost information for Australia, other research reports, and national input-output tables from elsewhere. As described earlier, the 2000-01 input-output model formed the basis for the scenario modelling for 2031. The 2031 model was developed using economic growth forecasts for each of the sectors, population growth forecasts, as well as up-to-date information on the growth in demand for water and electricity, and other likely government policies that would impact that growth (such as water demand management and energy efficiency programs).

This last issue represented perhaps the single greatest challenge in this research. Due to the contemporary nature of water and electricity industry reforms, and this research topic *per se*, this researcher witnessed substantial developments in water, energy and climate change policies, particularly during 2007 and 2008, such that substantial revisions were required to aspects of the research, in particular the literature review in Chapter 2 and final sections in Chapter 4. The more recent developments will be incorporated in the assessment of policy implications in Chapter 8, but no doubt, some of these policies might have already changed. Indeed, it is the aim of this research that these policies change and develop further, in terms of improved integration of water and energy policies.

Table 1-2 Data considerations for each specific objective

Specific Objective	Data requirements	Data sources	Data available	Data gaps	Strategies to overcome data gaps
1	Technological developments; regulatory, structure and ownership arrangements; political orientations; social & development paradigms; and information on historical events and movements	Books, heritage assessment reports, journal articles, legislation, policy papers, personal accounts	Scattered	Minor	N/A
2	(a) NSW & ACT input output tables (b) Water supply and use (c) Electricity supply and use (d) Energy (non-electric) supply and use (e) Water & energy unit prices and O&M data (f) Consumer price index	(a) CARE (UNE) (b) ABS, ANCID, DLWC, WSAA, annual reports, unpublished data (c) ABARE, ANCID, DWE, ESAA, WSAA, annual reports, personal communication, unpublished data (d) ABARE, ACA, AGA, ANCID, IPART, WSAA, annual reports, unpublished data (e) ESAA, WSAA, annual reports, unpublished data, (f) ABS	Highly scattered	Significant	Base on national data. Use other government reports as proxy to energy use, divide water use by financial data ratios.
3	Sectoral end use and price data for water and electricity	ABARE, ABS, ESAA, WSAA	Largely available	Small	Refine sectoral scope to those significant sectors for which data is available. Data quality in the early water accounts
4	(a) GDP and sectoral growth rate forecasts (b) Population growth forecasts (c) Input output data for new water and electricity sectors (d) Water and energy demand forecasts and efficiency improvements	(a) ABARE, ABS (b) ABS (c) Research papers, project reports, national input output tables (d) NSW and Federal Government reports, Transgrid, Owen Inquiry Submissions,	Highly scattered and partially available	Significant	Obtain expert industry advice and international data

Notes: ABARE – Australian Bureau of Agricultural and Resource Economics; ABS – Australian Bureau of Statistics; ACA – Australian Coal Association; ACT – Australian Capital Territory; AGA – Australian Gas Association; ANCID – Australian National Committee on Irrigation and Drainage; CARE – Centre for Agricultural and Regional Economics, University of New England; DWE – NSW Department of Water and Energy (previously Department of Energy and Department of Energy, Utilities and Sustainability); DLWC – NSW Department of Land and Water Conservation; ESAA – Energy Supply Association of Australia (previously Electricity Supply Association of Australia); IPART – NSW Independent Pricing and Regulatory Tribunal; NSW – New South Wales; WSAA – Water Services Association of Australia;

1.5 Significance

This research draws together policy issues of immense contemporary importance. Climate change, water and energy policies are being developed at a rapid rate the world over, there appears to be little understanding of the implications of the water-energy nexus on the efficacy of such policies. This research – which comprehensively analyses the nature of the nexus in the context of NSW – will significantly improve current understanding and offer policy makers timely inputs that will assist in the development of more integrated policies. In particular:

- This research is the first thesis known to the author that comprehensively analyses the wider implications of the water-energy nexus. It therefore represents a significant advancement of knowledge – in terms of the system to classify and explore the links, the integrated methodological framework, and policy implications – that may provide the foundations upon which to build future research in this area of contemporary importance.

- The methodological framework developed for this research contributes significantly to existing literature on the water-energy nexus by integrating methods from various academic disciplines, in order to capture various dimensions of the nexus. In contrast, existing literature is narrowly defined and focused on specific links. The framework may be useful for analysing the implications of the nexus on other regions that are similarly reforming their water and electricity industries. The framework may also be useful for capturing the important links between other infrastructure industries.

- The input-output models enable the quantification of both direct and indirect (also referred to as embedded) water and energy flows in the economy. The inclusion of indirect flows is critical – as in many cases indirect flows comprise the bulk of water and energy use in the economy – and therefore offers greater insights into the wider implications of the nexus. The scenarios developed for this research for 2031 concurrently model technological and policy alternatives in both the water and electricity industries. In contrast, existing scenarios tend to focus on either industry and therefore are not suitable for identifying the interactions and potential trade-offs between both industries.

- The focus of this research is NSW, which is located in south-eastern Australia. This state-level focus reflects the implementation of policy reforms in Australia that, whilst developed at the national level, are largely implemented at the state level. Further, the state-level focus better represents the different energy endowments across Australia. For example, NSW is heavily reliant on black coal for electricity generation, whereas brown coal dominates the Victorian electricity industry. In contrast, South Australia has significant reserves of natural gas, oil is a major contributor to energy in Western Australia, and electricity is largely generated by hydropower in Tasmania.

- This research puts forward recommendations that may benefit both Federal and State government institutions involved with the development and implementation of water and energy policies. For example, the recommendations would assit with reducing some of the water and energy trade-offs that may arise during the implementation of existing policies. These institutions include: the Council of Australian Governments, the Commonwealth Department of Climate Change, the Commonwealth Department of Environment, Water, Heritage and the Arts; the Commonwealth Department of Resources, Energy and Tourism, the Ministerial Council on Energy, the National Water Commission, the NSW Department of Water and Energy, and the NSW Department of Environment and Climate Change.

1.6 Organisation of the thesis

This thesis comprises nine chapters, which are structured in the following manner:

Chapter 2 comprehensively reviews existing links between water and electricity, and introduces a classification system to categorise the links. The purpose of the review is to explore the nature of the nexus, drawing upon examples from Australia and elsewhere. With this background, this chapter also reviews existing water-energy studies, in order to determine their suitability for examining the nature of the nexus and to identify important areas that would benefit from more in-depth research.

Chapter 3 introduces the methodological framework for this research. It begins with a discussion on the philosophical influences that have informed both the development of the framework and the selection of research methods. This chapter continues with descriptions of the research methods and the water-energy models developed for this research.

Chapter 4 presents the findings for Objective 1. It analyses the historical evolution of the nexus for Australia, with a particular focus on NSW. The purpose is to determine the forces that have shaped the development of the nexus, in order to gain a deeper appreciation of the nexus issues that are prevalent today.

Chapter 5 relates to Objective 2 and forms part one of the empirical analysis of the water-energy nexus. It begins by examining the structure of the NSW economy, in order to identify the key sectors driving economic growth, and to understand the role of the water and electricity sectors in the economy. In addition, this chapter quantifies water intensities for the energy sectors – with a particular focus on the electricity industry – and energy intensities for the water sectors. The input-output models form the basis of the calculations.

Chapter 6 relates to Objectives 2 and 3, and forms part two of the empirical analysis. This chapter focuses on the interaction between water and energy in the remaining sectors in the NSW economy. It begins by quantifying the water and energy intensities for these sectors, and explores some of the associated trade-offs, in terms of the impact on economic output, income and employment. This chapter explores substitution possibilities between water and electricity for a selection of key production sectors and Households. The elasticities also provide further validation for the input-output results.

Chapter 7 relates to Objective 4. This chapter describes the future use of water and energy in NSW in 2031, in the form of four scenarios. The scenarios are compared in terms of how the adoption of different water supply and electricity generation technologies and efficiency strategies might influence the total demand for water and energy in the economy. In doing so, it enables the identification of potential trade-offs in water and energy use in both industries.

Chapter 8 relates to Objective 5. The purpose of this chapter is to synthesise the findings from the previous chapter, in order to suggest inputs for the development of more integrated water and energy policies for NSW. **Chapter 9** presents the main conclusions of this research and puts forward recommendations for further research.

Chapter 2

A review of the water-energy nexus

In summary, the intimate link between clean, affordable energy and clean, affordable water is crystal clear. There cannot be one without the other.

Sandia Corporation

Water and electricity are fundamentally linked. At a basic level electricity generation requires water, and water treatment and transportation uses electricity. Historically, there has been little reason to understand the nature of these links, due largely to the presumption that water was not a threat to energy security, nor electricity a threat to water security. This presumption is now being challenged. Industry reforms, increasing demand, and more recently climate change – as discussed in Chapter 1 – are bringing into sharp focus the links between water and electricity in unprecedented ways. General awareness of the links between water and electricity is increasing daily, as the ramifications of the links are being felt the world over:

> 'water planners at the federal, state, and local levels have largely failed to consider the energy implications of their decisions…the State [of California] appears to not be consciously managing its rapidly evolving water and energy policies in a coherent manner'(Cohen, Nelson & Wolff 2004 page v).

For Hagebro & Cederwell (2003)

> 'there is acknowledgement of the potential synergies in water and energy management that have largely been neglected, as well as recognition that existing national policies do not to any substantial degree link the infrastructure systems' (page 189).

Society's ability to deal with the challenges and uncertainties arising from the links between water and electricity is being hindered by limited understanding of the nature of the links, and seeming lack of policy tools to effectively analyse them. The purpose of this chapter therefore is to comprehensively review the links between water and electricity. Section 2.1 presents a classification system for identifying links. Using the classification system, this section further discusses these links by drawing upon examples from Australia and elsewhere. Section 2.2 follows with a synopsis of the nature of these links. With this background, Section 2.3 reviews and compares existing water-energy studies in terms of scope, objectives, methodologies and key findings. Section 2.4 discusses major limitations of these studies and identifies important areas that would benefit from more in-depth research.

2.1 Emerging links between water and electricity

The links between water and electricity are many and varied, connecting different functions in both industries. To assist with reviewing emerging links, this research divides the functions of both industries into 'upstream', 'transportation' and 'downstream' categories. This classification system shows the common flow sequence in the water and electricity industries, from the Environment – the source of water and primary energy – to the end users. Functions close to the Environment, such as primary energy and secondary energy, wholesale electricity generation, bulk water supply, and desalination are placed in the 'upstream' category. Functions close to the end users, such as retail supply of water and electricity, wastewater treatment, embedded generation, and end users are placed in the 'downstream' category. The 'transportation' category includes transmission and distribution of electricity, and extraction, transfer, conveyance, distribution, and collection of water and wastewater.

The links between water and electricity in this research are similarly classified into 'upstream', 'transportation' and 'downstream' categories depending on the industry functions involved. An example of a downstream link is electricity consumed to treat wastewater. Links that occur across categories are assigned to the category that receives the water or electricity. For example, recycled water (downstream category) used for cooling purposes in a thermal power station (upstream category) is considered an upstream link.

Figure 2–1 illustrates this classification system and identifies key links in each category. These links are discussed in greater detail in the sub-sections that follow.

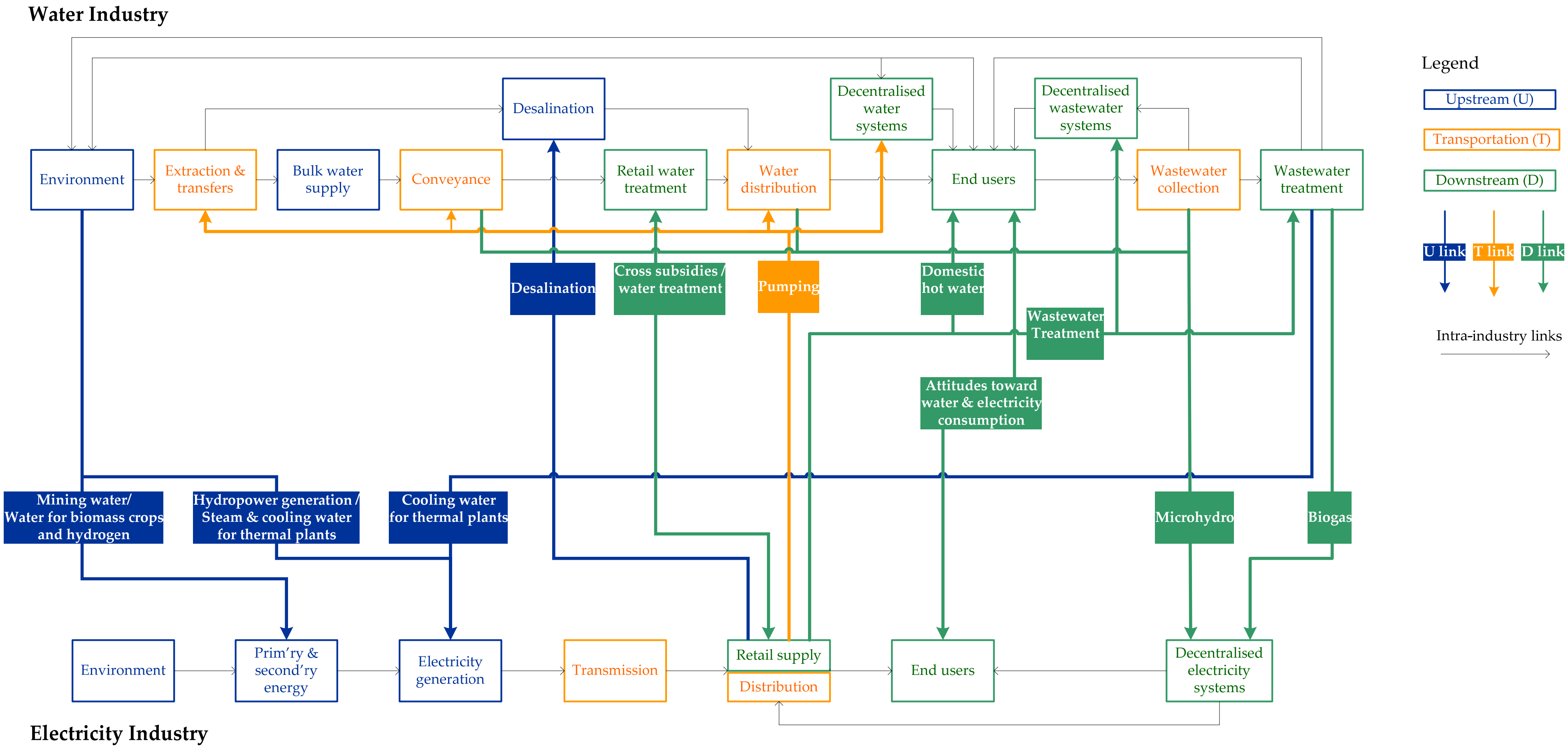

Figure 2–1 Upstream, transportation and downstream links between the water and electricity sectors

2.1.1 Upstream links

Upstream links, as identified in Figure 2–1 include: water collected during mining; water for electricity generation; water for alternative energy production; and electricity for desalination.

Mining water

Coal mining is a key sector in the Australian economy. In 2004-05, mining of coal and other minerals accounted for one third of the total value of exports (ABS 2006a). This sector generates large volumes of water during the mining and extraction process, which is referred to as dewatering. Rainfall, run off and water infiltration also contribute to water collected in mines. Depending on salinity levels, this water is discharged or treated and used on-site. Onsite uses include mineral recovery, quarrying, crushing, screening, washing, dust suppression and irrigation of rehabilitated land. Treated water may also be distributed locally for irrigation and livestock. In 2004-05, coal mines supplied approximately 4,255 ML of water to other users in this manner (ABS 2006d).

As a water supplier, coal mines have a potentially important role in regional water management policies, particularly in areas experiencing drought. The mining sector may therefore be affected by water policy reforms relating to water allocation, trading and pricing in the rural water market. The role of water in mining has been the focus of recent industry meetings[1], indicating an increasing interest in this water resource.

In addition to water collected in coal mines, water exists naturally in oil and gas reservoirs. Called ‘produced formation water’ (PFW), this water is separated from the oil or gas and treated before being discharged. Extraction volume estimates of PFW extracted are not available for Australia (ABS 2006d). It is reported, however, that coal seam gas reservoirs typically require rewatering from local water sources once the gas has been extracted, so that coal mining activities may commence. The use of coal seam gas, which is favoured over the use of coal due to the lower emissions factor, may therefore create local water imbalances in areas already experiencing water shortages (Moore 2008; Vink 2008).

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[1] For example, the Australian Water Association’s Symposium “Water Issues in Mining: A Focus on Solutions” held 13-14 September in Adelaide, Australia and the Australian Institute of Mining and Metallurgy’s Conference “Water in Mining 2006 – Multiple Values of Water” held 14-16 November 2006 in Brisbane, Australia

Water for electricity generation

The electricity industry is highly dependent on water for hydropower generation and for steam production and cooling in thermal power stations. It is, however, important to differentiate between water that is 'used' and water that is 'consumed'. In the case of hydropower generation, water is used rather than consumed as once discharged, this water is available for downstream users, such as irrigators. The significance of water use for hydropower generation cannot be underestimated, as the temporal and volumetric needs of downstream users may differ substantially from the needs of a hydropower generator. Further, hydropower generation uses the largest volume of water in the Australian economy, accounting for 75% of total use 2004-05 (ABS 2006d).

Water demanded by thermal power stations in contrast may either be 'consumed' or 'used'. Water for steam production is consumed as over time, additional water is required to make up for volumetric losses. Water for cooling varies depending on the system type. Closed loop systems with cooling towers recycle water, although a proportion of this water is lost to evaporation and is therefore consumed. Open loop or once through systems, as the terms suggest, do not recycle the cooling water and therefore require significantly larger volumes of water compared with closed loop systems. Similar to hydropower, this water may be available for other users once discharged. Table 2-1 summarises water use and consumption rates for typical generation technologies and cooling systems.

Table 2-1 Water use and consumption for typical generation technologies/cooling systems

Generation technology	Cooling system	Water Use (L/MWh)	Water Consumption (L/MWh)
Steam (coal/biomass co-firing)	Once-through	75,708 – 189,270	1,136
Steam (coal/biomass co-firing)	Pond	1,136 – 2,271	1,136
Steam (coal/biomass co-firing)	Cooling towers	1,893 – 2,271	1,817
Steam (nuclear)	Once-through	94,635 – 227,124	1,514
Steam (nuclear)	Pond	1,893 – 4,164	1,514
Steam (nuclear)	Cooling towers	3,028 – 4,164	2,725
Combined cycle (natural gas/oil)	Once-through	28,391 – 75,708	329
Combined cycle (natural gas/oil)	Cooling towers	871	681
Combined cycle (natural gas/oil)	Dry cooling	0	0
Combined cycle (coal/petroleum residuum)	Cooling towers	*1	757

*includes gasification process water. Source: Woods (2006)

It is evident from Table 2-1 that water use, and to a lesser extent water consumption, differs between both generation technologies and cooling systems. These differences become important for the electricity industry during times of critical water shortages. Related to the issue of water shortages – or more broadly speaking water availability – is the issue of trade-offs which may occur between electricity generators and other users of the same water resource. Both issues are currently being faced in Australia and in other parts of the world, and both issues are highlighting the significance of the nexus to the upstream electricity industry, as discussed in the following section.

Water availability

In mid 2007, thermal and hydro power stations in Australia faced serious threats to electricity generation capacity, as a result of a long-standing drought that afflicted much of the south east corner of the country (Anon. 2007a; Gordon & Kleinman 2007; Kleinman & Houston 2007). The consequences for the industry and economy were immense. In March 2007, it was reported that reductions in generation at Queensland's two major power stations, Swanbank and Tarong, cost the State government $1 million per day in lost revenue and resulted in job losses in the coal mining industry (Ludlow & Wisenthal 2007; Sheehan 2007). Further, in the absence of significant flows, salinity levels in water storages that supply power stations increased to alarming levels, requiring generators to install expensive salinity control devices, in order to protect station equipment from damage (Anon. 2007a).

Reductions in generation caused by water shortages have also been linked to unprecedented increases in the wholesale price of electricity in 2007. Prices in the spot market and wholesale contract market increased by up to 270 and 100 per cent respectively in May 2007, compared to the preceding 12 months (Bildstien 2007). Industry commentators at the time reported that high prices would flow on to electricity retailers and ultimately customers in subsequent price determinations by regulators (Warren 2007).

As a result of the electricity 'crisis' arising from water shortages, generators across the country have put in place contingency measures to secure their water supplies. These measures encompass more shorter term 'emergency' solutions and longer term plans. Regardless of time horizon, however, these measures appear to be largely 'knee jerk' responses by an industry caught unprepared.

In 2007, power stations in the La Trobe Valley of Victoria bought emergency water from an internet water auction site – accessed normally by smaller scale horticulturalists – to ensure their water supplies were sufficient to meet expected generation output in the few months that followed (Kleinman & Houston 2007). In NSW, a generating company transferred generation from an inland station located in a region experiencing water shortages to a coastal power station cooled by seawater. Other generators in NSW have secured additional water from nearby coal mines, have installed equipment to treat effluent from a local wastewater treatment plant for onsite reuse, and have obtained permission to extract additional river water that is normally reserved for periods of high river flows (Anon. 2007a; New South Wales Government 2007; Wilkinson & Smith 2007). In Queensland, two major power stations will soon access water from a large-scale centralised recycled water scheme called the Western Corridor Recycled Water Project. Use of this recycled water will increase their current generation cost of $35 per MWh by an additional $5-$10 (Queensland Government 2006; Roberts 2007a). Further, a new thermal power station in Queensland will be dry-cooled (Orchison 2007). Dry cooling technology reportedly reduces water use by 90 to 95 per cent, but may result in thermal efficiency losses of up to eight per cent (Electric Power Research Institute (EPRI) 2002).

Snowy Hydro, which operates Australia's Snowy Mountains Scheme near the border between Victoria and NSW, has also introduced a range of measures to reduce its exposure to water shortages. In 2007, the company commenced a winter cloud seeding program, in order to increase snowfall, thereby increasing water inflows into its water storages when the snow melts. The company is also recycling water through its largest power station, Tumut 3 (Snowy Hydro Limited 2007).

In order to further reduce its exposure to water shortages, Snowy Hydro recently procured two gas-fired power stations in Melbourne, Victoria. The company aims to use these stations to supplement hydropower generation during peak electricity demand when water storage levels are low. Generation from these two stations is controlled by an operating licence from the Victorian Environment Protection Authority (EPA), in order to limit carbon emissions. Given the severity of the recent drought, however, Snowy Hydro has transferred generation to the gas fired power stations above anticipated levels and has reached the limit set out in its EPA licence. Furthermore, the EPA has reduced the operating hours of the two stations, due to recent vibration complaints from nearby businesses (Gordon 2007).

The case of Snowy Hydro raises a significant issue for electricity generators seeking to secure limited water supplies. That is, due to the links between water and energy, difficult trade-offs are likely to occur when there are insufficient volumes to meet the needs of all water users.

Shared water resources and potential for trade-offs

Water resources typically serve different purposes, including electricity generation, urban water supply, irrigation, recreational activities and navigation. Beyond these physical uses, water resources may be valued for their inherent beauty, or cultural and spiritual significance. The diverse values placed on water, therefore, can give rise to potential trade-offs, particularly during times of water shortages. The preceding section outlines some of the challenges being faced by generators and some of the measures to cope with water shortages. The wider implications of these challenges for other water users are now discussed.

The Snowy Mountains Scheme offers insights into the types of trade-offs being experienced between Snowy Hydro, irrigators and the Environment. The Scheme diverts water for hydropower generation from the Snowy River and discharges the water into the Murray and Murrumbidgee Rivers to serve farming interests west of the Dividing Ranges, as well as downstream users in Victoria and South Australia. Water allocations between users are generally defined under Snowy Hydro's water licence. In 1998, the Federal and state governments of NSW and Victoria established the Snowy Water Inquiry 2000, due to the poor environmental state of the Snowy River. As a result of the inquiry, the three governments agreed to return 21 per cent of average natural flow to the Snowy River, and an additional 7 per cent in the longer term (Heads of Agreement 2000). Environmental flows would be largely met by water saving measures in the Murray and Murrumbidgee Rivers and if required by purchasing water entitlements in NSW and Victoria. The initial 21 per cent represents 150 GWh of foregone electricity for Snowy Hydro, and as this target is increased to 28 per cent, additional generation will be foregone (Heads of Agreement 2000).

Despite this agreement, irrigators have claimed that recent actions by Snowy Hydro have placed their access to irrigation water in jeopardy. In one incident, irrigators asserted that Snowy Hydro reduced water releases from its storages, in order to conserve water until peak summer demand, when electricity prices are highest in the National Electricity Market (NEM). The company, however, has maintained that it acted in accordance with its licence (Wahlquist & Mitchell 2006). In a separate incident, Victoria accused NSW of entering into a secret deal with

Snowy Hydro to release irrigation water to rice farmers in NSW, at the expense of future hydropower generation in Victoria (Egan & Dowling 2007). Further, in 2002-03, it was reported that Murrumbidgee irrigators paid an additional premium for water, so that Snowy Hydro would increase its releases into the Murrumbidgee River, rather than into the Murray River (Campbell 2008). No doubt the profit-maximising objective of the wholesale electricity generation market within which Snowy Hydro operates would have contributed to Snowy Hydro's decision. Regardless of the veracity of the claims, these incidences highlight current tensions between hydropower generators and other users.

Thermal power stations have also been engaged in water trade-offs with other users. For example, Roberts (2007b) reported that NSW imported cheap electricity from Queensland via the NEM in early 2007. At the time, the Queensland power stations were sourcing cooling water from Brisbane's main drinking water supply, Wivenhoe Dam, despite the imposition of water restrictions in the region, and despite sufficient generation capacity in NSW to meet its own demand. Supporters of the NEM, however, claimed that it brought continuity of supply and significant economic benefits to Queensland (Roberts 2006). In NSW, conditions governing river water access rights for at least one thermal power station have changed. In the past, this station supplemented water from the Hunter River during times of high river flows. Due to water shortages, the station has been permitted to extract water from the Hunter River outside of high flow periods, with implications for downstream irrigators (Wilkinson & Smith 2007).

This trend of trading water between generators and other users is likely to become more frequent and more severe with climate change. The National Generators Forum, which is the peak representative body for generators in Australia, has already argued the likelihood in future that governments will need to lift environmental constraints – such as reducing environmental flow allocations – for the benefit of electricity generators (Cowan 2007).

Similar patterns have developed elsewhere in the world. In California, reforms in the late 1990s led to the creation of a contestable wholesale electricity market, and establishment of fixed prices in the retail sector. In early 2001, California experienced a severe energy crisis when wholesale market prices far exceeded the fixed retail price, resulting in two retail companies becoming insolvent. In order to prevent widespread blackouts, hydropower plants in Oregon and Washington were obliged to produce power for California, despite these states experiencing drought and committing to reserve water for endangered fish stock along the Columbian River. The resulting trade-off was the largest recorded number of salmon killed in the Columbian River (Lofman, Petersen & Bower 2002; Oak Ridge National Laboratory 2002). Such widespread killing significantly impacted many of the native Indian tribes in the Columbian Basin who have a cultural and spiritual identity with salmon (Gaard 2001).

Shared water resources between riparian states may give rise to further challenges as well as opportunities. In Central Asia, for example, dismantling of the former USSR brought about a decline of resource sharing between the newly independent countries. Resource decisions were made independently, resulting in a less than optimal allocation of water, and greater environmental impacts (USAID 2003). In the region, upstream countries rely heavily on water resources for power generation, which reduces the irrigation capacity of downstream countries during other times (downstream countries have alternative power sources, such as coal). The export price of electricity also increased, thereby increasing the debt of utilities when electricity was imported to meet local demand (Kennedy, Frankhauser & Raiser 2003).

To foster greater cooperation in this region, a *Framework Agreement on the Use of Water and Energy Resources of the Syr Darya Basin* was established in 1998 (Antipova et al. 2002). The longer-term aim of the Framework is to develop a power pool in the region, in order to take advantage of regional trade benefits, as peak demand can be supplied by another state in a different time zone. Further, proponents of the Framework believe that encouraging private investment – through institutional reform – would assist in rehabilitating the network, improve tariff collection rates and improve technical efficiency of the power system (USAID 2003).

Water for alternative energy production

Alternative energy sources, such as biomass, hydrogen and geothermal power, have the potential to reduce society's reliance on fossil fuels. Biomass is biological material that may be burned to produce steam in thermal power plants or be converted to transportation fuel. Common examples include agricultural and forestry waste, methane from sewage, and bagasse from the sugar cane refinery process. Crops grown specifically for biomass such as switchgrass, however, would compete with food crops for irrigation water and land.

Hydrogen may be used in fuel cells to generate electricity or as a fuel for transportation. Two methods are currently available to produce hydrogen: reforming of fossil fuels and electrolysis of water. Reforming of fossil fuels involves separating hydrogen from carbon. The electrolysis process uses electricity to split water into H_2 and O_2 molecules. When coupled with a renewable energy such as solar power, this method would result in zero carbon emissions. Whilst electrolysis of water may be the preferred option – due to zero reliance on fossil fuels – uptake of the technology may be restrained by the availability of water. Moves toward a hydrogen economy would also require sufficient volumes of hydrogen for transportation, further increasing the dependency on water resources (Veziroglu 2004).

Geothermal power harnesses heat under the earth's surface. Steam or hot water is typically pumped to the surface through rock fractures to generate electricity or provide space heating before being reinjected to the hot rocks to take up additional heat. Geothermal power is being harnessed in over 20 countries around the world, including Italy, the United States, and Africa. In Australia, hot dry rock (HDR) technology – which comprises pumping surface water underground to harness hot rock energy – is being explored in NSW and South Australia (Australian National University 2003). HDR recycles water through the bed rock, although some water loss occurs.

Electricity for desalination

Surface water supplies most of the freshwater needs in Australia. Large-scale storage dams were constructed to offer additional supply security in areas where precipitation varied significantly, and were the mainstay of water planning strategies. However, the recent drought and the extended drought that preceded it jeopardised this supply security, as dam levels fell with little replenishment.

It is argued that non-rainfall dependent supply options, such as seawater desalination, offer better supply security and warrant consideration. There are already 17,000 desalination plants operating in 120 countries that supply 23 million m3 of water worldwide (Smith 2005). Most of these plants are located in the Middle East and North Africa. In Australia, desalination plants are operational in Western Australia and South Australia and are under construction in NSW, Victoria and Queensland. Seawater desalination, however, is extremely energy-intensive and consumes more energy compared with other water supply options, as Table 2-2 illustrates.

Table 2-2 Energy consumption by various water sources

Water source	Energy consumption (kWh/kL)
Conventional water treatment	0.1 – 0.6
Conventional wastewater treatment	0.4 – 0.5
Brackish water desalination	0.7 – 1.2
Advanced wastewater treatment	0.8 – 1.5
Seawater desalination	3.0 – 5.0

Source: Adapted from Ball & Keane (2006), Radcliff (2004) and Voutchkov (2007)

Some proponents of desalination argue in favour of co-locating desalination plants with nuclear power plants. Both technologies, it is argued, offer solutions to water shortages and climate change (Maiden & Kerr 2006). To demonstrate the economic competitiveness of nuclear desalination, the International Atomic Energy Agency (IAEA) developed an evaluation software titled *Desalination Economic Evaluation Program* (DEEP). This software program compares different energy options in terms of the per unit cost of water and power, energy consumption for desalination, and net saleable power for a specific site (Ebensperger & Isley 2005). Critics of nuclear power argue that nuclear power is not carbon-free, as fossil fuels are consumed to mine and process uranium, and to build the plants. It is also argued that nuclear power is economically unfeasible without heavy government subsidies, and plant safety and nuclear proliferation risks are still causes for concern (Lowe AO 2005). Furthermore, nuclear power stations consume 30 to 50 per cent more water than other types of thermal power plants, which would restrict the construction of any future stations to coastal areas (refer to Table 2-1).

Desalination may also be used for treating groundwater (termed brackish water) to potable standards. The electricity demand is comparatively less than seawater desalination, because of the lower salt content (refer to Table 2-2). This technology may be powered by renewable energy, such as solar power, which is particularly useful for remote areas that are not connected to the grid.

2.1.2 Transportation links

Transportation refers to the network functions in the water and electricity industries. For water, this includes groundwater extraction, bulk surface water transfers, retail water distribution and wastewater collection. It is estimated that pumping water consumes up to seven per cent of energy produced worldwide (James, Campbell & Godlove 2002). In contrast, the transportation functions of the electricity industry – transmission and distribution – consume negligible amounts of water, and this would be dominated by potable water consumed by employees (Energy Australia 2006).

Electricity for groundwater extraction

Groundwater is a valuable water resource, particularly in regions where surface water supplies are insufficient to meet demand. Drought and climate change are likely to further increase the reliance on groundwater. Extracting groundwater, however, is energy-intensive. Further, high extraction rates would lower the groundwater table, requiring more energy for pumping per unit volume of water. High extraction rates may also lead to exhaustion of the groundwater aquifer, if the rates are higher than the natural replenishment rate.

In eastern Australia, surface water is typically cheaper than groundwater. Nevertheless, due to the current drought surface water prices have exceeded groundwater prices in the rural water market (Kelly 2005, personal communication). This shift towards extracting cheaper groundwater would increase electricity consumption.

In India, poor electricity quality (such as blackouts and low voltage), highly subsidised electricity prices, and regulation governing the use of electricity and groundwater are major concerns for both the water and electricity industries (Malik 2002; USAID Global Environment Centre 2001). Groundwater is a vital water source in parts of western India but frequent blackouts have forced farmers, households and industries to install diesel backup generators and pumps in order to access groundwater. Highly subsidised electricity prices and lack of regulatory controls over electricity consumption and groundwater extraction have also encouraged many water users to install inefficient pumps and have led to an overexploitation of groundwater. Localised lowering of the water table, increased salinity, and arsenic contamination of water supplies are consequences of groundwater overexploitation, and have serious social and environmental ramifications for affected communities (Padmanaban 2001). The links between groundwater and electricity are being examined in detail in India as part of the U.S. Agency for International Development's (USAID) Wenexa Program. Participants in this program argue that energy pricing reform may be more effective for managing water consumption than water pricing reform (PA Government Services Inc. 2006).

Electricity for surface water transfers

Surface water transfers can supplement local water supplies that are insufficient to meet demand. Whilst water is relatively cheap, it is heavy to transport and typically requires electricity for pumping, particularly in hilly or mountainous terrain.

One of the largest proposed water transfer schemes in the world, the South-North Water Transfer Project in China comprises three routes – Eastern, Middle and Western – that will transport an estimated 44.8 billion m^3 of water per annum from the Yangtze River to a dozen water-scarce regions in north and north-west China upon completion (Xinhua 2005). An estimated 67 pumping stations will transfer water along 1,156 km of the Eastern route. The 1,273 km-long Middle route is gravity-fed and therefore would not consume energy for pumping. In contrast, a segment of the 450 km-long western route comprises a lift of 458m that will consume an estimated 7.1 billion kWh of electricity per annum for pumping (McNeill 2000). This segment is equivalent to over ten per cent of the electricity generated in NSW and the ACT in 2005 alone (Energy Supply Association of Australia 2006).

In California, water transfers consume five per cent of peak load and seven per cent of total electricity usage (Ameriscan, 2001 in Lofman, Petersen & Bower 2002). The largest single user is The State Water Project that delivers water from the San Francisco Bay Delta to Southern California. This project has the highest lift of any water system in the world, pumping 2000 feet (approximately 610 metres) over the Tehachapi Mountains.

In NSW, water transfers from the Shoalhaven and Kangaroo Rivers in the south of the state augment supplies for greater Sydney during drought. Over the last five years, approximately 28 per cent of Sydney's water supplies have originated from these southern rivers, effectively saving Sydney from a potential water crisis[2]. These transfers would have increased the electricity consumed by the industry.

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[2] Presentation by Dr Kerry Schott, Managing Director of Sydney Water, at "Accounting for Carbon in the Water Industry Conference", 27 February 2008, Sydney

Electricity for retail water distribution and wastewater collection

Water distribution and wastewater collection systems that are not gravity-fed consume electricity for pumping. Pumping needs – and therefore electricity consumption – vary depending on the topography of the land. Table 2-3 presents some data from Queensland, Australia, on the electricity consumption rates for water and wastewater pumping stations. Household pressure pumps have also been included in the table for the purpose of comparison.

Table 2-3 Electricity consumed to pump water and wastewater

Type	Electricity consumed (kWh/kL)
Water pumping station	0.04 – 0.45
Wastewater pumping station	0.07 – 0.14
Household pressure pump	0.23 – 3.10

Source: Gold Coast Water (2003b) and Griffiths (2003) in Radcliff (2004)

In order to reduce electricity consumed to transport water, water utilities worldwide are establishing leak detection programs and installing more energy efficient pumps (James, Campbell & Godlove 2002). These electricity savings will become more important as urban water utilities expand their systems to keep up with population growth whilst trying to reduce their carbon emissions.

Road transportation is an alternate option in areas where water distribution infrastructure is inadequate, especially in developing countries. Associated energy needs would include transportation fuel, and electricity for pumping, if the water is temporarily stored underground by end users.

2.1.3 Downstream links

Downstream links include water and electricity cross subsidies, electricity for water and wastewater treatment, decentralised electricity systems, and water and electricity consumption by end users.

Water and electricity cross subsidies

Multi utilities have emerged over the last decade or so to offer multiple infrastructure services, including water, electricity, gas and telecommunications. In developing countries, private sector multi utilities are being awarded concessions[3] to provide water and electricity services. In 1997, the west African nation of Gabon awarded French company Vivendi Water a concession to manage the national utility, Société d'Eau et d'Electricité du Gabon (SEEG) for 20 years. More than ten years of reform preceded the award of the concession, in order to prepare the country's legal framework and to raise prices to reflect the cost of supply. Vivendi Water won the concession on the premise that prices would decrease by 17.25 per cent, and that US$800 million would be invested to improve services and increase coverage. The company inherited an established electricity business and a less-developed water business that was in a poorer financial state. Social attitudes, it has been suggested, have contributed to the differing financial health of both businesses. It is argued that customers are more willing to pay for electricity than water, because of the perception that water is a free good provided by nature[4]. The electricity business is therefore heavily cross subsidising the water business. Whilst water accounts for only 15 per cent of revenue, up to 60 per cent of investment has been assigned to upgrade and expand water services over the life of the concession (Tremolet & Neale 2002).

Electricity for water and wastewater treatment

Water and wastewater treatment processes use a range of technologies that consume electricity to varying degrees. The choice of technology is dependent on several factors, including the quality of water entering the water treatment plant, policies controlling the discharge quality of treated effluent, intended reuse of treated effluent, and cost implications. Most of the water infrastructure today comprises large-scale centralised systems, however, more decentralised options are being considered in order to reduce reliance on mains supply. Proponents also argue that decentralised systems enable more localised solutions, avoid large financial risks inherent in big projects, and can meet demand incrementally (Fane & Mitchell 2006).

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[3] Arrangement whereby a private company enters a contract with a government to operate and maintain existing assets that remain in the public sector, and develop new investments.

[4] Presentation by Pierre Victoria at the IWA World Water Congress, 11 – 14 September 2006, Beijing

A conventional, centralised water treatment process typically involves coagulation and flocculation, sedimentation, filtration, and disinfection. This process consumes approximately 0.1 – 0.6 kWh/kL, depending on the quality of the water entering the treatment plant (refer to Table 2-1). Decentralised systems include rainwater harvesting and stormwater collection. Both systems would save electricity otherwise used to treat and transport water via the distribution network, but would consume electricity if pumping is required. Smaller-scale pumps – such as those used by households to pump rainwater – generally consume more electricity per unit volume of water than pumping stations (refer to Table 2-3). It is quite possible therefore that a decentralised water system consumes more electricity than the centralised system it is replacing.

A conventional, centralised wastewater treatment process commonly involves preliminary, primary and secondary treatment. During preliminary treatment, large inorganic objects and smaller particles are removed. The wastewater is subsequently transferred to a primary settling basin to remove settled organic solids (primary sludge) and floating scum. Secondary treatment commonly uses biological processes, such as conventional activated sludge (CAS), to remove dissolved or colloidal organic matter. Variations to this secondary process include sequencing batch reactors (SBR), and membrane bioreactors (MBR). Tertiary treatment, such as nutrient removal and disinfection, may also be used to achieve a higher treated effluent quality.

More advanced processes are required to treat wastewater to potable standards. There are two common processes, both of which involve pre-treatment and reverse osmosis (RO). The first process filters secondary treated effluent through membranes (microfiltration or ultrafiltration) prior to RO treatment. The second process replaces both the CAS treatment and membrane filtration with an MBR prior to RO treatment. This process requires a smaller land footprint and enables onsite treatment and reuse, without needing to source secondary treated effluent offsite. Table 2-2 compares the electricity consumed for a selection of water and wastewater treatment processes. Advanced wastewater treatment (0.8 – 1.5 kWh/kL) consumes significantly more electricity compared with conventional water (0.1 – 0.6 kWh/kL) and wastewater treatment (0.4 – 0.5 kWh/kL). Increasing the use of recycled water – in order to meet increases in demand or to drought-proof water supplies – would significantly increase electricity consumption in the industry.

Decentralised wastewater systems enable the onsite reuse of water and therefore improve water efficiency. Similar to large scale systems, technologies comprise a mix of physical, chemical and biological processes. Physical refers to filtration, sedimentation and flotation. Chemical refers to the use of coagulants to assist with the removal of pollutants. Biological processes transform pollutants to more manageable forms. Electricity consumption for these processes vary from as low as conventional wastewater treatment (0.4 – 0.5 kWh/kL), but are generally similar to advanced treatment processes (0.8 – 1.5 kWh/kL). Some processes, however, consume up to 47 kWh/kL (Holt & James 2006).

It is clear that technology determines the amount of electricity consumed to treat water and wastewater. The choice of technology in turn is influenced by policies governing water and wastewater quality. In developed countries such as the United Kingdom, water utilities are installing more sophisticated and energy-intensive treatment systems, as a result of the introduction of stricter environmental quality controls over wastewater discharges. Water utilities are also faced with conflicting goals of reducing their electricity consumption to meet carbon emission targets (Zakkour et al. 2002). In developing countries, highly subsidised water and wastewater services would reduce the revenue needed to properly maintain treatment plants, potentially leading to electricity losses from inefficient equipment. Further, if environmental regulatory controls are weak, utilities may ‘economise’ on electricity by not treating wastewater to adequate levels (PA Government Services Inc. 2006).

Decentralised electricity generation systems

Decentralised electricity generation systems – also referred to as embedded or distributed generation – bypass high voltage transmission lines by connecting directly to the local distribution network (refer to Sharma & Bartels (Sharma & Bartels 1998) for an analysis of distributed electricity generation in the context of Australia). The term applies to a range of renewable and non-renewable technologies, from small roof top photovoltaics (<20 kW) to larger systems such as biogas generators (5 MW). Embedded generation offers several advantages over electricity from the grid. It enables electricity consumers to produce their own electricity and to sell any excess to the grid. Embedded generation may therefore ease constraints in the distribution network and delay investment in expensive infrastructure. It also enables large electricity consumers the opportunity to reduce their carbon footprint and generate carbon offsets.

The water industry is already taking advantage of opportunities to generate its own electricity. Small hydroelectric turbines are becoming commonplace across the water industry and often serve as pressure reduction valves. Water utilities are installing these turbines in bulk storage reservoirs, irrigation channels, water distribution networks and wastewater collection networks (Melbourne Water 2002; Pacific Hydro 2006; Sydney Catchment Authority 2003). Wastewater treatment plants are also generating electricity by combusting methane that is produced from the anaerobic digestion of sludge (Australian Business Council for Sustainable Energy 2005). The role of embedded generation in the water industry is likely to increase in the future, as part of carbon reduction strategies.

Water and electricity consumption by end users

There are several factors that influence how water and electricity are consumed by end users. These factors include the value society places on water and electricity, pricing policies, and voluntary and mandatory demand management programs. Due to embedded water in electricity and embedded electricity in water, changes to consumption patterns of either water or electricity by end users would have flow on effects to the other resource.

In Australia, historically cheap retail prices have perpetuated the perception that water and electricity are low in value, and therefore do not need to be used conservatively. In addition, pricing structures were tied to the size or value of properties, rather than the volume of water consumed (refer to Chapter 4 for further details). Recent reforms have brought about changes to pricing policies, including implementation of full cost recovery and volumetric pricing. These changes provide a more direct link between how much end users consume and how much they pay for water and electricity, which would positively influence consumption rates. Smart meters that monitor real time use of water and electricity would further enforce the links between consumption patterns, and water and electricity bills.

In Australia, voluntary and mandatory demand management programs are being implemented in both industries as a result of the recent drought and localised constraints in the electricity distribution network. Some examples of voluntary programs in NSW include Sydney Water's Waterfix Program for households, and Every Drop Counts Program for businesses (Sydney Water 2008b). Mandatory water restrictions are also in place across much of the state's metropolitan areas, which limit when and how water may be consumed (Sydney Water 2008c). These programs would also reduce electricity consumption.

In developing countries, it is not uncommon for water and electricity to be provided at near zero cost, offering little incentive for resource conservation. The link between electricity price and overexploitation of groundwater in India has been discussed earlier in this chapter. In an effort to reduce groundwater and electricity consumption in the agricultural sector, water saving irrigation techniques, water efficient crops and rainwater harvesting are being piloted as part of USAID's Wenexa Program (USAID 2006). In contrast, the industrial sector in India is charged the highest for water and electricity. High electricity costs associated with industrial wastewater treatment and poor enforcement of environmental regulation would encourage industries to forego treatment, thereby passing this burden onto downstream water users (PA Government Services Inc. 2006).

2.2 Nature of nexus: a synopsis

The above-mentioned discussion clearly illustrates that water and electricity are inextricably linked and that these links occur in all three categories – upstream, transportation and downstream. The implications of the nexus are being felt the world over, as increasing pressures of drought, climate change, industry reform and a rise in demand for water and electricity, intensify this interaction.

It is also clearly evident from the above discussion that the nexus is multidimensional in nature. This research classifies the dimensions as: environmental, technological, economic, political and social. The many examples and case studies cited above also suggest that these dimensions influence each other, quite often antagonistically. In order to develop a greater understanding of the nature of the nexus, the following section analyses each of the dimensions in turn, and draws largely from the discussion in the preceding section.

2.2.1 Environmental dimension

This research considers the environmental dimension as the starting point for discussing the nature of the nexus, because the Environment is the source of all water and energy resources. This dimension therefore provides a backdrop for many of the links.

The first environmental dimension is climate change, which is accelerating because of greenhouse gases emitted by human activity. One of the largest causes of climate change is burning of fossil fuel – such as coal – to generate electricity. Climate change is creating uncertainty over future supplies of water, which has implications for long-term water and energy security. In addition, climate change mitigation policies, such as afforestation associated with electricity generation, may increase the water impacts of the electricity industry.

Drought represents a second environmental dimension and has been the underlying reason for the focus on water and energy links in the recent past and present, particularly in Australia. Although Australia is prone to drought, until recently we have developed infrastructure and consumed water and electricity with little regard to the finite quantities of natural resources, especially water. Ecosystems also need water to survive, yet due to drought, the 'pool' of water available to share is shrinking, and may shrink further with climate change. At the same time, demand for water and electricity is increasing and with it are carbon emissions.

Both industries are responding to drought in several ways, including sourcing alternative water supplies, installing advanced wastewater treatment technologies to recycle water, constructing desalination plants, and investing in technologies that reduce water consumption, to name a few (refer to Section 2.1.1). Some of these measures will inevitably increase electricity consumption and therefore carbon emissions, and further contribute to climate change.

Conflicts and trade-offs between users are increasing as our water supplies decrease. These users – including the water industry, electricity industry, agricultural sector and the Environment – all have legitimate and vital claim to water, yet which user takes priority when the water is short? Do we prefer to preserve an ecosystem under threat, or to ensure that our taps flow and our lights turn on? Such questions are not hypotheticals. The USA has already experienced this to an acute degree in 2001 with the Californian Energy Crisis, and Australian generators have already alluded to the issue (refer to Section 2.1.1). It appears so far that the path of least resistance is to sacrifice the Environment. Cuts in water and electricity supplies have too many political implications.

Even policies designed to protect the Environment may create water-energy imbalances elsewhere. For example, more stringent environmental controls to improve the health of ecosystems requires improvements to the quality of treated effluent being discharged (refer to Section 2.1.3). This comes at an energy cost, because of the need for more energy-intensive treatment technologies. Conversely, in the absence of policies or policy enforcement, the Environment may stand to lose more and the implications of the nexus may be more acute. In developing countries, for example, groundwater extraction in rural areas is not regulated and electricity prices are highly subsidised. Both conditions have resulted in increased salinity and arsenic contamination (refer to Section 2.1.3). In more urban areas where electricity prices are higher and industries are required to treat wastewater, lack of monitoring or enforcement of policies may result in untreated wastewater being discharged into the Environment (refer to Section 2.1.3).

2.2.2 Technological dimension

The technological dimensions described the physical links between water and electricity. In the electricity industry, generation technologies and alternative energy sources consume different amounts of water and emit different amounts of carbon (refer to Section 2.1.1). The water needs in cooling systems also differ (refer to Section 2.1.1). In the water industry, technological options are becoming increasing energy-intensive – such as desalination, water recycling, water transfers and groundwater extraction – as traditional easily-accessible sources become depleted due to drought, more stringent environmental controls and, in the longer term, climate change. Decentralised systems, such as rainwater tanks, reduce reliance on mains water supply but may increase electricity consumption (refer to Section 2.1.3).

The technological dimension is becoming more topical, as it is seen to have created some of the environmental problems we currently face, such as climate change. In the process of preparing for climate change and mitigating other environmental problems, it may create even more, yet technology is important for a modern society to function and therefore the choice of technology will become more important as utilities seek to augment supply or reduce demand. This raises important questions regarding the mix of technologies adopted in both industries. Is an energy-efficient technology more water intensive, and vice versa? Would efforts in one industry be nullified or at least lessened by efforts in the other industry? What is the sum effect on water and electricity consumption of adopting a matrix of technologies in both industries?

2.2.3 Economic dimension

The economic dimension of the water-energy nexus is gaining in prominence, due in part to reforms occurring in both industries. In Australia, the reforms have brought about changes to the structure, ownership and regulatory arrangements in both industries. The industries have been functionally unbundled, competition has been introduced in the competitive segments, and monopoly segments have been opened to third party access. Further, pricing policies have shifted from the support of subsidies to full cost recovery. In the electricity industry, a national electricity market was established to trade wholesale electricity, and contestability was introduced to the retail function. In the water industry, a rural water market was established, with the aim of allocating water to high value users and of promoting water efficiency (refer to Chapter 4 for further details).

In the electricity industry, wholesale market and long term contract prices increased significantly across the NEM in May 2007 because of drought and concern over water supplies. At the time, the generation industry suggested that the high prices reflected the market at work, and enabled generators to invest in alternative technologies to provide water security for their operations (refer to Section 2.1.1).

At the same time, however, it was argued that the NEM was distorting how water was allocated, because of the profit-maximising objective of markets. This was supported by claims that hydropower generators were hoarding water to maximise profits at the expense of the Environment and irrigators, and that NSW was importing cheap electricity from areas in Queensland that were experiencing significant water shortages, at the expense of drinking water supplies (refer to Section 2.1.1).

It appears that individual segments of the electricity industry were acting out of individual interests, with apparently little consideration for net public benefit. This can be attributed to the introduction of markets that fail to include externalities, which appears to have fostered a disconnect between the water and electricity industries, and their wider economic and social settings. The market failed to capture the full environmental (including water) and social cost of supplying electricity, leading to fragmented decisions based on incomplete information. Overall, is this fragmented approach the best way forward?

The economic dimension is also prevalent in the downstream category with retail water and electricity pricing. It can be argued that price subsidies and tariff structures that do not charge on a volumetric basis undervalue water and electricity, leading to the perception that water and electricity are cheap. In India, for example, highly subsidised electricity prices are resulting in the overexploitation of groundwater resources, with detrimental environmental and social consequences (refer to Section 2.1.2). In other instances, subsidies may have wider social or political objectives. In Gabon, for example, cross subsidies between water and electricity prices are assisting with expanding much needed water infrastructure (refer to Section 2.1.3).

2.2.4 Social dimension

Water and electricity are fundamental for a society to function. Any links between the two inevitably have a strong social dimension. For some segments of society, this dimension features more strongly, because they are directly impacted by the nexus. For example, irrigators downstream of hydropower stations are at risk of losing their water allocation to hydropower generation, especially during times of drought. Such trade-offs have occurred in Australia and elsewhere, and may result in tensions between states and countries (refer to Section 2.1.1). For others, trade-offs have more profound spiritual implications, as the case of indigenous communities in north western America highlighted (refer to Section 2.1.1). Indirectly, however, society at large is susceptible to the links between water and electricity, because of climate change. Climate change will inevitably influence how we use water and electricity, as we seek to adapt to more extreme weather. For example, use of air conditioners will increase in hotter weather, demanding more electricity and indirectly more water.

Social attitudes to water and electricity may also serve to reinforce the links between the two, and one could argue that the public’s perception of the value of water and electricity is linked to consumption. There may be less of a tendency to conserve water and electricity if we perceive that they are of little value. This perception is changing with the implementation of demand management programs in the water industry, energy efficiency awareness programs in the electricity industry, and pricing reforms (refer to Section 2.1.3). Elsewhere, social perception of the value of water and electricity may not correlate with pricing regimes. In Gabon, for example, water is valued, yet communities are used to accessing water for free and therefore are more reluctant to pay for water than electricity (refer to Section 2.1.3).

There is also a social dimension to the uptake of technologies in both industries. The decision to build a desalination plant in Sydney prompted several protests by the public and environmental advocacy groups that were concerned with the energy implication of the plant (Hodge 2005; Robins 2007; Wilkinson & Clennell 2007). Development of water recycling schemes – particularly for potable reuse – also requires careful management of the public's perception of drinking treated effluent. An example is the recent controversy in Queensland regarding the opposition by the end users to a recycled water scheme that proposed to introduce treated effluent to drinking water supplies (Burley 2008). This technology is also more energy-intensive than conventional water treatment (refer to Section 2.1.3). In the electricity industry, there are strong views regarding which are the most suitable technologies to meet our future needs, whilst reducing carbon emissions. Some of these technologies include nuclear power, renewables, clean coal technology, geothermal, biomass, and hydrogen to name a few. The water demand of each would also differ (refer to Section 2.1.1).

The general public is encountering water and energy issues on a daily basis, be it through education awareness programs or media reports about drought and climate change. These issues are increasing awareness of the connection between individual actions and larger regional and global problems. There appears to be a shift in how we perceive the value of water and energy. Are these shifts, however, sufficient to prepare for the challenges and uncertainties that will inevitably increase as the links between water and electricity become more pronounced? Are there alternative ways to approach the future? Such questions go to the core of the philosophies underpinning society's worldview.

2.2.5 Political dimension

The political dimension is equally important as it can influence the extent to which water-energy nexus issues manifest in the other dimensions. Policies arising from industry reforms – that have a strong economic focus – appear to have exacerbated some of the links between water and electricity, through the creation of markets (previously discussed under economic dimension). In terms of the environmental dimension, stricter environmental controls over effluent discharge would require more energy-intensive treatment processes and conflict with goals to reduce carbon emissions (refer to Section 2.1.3). Conversely, the lack of appropriate water and electricity policies or poor enforcement of regulation may result in an increase in electricity use, overexploitation of groundwater, and discharge of effluent without proper treatment (refer to Section 2.1.3).

From the above discussion, it is evident that policies are being developed and implemented in isolation from each other in both the water and electricity industries (refer to Section 2.1.1). Even within one industry, environmental policies – whilst built on sound science – are myopic, because perverse outcomes may result. Both industries would benefit from more integrated policies with sufficient flexibility in order to handle the challenges brought about by the nature of the nexus, which will inevitably increase with continuing drought, increases in demand and in the longer term climate change.

2.2.6 Some further discussion

The aforementioned discussion highlights that there is a link between water and electricity and that there is an apparent fragmentation in the policies governing the water and electricity industries. This fragmentation raises some important points for discussion and questions for policy makers:

- It appears that both industries are balancing between securing water and electricity supplies in the shorter term, addressing immediate environmental needs, planning for growth in demand and preparing for climate change. Events from the recent past suggest that these goals are often in conflict, leading to trade-offs. How should the industries, therefore, prioritise these goals?

- There are isolated cases where water and electricity policies are linked, such as agreements to allocate water. Recent experiences, however, suggest that water shortages can still give rise to conflict as these agreements may not be adhered to.

- There are many supply- and demand-side options to meet future water and electricity needs. Some of these options are currently being explored, yet there appears to be little understanding of the net water-energy impact of the combination of options in both the water and electricity industries. For example, would efforts in one industry be nullified or at least lessened by efforts in another?

- The links between water and electricity are also present outside the boundaries of the water and electricity industries, such as the agricultural sector. To what extend does the nexus impact on other sectors?

- Can the western worldview support the philosophical shifts required to better integrate water and energy policies, and to prepare for the challenges and uncertainties that may arise due to climate change? Further, can the inexorable march of the eastern worldview leading to western-level consumption patterns be moderated?

It is apparent in the foregoing discussion that the nexus is multidimensional in nature, and that these dimensions influence each other. It is also apparent that current policies do not take into consideration these links, with alarming consequences. A possible explanation is the proclivity for professional discourses based on compartmentalisation of knowledge, resulting in narrow solutions within distinct professional spheres. Given the widespread implication of the nexus, studies examining the links between water and energy have emerged in recent years. The next section reviews these studies and their effectiveness at capturing the various dimensions of the nexus, with a view to determining their suitability for policy analysis.

2.3 A review of existing studies

This section reviews existing water-energy studies in terms of objective, scope, underlying research methods and key findings. Table 2-4 summarises some salient aspects of the studies. Outcomes from this review will assist in identifying major limitations in current research and assist in developing a more integrated research framework. The studies listed in Table 2-4 are now discussed in further detail.

a) Horvarth, A. (2005): California, US

By 2025, the demand for urban water in California is likely to exceed supply. To prevent a shortage of water, urban utilities are beginning to investigate alternative supplies. The purpose of this study, therefore, is to assist water utilities with examining alternatives by developing and applying a lifecycle assessment tool termed the 'Water-Energy Sustainability Tool' (WEST).

The study applies WEST to two case studies involving the Main Municipal Water District in the San Francisco Bay Area and the Oceanside Water Department in northern San Diego County. Both studies compare the delivery of 100 acre feet (af) of water to end users (approximately 123.3ML) from imported sources, a water recycling plant (for non potable uses) and a desalination plant. The case studies assess the environmental impacts – such as energy consumption, attributable air emissions and economic impact – of the alternative sources, for the different lifecycle phases (construction, operation and maintenance) and for specific activities (material production, material delivery, equipment use, and energy production). The study concludes that the environmental impacts of transporting imported and recycled water are generally greater than treating the water. The reverse, however, is true for desalination, because the treatment process is relatively more energy-intensive.

This study has a strong technological and environmental focus and is useful for utilities that are making decisions over future water supplies, because the assessment focuses on projects in a given location. The study has limited application for assessing the environmental impacts at a utility-wide level, because the efficacy of demand management programs and changes to end use behaviour are not considered. Furthermore, at the time of publication, there was no scope to examine the impact of changes to the electricity generation mix. This is of particular importance for utilities that are considering renewable energy and embedded energy generation sources in order to reduce their carbon footprint.

Table 2-4 Major water-energy studies

Author	Focus		Scope		Objective	Method	Key findings
	Category	Dimension	Region	Sector			
a) Horvath (2005)	Upstream Transportation Downstream	Technological Environmental	San Francisco and San Diego, USA	Water	To compare the energy impact of supplying water from alternative sources, including imported water, recycled water for non-potable uses and desalinated water	Life-cycle assessment	The energy impacts of transporting imported and recycled water are generally greater than treating the water. The reverse is true for desalinated water.
b) Lundie, Peters & Beavis (2004)	Upstream Transportation Downstream	Technological Environmental	Sydney, Australia	Water	To evaluate the environmental impact of future operational scenarios for Sydney Water	Life-cycle assessment	There were general improvements for all scenarios compared to the base case, with the exception of two scenarios involving desalination and the upgrade of coastal sewage treatment plants.
c) Cohen, Nelson & Wolff (2004)a	Upstream	Technological Environmental	Columbian River Basin, USA	Electricity Agriculture	To examine the energy implications of diverting water for irrigation upstream of a hydropower station	Numerical modelling of scenarios	Energy embedded in agriculture is high, however the opportunity cost of foregoing electricity is higher. Voluntary fallowing programs (VFP) are solutions to manage competing uses and prevent an electricity crisis
d) Cohen, Nelson & Wolff (2004)b	Upstream	Technological	San Diego, USA	Water	To compare the energy intensity of an additional 100,000 af/yr of urban water demand from various sources, including recycling, conservation, transfers and desalination.	Numerical modelling of scenarios	Conservation and recycling are the least energy-intensive. Desalination and recycling are the most reliable
e) Antipova et al. (2002)	Upstream	Technological Economical Political	Toktogul Reservoir, Kyrgyzstan	Electricity Agriculture	To assess scenarios of releasing water from the Toktogul Reservoir in Kyrgyzstan for domestic hydropower generation and irrigation in downstream countries	Optimisation model	Hydropower generation is the main source of energy for Kyrgystan. There is scope to change the regime of water releases to benefit irrigators in downstream countries, if these countries increase their compensatory supply of energy to Kyrgystan

Notes: Table includes salient points of existing major studies (continued on the next page)

Table 2-4 Major water-energy studies (continued)

Author	Focus		Scope		Objective	Method	Key findings
	Category	Dimension	Region	Sector			
f) Nunn et al. (2002)	Upstream	Technological Environmental	NSW, Australia	Electricity	To evaluate the environmental impact of generating 1 MWh of electricity	Life-cycle assessment	Freshwater consumption is insignificant compared to total water consumption in NSW, except for inland power stations
g) Leavesley et al. (1996)	Upstream	Technological Environmental	USA	Electricity Agriculture Environment	To assist with allocating water to generators, irrigators and the Environment	Optimisation model	The decision support system assists water managers with developing reservoir-specific models that are useful for allocating water between competing users
h) Cohen, Nelson & Wolff (2004)c	Transportation	Technological	Westlands Water District, USA	Water Agriculture Environment	To evaluate energy implications of transferring water formerly used for retired lands to: the Environment; urban users, and other agricultural lands in district	Numerical modelling of scenarios	Transferring water to Environment conserves energy. Transferring to urban users consumes considerable amounts for pumping and treatment. Reallocating water to other lands increases consumption, but extent depends on crop types (some require more fertilisers)
i) Kumar (2003)	Transportation	Environmental Economic Political Social	Western India	Agriculture	To analyse the potential impacts of different modes of electricity pricing on productivity of groundwater use	Productivity analysis	Electricity prices may be used to influence groundwater use, at a level of price that is also socio-economically viable. Impact is highest when water is allocated volumetrically

Notes: Table includes salient points of existing major studies (continued on the next page)

Table 2-4 Major water-energy studies (continued)

Author	Focus		Scope		Objective	Method	Key findings
	Category	Dimension	Region	Sector			
j) Schuck & Green (2002)	Transportation	Economic	Kern County, USA	Agriculture	To develop a supply based pricing (SBP) function that takes into account costs for irrigation districts, revenue, interest on financial reserves, as well as growers' profit.	Econometrics	SBP conserves more water and energy compared with uniform pricing. Recommendations include: lowering prices when imported surface water levels are high to reduce aquifer recharge costs; and increasing prices when imported surface water levels are low in order to reflect water scarcity, to discourage groundwater use and to lower energy costs.
k) Nowak (2003)	Downstream	Technological	Austria	Water	To evaluate the electricity demand of wastewater treatment plants that also recover energy	Numerical model using engineering data	Poor design and maintenance causes excess electricity consumption. Electricity demand is strongly dependent on N:COD ratio in raw wastewater (the lower the ratio the less electricity consumed).
l) deMonsabert & Liner (1998)	Downstream	Technological Economic	USA	Government	To develop an integrated energy and water conservation model to identify water conservation options with simple payback periods of <= 10yrs	Numerical model using engineering data	Potential water and energy savings (quantity and value) were greatest for conservation options targeting showers, boiler blowdown and landscape.
m) Hansen (1996)	Downstream	Technological Economic	Copenhagen, Denmark	Residential	To estimate the impacts of water and energy prices on residential water demand.	Econometrics and price elasticities	Water demand appears to be dependent on energy price. Scenarios of increases in energy prices and carbon taxes may have substantial impacts on residential water demand.

Notes: Table includes salient points of existing major studies

b) Lundie et. al. 2004: Sydney, Australia

The authors of this study suggest that water utilities undertaking strategic planning would benefit from understanding the environmental impacts of future operational scenarios. Using a lifecycle software program termed GaBi, the authors assess the operation of Australia's largest metropolitan water utility, Sydney Water, for the year 2021 under nine different scenarios. These scenarios include a base case (where current operating assets were augmented and upgraded), a desalination plant that provides six per cent of supply, additional initiatives that reduce demand by six per cent, four alternative population growth estimates, improvements in energy efficiency, embedded energy generation, co-combusting biosolids in a power station to generate additional energy, upgrade of coastal sewage treatment plants, and development of a greenfield site using local cycle water management strategies. The study compares the scenarios in terms of the total energy consumed and recovered, gaseous emissions, freshwater and marine eutrophication, photochemical oxidant formation, human ecotoxicity, aquatic ecotoxicity and terrestrial ecotoxicity. There were general improvements to environmental impacts for all scenarios compared to the base case, with the exception of desalination and the upgrade of coastal sewage treatment plants.

Similar to the previous study, this study has a strong technological and environmental focus, but does include social drivers such as population growth. In addition, it assesses the operation of the entire water system and claims to be the first LCA to do so. Therefore, the impact of both demand and supply side options may be considered, as well as scenarios of generating electricity within the industry. The links between water and energy, however, are only specific to the water industry and are only part of a wider set of environmental indicators.

c) Cohen et al. 2004 a: Columbian River Basin, US

The Californian Energy Crisis provides the motivation for this study (refer to page 29 for further discussion). During this Crisis, significant trade-offs occurred in the drought-stricken north western United States (US) between hydroelectric generators, other water users and the Environment, in order to avert major blackouts in California. This study examines such trade-offs. The objective is to determine the energy implication of diverting water for irrigation upstream of a hydropower plant in the Columbian River Basin in north western USA. A series of spreadsheets calculates the energy required to plant, cultivate and harvest crops and to divert water to the fields. The calculations also consider the opportunity cost of forgoing electricity generation as a result of the diversions. The model is based on potato, which is the signature crop in the region. Further, liquid fuels, such as diesel for transportation and pumping are included, and are converted to kWh based on the conversion rate if used in a thermal power plant to produce electricity. The study concludes that energy consumed by irrigators is substantial (725 kWh/af), however, the opportunity cost of forgoing electricity generation is higher (745 kWh/af). It suggests that during times of peak demand, revenue from high energy prices could pay farmers not to irrigate through voluntary fallowing programs and to purchase water for environmental flows.

This study investigates the challenging issue of trade-offs between water users, which is relevant to other parts of the world experiencing drought, such as Australia. The results are based on direct energy consumption and do not account for energy embedded in material inputs, and therefore may underestimate energy consumption. The study is also limited to one function within the electricity industry.

d) Cohen et. al. 2004 b: San Diego, USA

The San Diego County Water Authority is investigating ways to meet current and projected demand in 2020, whilst reducing the dependence on imported water. Authors of this study report that previous investigations have not considered energy consumption. To address this situation, the study examines the energy implication of satisfying an additional 100,000 af/yr (approximately 123 349 ML/year) of urban water demand in the County from the following sources: water conservation, recycling, water bag transfers, Imperial Irrigation District transfers, additional water from the State Water Project and seawater desalination.

The model comprises three spreadsheet layers that divide the urban water cycle into five stages: source and conveyance, water treatment, distribution, end use, and wastewater collection and reuse. Data is entered into the second and third layers, and summarised in the first layer. The model includes direct energy, but excludes indirect energy that is embedded in construction materials, maintenance and operation.

The study concludes that end use constitutes the largest component of energy embedded in the urban water use cycle. Conservation and water recycling are the least energy-intensive options and would generate large energy savings of thirteen per cent and six per cent respectively. Desalination and recycling are more intensive, but would offer greater levels of reliability.

The model provides a useful comparison of the main options available to utilities seeking to augment their supplies. The model may be strengthened by including the 'indirect' energy contained in materials, chemicals and other inputs. Additionally, the model should be modified to examine scenarios comprising a mix of water supply sources, as it is not uncommon for utilities to adopt a range of options, rather than one. Similar to the studies discussed above, this study focuses on one industry.

e) Antipova et. al. (2002): Central Asia

Since independence from the former USSR, water resources planning in the Aral Sea Basin region – and more specifically the Syr Darya Basin – has become fragmented for Central Asian countries, resulting in competition for water for irrigation and for hydropower generation. In order to improve water sharing, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan signed an agreement on the use of water and energy resources in 1999 (see Section 2.1.1 for further details). To assist with enacting the agreement, this study developed an optimisation model for the Toktogul Reservoir in Kyrgystan that controls the Naryn Cascade of hydropower plants in the Syr Darya Basin. The Toktogul reservoir was initially constructed to meet agricultural production targets in downstream states, but its operational mode shifted to electricity generation upstream when the countries gained independence.

The study uses General Algebraic Modelling System (GAMS) programming language to develop three sub-models that integrate river, energy and economic systems. The river sub-model captures water sources, downstream users, flow rates through hydropower plants and outputs from these plants. The energy sub-model calculates the most efficient load on thermal and hydropower plants in the region, energy demand, and electricity transfers through the Central Asian Energy Pool (CEAP). The economic sub-model incorporates the cost of energy production and tariffs for electricity transfers. The sub-models are optimised by minimising the cost of meeting the electricity demand in Kyrgyzstan, whilst taking into account irrigation needs downstream.

The model analyses three operational scenarios. Scenario 1 supplies electricity to domestic consumers in Kyrgystan with no transfers through the CEAP. Scenario 2 operates the Toktogul reservoir according to irrigation needs in downstream countries. Scenario 3 examines the long-term control of the Naryn River – which supplies the Toktogul reservoir – by ensuring that inflows from the Naryn River are equal to water releases from the Toktogul reservoir. The study concludes that it is possible to change the regime of releases from the Toktogul Reservoir, provided that downstream countries increase their compensating supply of energy resources to Kyrgystan.

Energy planners in Kyrgystan would benefit from the results of the study. However, there needs to be political will and cooperation from downstream states to compensate Kyrgystan for losses in hydropower generation capacity. It is also unclear how this compensatory supply would function within the Central Asian Energy Pool (CEAP). Like many of the studies above, this study is focused on the electricity sector in one country. The authors, however, plan to develop a more comprehensive model that includes the water and electricity generation sectors of all five Central Asian countries.

f) Nunn et. al. 2002: NSW, Australia

This study, titled *A Life Cycle Assessment of the NSW Electricity Grid* was conducted as part of the 'Coal in a Sustainable Society' Project at the Cooperative Research Centre for Coal in Sustainable Development (CCSD) in Australia. The study is based on a cradle-to-end user analysis for generating, transmitting and distributing power in NSW in the 12 months ending June 2001 (similar studies were subsequently undertaken for Victoria and Queensland). It calculates key performance indicators for different power stations, including freshwater consumption, resource energy consumption, carbon emissions, NOx and SOx, particulates and solid waste emissions to generate. The study concludes that freshwater consumption is generally insignificant compared to total water consumption in NSW, except for inland power stations. Recent events in the industry have demonstrated that adequate volumes of freshwater are enormously important for inland power stations and for the stability of the electricity industry as a whole (refer to Section 2.1.1). The other key finding is agreement between the carbon emissions calculated for the power stations with figures from other sources.

This study focuses on the technological and environmental dimensions. The scope is limited to existing power stations and therefore would not be useful for examining the environmental impacts of a new station or emerging generation technologies. Further, the study only takes into account electricity generation, which represents one function in the industry. Lastly, the water-energy nexus is subsumed under a larger assessment of environmental impacts.

g) Leavesley et. al. 1996: Western US

The authors argue that increasing complexity of environmental and water resource problems require models that incorporate knowledge from a broad range of disciplines. A large number of models exist that – according to the authors – may not be suitable in terms of objective, data constraints, and temporal and spatial scales. To address the problem of model selection, the US Geological Survey and the Bureau of Reclamation in the United States have developed a database-centred decision support system to assist with making decisions on multipurpose reservoirs and watersheds. The system links two existing models – a modular modelling system (MMS) and a power reservoir system (PRSYM) – to a common database. The MMS allows users to 'build' a reservoir model, by selecting appropriate algorithms for a variety of water, energy, and biogeochemical processes. The PRSYM is a general-purpose reservoir simulation and optimisation model based on linear programming, goal programming and rule-based simulation modelling. It is suggested that constructing a model using both MMS and PRSYM via the common database would enable reservoir managers to optimise competing uses of water for electricity generation and irrigation, within environmental constraints such as water temperature limits or fish habitat needs.

For areas experiencing water shortages, this system would be useful for developing allocation policies based on sound scientific data. Events from the recent past, however, indicate that such allocation policies appear to be largely ignored in times of crisis (for example the Californian Energy Crisis and the impact of drought in Australia in 2007). Furthermore, the system only focuses on the water needs of electricity generators, and therefore ignores water-energy links elsewhere in the electricity and water industries.

h) Cohen et. al. 2004 c: Westlands Water District, US

Retiring of agricultural lands is considered a solution to deal with the long-standing problems of soil quality and poor water drainage in the Westlands Water District of the USA. Past land retiring proposals have not accounted for energy use. This study proposes a spreadsheet model, similar to **(b)** and **(c)** above, to investigate the energy implications of three scenarios using water previously allocated to retired agricultural lands. Non-irrigation energy sources, such as diesel for operating farming equipment is also considered. The three scenarios include dedicating water to environmental flows, transferring it to urban users, and reallocating it to other lands in the district.

The study concludes that significant energy savings are made by dedicating water to the Environment, because no electricity will be required for pumping. Transferring water to urban areas, on the other hand, would increase electricity consumption considerably because of pumping and treatment. Reallocating water to other lands would also increase energy consumption, the extent of which – particularly for non-irrigation energy – would depend on cropping patterns. Some crops require more fertilisers that need to be applied by machinery which would therefore consume more diesel.

This study is useful for highlighting the energy implications of water use in other sectors, in particular agriculture. Similar to studies **(b)** and **(c)** above, this study could be strengthened by accounting for indirect energy use of the different scenarios.

i) Kumar, 2003: Western India

In India, it is reported that highly subsidised electricity prices in the agricultural sector have triggered excessive use of groundwater for irrigation and have jeopardised the financial state of the electricity industry. Changes to electricity prices may curb groundwater use, but raise questions of political and socio-economic viability. The objective of this study is to analyse the potential impact of different modes of electricity pricing on gross and net productivity[5] of groundwater use. The modes of pricing are: 1) flat rate based on horsepower rating of pumps; 2) volumetric pricing with a positive marginal cost[6]; and 3) positive marginal cost with fixed water and electricity allocations. Samples of farmers are selected as proxies for the three modes of pricing. Further, the links between irrigation water and gross revenue earned from crops, and between fixed water allocations and cropping patterns are investigated.

The study reveals that electricity pricing levels – at which demand for electricity and groundwater become elastic – are also socio-economically viable. Furthermore, the impact of electricity pricing on water productivity is highest when water is allocated volumetrically. It is suggested that electricity price reform and water rights reform would reduce exploitation of groundwater resources, but require proper institutional frameworks and political support in order to achieve equity, efficiency and sustainability.

The study highlights the multi-dimensional nature of the water-energy nexus and raises some important issues for a developing country context, namely that solutions to ameliorate

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[5] productivity = return on crops/volume of water used

[6] marginal cost = the cost of supplying an additional unit of output (ie., electricity unit price)

problems resulting from the interaction between water and energy are not necessarily straightforward. 'Engineered solutions' need to have political currency and take account of wider social ramifications, whilst 'pricing solutions' require the development of supporting institutional structures.

j) Shuck and Green, 2002: Kern County California, USA

Since 1996, irrigation districts in the Central Valley Project of California have been required to shift from right of use to uniform volumetric pricing of water. It is argued that uniform volumetric pricing does not encourage conservation nor reflect the cost of supplying water, especially where both surface water and groundwater sources are used conjunctively. The objective of this study, therefore, is to develop a price policy that is sensitive to variations in surface and groundwater supplies, whilst ensuring sufficient revenue for the districts. A supply-based pricing (SBP) function has been developed that takes into account costs (such as pumping groundwater in drought and recharging aquifers when wet), revenue, interest on financial reserves, and growers' profits. The model is empirically applied to the Arvin-Edison Water Storage District (District) in Kern County, which relies on both imported surface water and local groundwater when surface water levels are low.

Using 1995 data, the effectiveness of the SBP function versus uniform volumetric pricing is compared in terms of water demand, aquifer levels, the District's financial reserves, and energy use for various volumes of imported water. The study concludes that volumetric water pricing impacts water consumption, land use, and energy consumption. Recommendations include increasing prices when imported surface water levels are low to reflect the cost of pumping groundwater, thereby encouraging conservation, and decreasing prices when imported surface water levels are high to encourage consumption. Higher consumption would reduce aquifer recharge costs that would otherwise increase when imported surface water levels are high; it is less expensive to deliver water to end users when it is available, rather than pay for aquifer recharging now, then pump and deliver water at a later date.

This study demonstrates the impact of water pricing policies on energy consumption, and highlights the need for water policy makers to be aware of the wider energy implications of policies. It appears, however, that the focus of this study is cost reduction rather than resource conservation. The study did not set out to examine the link between water pricing and energy consumption, but rather the importance of this link emerged from the model results.

k) Nowak 2003: Austria

Whilst electricity is not the highest cost in municipal wastewater treatment plants in the European Union (EU) countries, this study argues that efforts should be made nonetheless to reduce energy consumption because of the associated environmental impacts such as carbon emissions. To achieve this goal, this study evaluates the energy demand of nutrient removal plants that are equipped with primary clarifiers, an activated sludge system, anaerobic sludge digestion, and a combined heat and power unit (CHP) that recovers energy. The energy demand for the aeration tank and energy recovered from the CHP was estimated as a function of the COD removal by primary sedimentation and of the N:COD ratio of the raw wastewater for a treatment plant with an average load of 50,000 person equivalent (pe). The estimate was then compared with 1997 operational data for twelve plants.

Results indicate that theoretical and actual external energy demand is approximately 5 – 10 kWh/(pe.a), whilst 12-14 kWh/(pe.a) can be recovered internally from the CHP. Excess consumption may be caused by low oxygenation capacity due to aging membrane aerators, inefficient aeration control, and excessive energy used by stirring devices in the aeration tank due to poor hydraulic design. In addition, energy demand is strongly dependent on the N:COD ratio in raw wastewater (the lower the ratio the less energy is consumed).

This study has a strong technological focus and would be useful for water utilities that are implementing energy saving strategies to meet carbon reduction targets. The model presented is less useful for policy analysis, as it is limited to one function within the water industry.

l) de Monsabert et. al. 1998: US

The *Energy Policy Act, 1992* requires US federal agencies to implement energy and water conservation options (installations and devices) with payback periods of less than ten years. As part of the Federal Energy Management Program (FEMP), the SAVEnergy Program conducted a survey of federal facilities to identify energy and water projects that met this payback period.

To further this objective, a spreadsheet model called WATERGY, was developed to calculate both direct savings – defined as savings to end user in terms of energy usage, water usage and sewage production – and indirect savings – defined as savings to utilities that supply water and power and treated wastewater – associated with a water conservation project. The model is based on engineering specifications, and includes energy sources of electricity, natural gas and fuel oil. WATERGY is applicable to both commercial and residential buildings, although at the time of publication, the results of the study were based on a hypothetical facility. A main finding of the study is that conservation options targeting showers, boiler blowdown and landscaping offer the greatest potential for water and energy savings.

The WATERGY model is useful for building managers who need to identify cost-effective water savings projects that also save energy. The model has little applicability for in-depth policy analysis, because the scope is limited to end users of water.

m) Hansen 1996: Denmark

The cost of supplying clean water for residential use is increasing, due to rising demand. The author of this study suggests that information on what influences residential energy demand may therefore be useful for water authorities. The objective of this study is to estimate the impacts of water and energy prices on residential water demand in Copenhagen, Denmark.

The authors use regression analysis and pooled time series data to estimate the residential water demand function. Inputs include water, energy and an aggregate of other goods, as well as a meteorological variable. Energy sources include electricity, district heating and gas. Two functional forms were adopted – linear and log-linear – using the ordinary least square (OLS) method. The forms were each amended to allow sprinkling demand to be more dependent on the meteorological variable. Water and electricity price elasticities – which measure the change in demand in response to a change in price – were then estimated for the four forms.

Results from the study indicate that all forms exhibit a significant negative energy cross-price elasticity[7] of -0.2. That is, water demand appears to be dependent on energy price, which according to the author appears to be in line with other engineering studies on residential water demand in Denmark. The author speculates that higher energy prices or carbon taxes in the future may reduce water demand, and suggests that taking into account the demand effects of changing energy prices may be as important as taking into account changing water prices.

The results offer useful insights into the links between water demand and energy price at the household level. Similar to previous studies, the study scope is limited to end users of water, which reduces its usefulness for policy analysis.

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[7] Energy cross price elasticity refers to energy required to heat water from either district heating, gas or electricity

2.4 Major limitations of existing studies

This section discusses the major limitations of existing studies in terms of objective, scope, focus and underlying research methods.

Objective

The water-energy nexus encompasses a broad range of issues and therefore studies on this topic vary considerably in terms of objective. The studies can be divided into three broad groups.

The first group examines the electricity impact of supplying water and wastewater services. There are five studies in this group, which are listed as **(a)**, **(b)**, **(d)**, **(h)** and **(k)** in Table 2-4. Studies **(a)** and **(b)** examine future scenarios in the water industry, with a view to determining the energy/environmental implications of each. Studies **(d)** and **(h)** have been undertaken by the same authors, and are motivated by the need to better understand water and electricity interactions, in light of the Californian Energy Crisis in 2001. Study **(k)** examines the energy impact of existing wastewater treatment plants, in recognition that introduction of carbon emissions policies in the water industry would require treatment plant operators to minimise electricity consumption.

The second group quantifies the water impact of generating electricity and includes studies **(c)**, **(e)**, **(g)** and **(f)**. The rationale behind the first three studies is that electricity generation – particularly from hydropower – can lead to potentially significant trade-offs for other water users, such as irrigators and the Environment. Study **(f)** more specifically focuses on the water impact – among other environmental impacts – of existing power plants in NSW.

The third group examines the electricity impact of water users and includes studies **(i)**, **(j)**, **(l)** and **(m)**. The underlying motivation for these studies is to analyse the interaction between the price of water and/or electricity and water use. In addition, studies **(j)** and **(l)** have been carried out in response to policy changes.

The objectives of the studies appear to address some of the existing water-energy nexus issues, including: the need to consider the electricity implications of future water scenarios in the planning stage; the impact of changes to policy; and trade-offs between electricity generators and other water users. In three studies, however, the objective was not to explicitly examine the links. Rather, the links were subsumed under a wider objective of examining environmental impacts (studies **(b)** and **(f)**) or the links became apparent in the study findings (study **(j)**). It is apparent therefore that the objectives of the studies offer a narrow viewpoint of the water-energy nexus, often from the perspective of either the water or electricity industries, or from another sector.

Scope

Similar to the objective, the scope of the studies varies considerably. Some studies focus on a specific facility, such as a wastewater treatment plant in study **(k)** or an individual building in study **(l)**. Other studies focus on one or more functions within the water industry (studies **(a)**, **(d)** and **(h)**) or electricity industry (study **(f)**). In comparison, studies **(c)**, **(e)** and **(g)** examine the interactions between electricity generation, other sectors and the Environment. Only study **(b)** examines the links between water and electricity at a utility-wide level. Yet this study only considers the water industry, and subsumes electricity under a larger set of environmental indicators. The remaining studies focus on end users of water, such as agriculture in **(i)** and **(j),** and the residential sector in **(m)**. Furthermore, the studies appear to have short-term time horizons. Only study **(b)** examines the energy implications of water scenarios in the longer term (for 2021). This would limit the usefulness of the findings for contributing to the development of policies and for considering issues such as climate change that would affect the industries in the longer term.

The studies above provide useful insights into the water-energy nexus. Yet, there appear to be no studies that examine the interactions between the water and electricity industries collectively, nor that link them with the wider economy. Possible explanations for this limitation include: the inherent challenges of collecting data from industries that are traditionally 'compartmentalised'; the move to market-based systems that may prevent access to data considered 'commercial in confidence'; and the disciplines-based approach of much academic discourse, which lends itself to research that is more narrow in scope.

Focus

It appears that the technological dimension is the primary focus of all the studies, and indeed is the only dimension analysed in studies **(d)**, **(h)** and **(k)**. Others studies link the technological dimension to the environmental (**(a)**, **(b)**, **(c)** and **(g)**) or economic (**(j)**, **(l)** and **(m)**) dimensions. Only two studies consider more than two dimensions. Study **(e)** for example quantifies the technological and economic impact of allocating reservoir water and discusses the political ramifications, whilst study **(i)** examines the impact of electricity price on groundwater productivity and discusses the results in terms of wider environmental, political and social ramifications. It appears that the focus of existing studies do not sufficiently acknowledge nor analyse the interrelationships between the various dimensions of the nexus. The social and political dimensions also appear to be the least understood.

Research methods

The studies employ several research methods for quantifying the links between water and electricity. These methods include life-cycle assessment (LCA), numerical modelling, econometrics, productivity analysis and simulation/optimisation models.

Studies **(a)** and **(b)** use LCA to compare various scenarios for the water industry, whilst study **(f)** uses LCA to assess the environmental impact of generation plants in NSW. In the case of study **(a)**, the authors develop a comprehensive assessment tool called WEST, based on process analysis and input-output analysis. This hybrid LCA is useful for quantifying the energy consumption during different project phases, which include construction, operation and maintenance. A shortcoming of the method is that it is extremely data-intensive, requiring detailed engineering data about the water supply project options. Further, it appears that the study uses the national input-output table for the US, which may not reflect regional specificities of material and energy production. The tool also appears to be static and may not be directly suitable for analysing options in the longer term, during which time the structure of any economy is likely to change. The tool's databases would also require revision as processes and technologies change.

Study **(b)** uses a commercial software package called GaBi to undertake the LCA of water supply options, which is based on process analysis. Whilst the software enables users to define some input parameters, it is unclear the extent to which the software can be modified to reflect the economic structure and electricity generation realities of the region under investigation. Study **(f)** uses process analysis and published inventories of emissions to perform an LCA of the NSW electricity grid. As with other process-based LCAs, it is likely to be subjected to truncation errors. Truncation errors occur because of the need to place boundaries around the processes that form part of the LCA. Some upstream processes are therefore inevitably omitted. Further, process-based LCAs are not suitable for analysing multiple water-energy links, because of the complexities in mapping all the relevant processes involved. Therefore, as with the previous two studies, the resulting analysis would only be suitable for analysing the technological dimension of a specific link.

Studies **(c)**, **(d)** and **(h)** use spreadsheets to numerically model the energy impact of using or supplying water under various scenarios. The models are simplistic and effective for undertaking broad comparisons of the various scenarios. However, a common weakness in the models is that they do not capture the embedded or indirect energy contained in materials and other inputs and therefore underestimate energy consumption. The numerical models would also require extensive modification in order to model longer-term scenarios. The models are designed to focus on very specific links and therefore cannot effectively capture the multitude of links between water and electricity, nor the various dimensions.

The numerical models presented in studies **(k)** and **(l)** are largely based on engineering and scientific data. Study **(k)** assesses the energy demand of wastewater treatment plants by modelling the chemical reactions in the wastewater treatment processes and the associated energy requirements of different equipment. Due to the substantial technological focus of the model, it is unsuitable for policy analysis. The WATERGY tool developed as part of study **(l)** offers a static assessment of various water conservation options for commercial and residential buildings, in terms of relative payback periods. As with the model in study **(k)**, the tool has limited use for analysing the impact of policies on the water and electricity industries.

Studies **(e)** and **(g)** develop optimisation and simulation models to assess various strategies to allocate water between electricity generators and other users. The optimisation model in study **(e)** is written with the programming language, General Algebraic Modelling System (GAMS). It is based on a cost minimisation constraint, which is to minimise the cost of supplying electricity to upstream Kyrgyzstan whilst meeting the needs of downstream countries. This constraint is used to allocate water resources in the region, yet based on the findings of the review earlier in this chapter, cost minimisation/profit maximisation objectives can result in significant trade-offs for other water users. The model results would require careful consideration of the institutional environment of the countries involved, as well as the political tensions over water resources that may be present. Study **(g)** presents a platform for users to build reservoir models, in order to assist with the allocation of water under certain environmental restrictions. The platform comprises two models. The first model enables users to select algorithms for constructing reservoirs whilst the second model is an optimisation and simulation model of a power reservoir system based on linear programming. A weakness in the platform is that it focuses on upstream water-energy links and therefore cannot readily capture the multiple links between water and electricity. Further, whilst linear programming is commonly applied for optimisation problems, linear objective functions do not necessarily reflect real-world relationships. As with study **(e)**, the model presented in study **(f)** is useful for establishing guidelines for allocating water, but would need political support, particularly if applied across jurisdictional boundaries.

The remaining three studies model the relationship between the price and consumption of water and electricity. Study **(i)** uses productivity analysis to quantify the links between electricity price and groundwater consumption. Productivity analysis relates output quantities (in this case groundwater consumption) to input quantities (in this case electricity price) using a production function. It assumes that the production function has a constant returns to scale, that the market is perfectly competitive, and that costs are minimised. Whilst these assumptions rarely exist in reality, productivity analysis is well documented and has been used to provide evidence for the success of industry reform programs (Fathollahzadeh 2005). The method is most suited for analysing specific links between two variables, and therefore one of its weaknesses is that it cannot consider multiple links concurrently.

The models developed in studies **(j)** and **(m)** are based on econometrics, which is a widely used policy modelling technique for examining causal relationships. Study **(j)** examines the impact of water supply-based pricing on surface and groundwater use in the agricultural sector, whilst study **(m)** focuses on developing water and electricity price elasticities for water demand in the residential sector. Using regression analysis, econometrics examines the causal relationships by estimating parameters for a selected functional form, in order to best fit the empirical data. The technique does have underlying assumptions about the dependent variable, independent variable and error term that comprise the relationship function (Gujarati 2006), and the nature of the relationship between the variables is uni-directional, from the independent to the dependent variables. Mutually reinforcing feedback loops – which is a characteristic of the water-energy nexus – therefore cannot be considered.

In summary, existing studies generally focus on the technological optimisation of narrowly defined problems, such as the supply of potable water, generation of electricity, or allocation of water resources between competing users. Studies that consider the economic dimension of the water-energy nexus are based on an unquestioning faith that the market mechanism is the best allocator of water and energy resources. The review earlier in this Chapter already highlights some recent events that run counter to this faith, and many of the studies do not extend the results into the analysis of trade-offs, which is the raison d'être of policy analysis.

2.5 Summary and conclusion

Water and electricity are inextricably linked. Awareness of these links is increasing the world over, due to reform, drought, increases in demand, and climate change. This research classifies the links into upstream, transportation and downstream categories. For the electricity industry, the upstream links are most prominent, as generators endeavour to secure sufficient water to generate electricity. For the water industry, transportation and downstream links appear to be more prominent. Water is bulky and heavy to transport, and it is becoming more energy-intensive to treat water and wastewater. It is also clear that the links between water and electricity extend beyond the boundaries of the two industries; links are evident in the agricultural and residential sectors, for example. It may hold true that the links are significant for other sectors, but there is currently little research to substantiate this.

Despite the growing awareness of the implications of the nexus, existing studies do not adequately address the complexity and multidimensional nature of the nexus, which have been identified by this research as environmental, technological, economic, social and political. Some of the weaknesses of existing models are summarised as follows:

- The objectives of existing studies offer a narrow viewpoint of the water-energy nexus, often from the perspective of either the water or electricity industries, or from one other sector such as agriculture. This is also reflected in the scope of the studies, in that there are no studies that present a framework for comprehensively assessing the multiple links and multiple dimensions concurrently;
- The research methods adopted are, as a result, inherently restrictive. Some methods, such as econometrics and productivity analysis, focus on causal relationships between specific aspects of the water and electricity industries (such as groundwater use and electricity price), or specific segments (such as water demand in the residential sector);

- All the studies present quantitative models which focus predominantly on the technological dimension. Whilst some studies consider the Environment and economic dimensions, the remaining social and political dimensions rarely feature;

- With the exception of the LCA studies, the models largely do not account for indirect water or electricity consumption and therefore underestimate consumption. Furthermore, the LCA studies that are process-based would still be subjected to truncation errors and would also underestimate consumption to a lesser degree;

- The models are generally static in nature, and may assist in informing pricing policies and investment decisions in the short term. This limits the usefulness of the models for more long-term analysis. Even models that have been developed for the purpose of scenario analysis would require extensive modification;

- The more complex models that integrate sub-models from various professional disciplines are both data-extensive and data-intensive, requiring a diverse collection of information. The models would require regular updating and monitoring to ensure that they are consistent with the effects of climate change on environmental processes, and other changes to water resources and electricity generation.

Whilst existing studies provide useful insights into the nature of the water-energy nexus, they do not adequately capture the issues that emerge at the interface of these sectors. It is clear that a more comprehensive methodological framework is required to capture the multiple water-energy links, their various dimensions, and the implications for the wider economy.

Chapter 3

Development of an integrated research framework

We can't solve problems by using the same kind of thinking we used when we created them

Albert Einstein

The existing water-energy studies discussed in Chapter 2 appear to be narrow in focus and limited to the analysis of specific links. This fragmented approach is also reflected in much of academic praxis today that is largely discipline-based. This research contends that this type of approach is unsuitable in the longer term, particularly when examining complex and multidimensional issues like the water-energy nexus.

This research suggests that the nature of the nexus should and can be explored from a wider perspective, by developing a suitable integrated methodological framework to serve as a platform for such exploration. The purpose of this chapter, therefore, is to outline the development of such a framework. Section 3.1 introduces Integral Theory and discusses how Integral Theory has shaped the development of the methodological framework employed in this research. Section 3.2 presents the framework and describes the suite of research methods.

3.1 Integral theory – a guiding philosophy

This research adopts Integral Theory to guide the development of the methodological framework. American philosopher Ken Wilber (1949~) developed Integral Theory after years of cross-cultural research into various fields of human knowledge. Through his research, Wilber concluded that knowledge has five major elements represented by quadrants, levels, lines, states and types. Wilber's resulting framework – termed 'all quadrants all levels' or AQAL for short – depicts these five major elements. It is considered by integral theorists a comprehensive map of human capacities and potential.

Wilber discusses the evolution of Integral Theory in several of his books (see for example 2000a; and 2000b). *A Theory of Everything* (2000c) offers an abridged version for the interested reader. Applications of Integral Theory are emerging in different fields, including education, medicine and sustainable development (see Esbjorn-Hargens (2005) for a comprehensive list of recent studies, or Riedy (2005) on sustainable development and climate change responses in Australia). The following section offers a brief introduction to Integral Theory and its application to this research.

3.1.1 The AQAL framework

Integral theory postulates that reality comprises individual/collective and interior/exterior realms. These realms intersect to form the four quadrants of the AQAL framework depicted in Figure 3-1. These quadrants are also found in the first-, and third- person pronouns of major languages: I, WE, and IT. Wilber also adopts ITS in his AQAL framework.

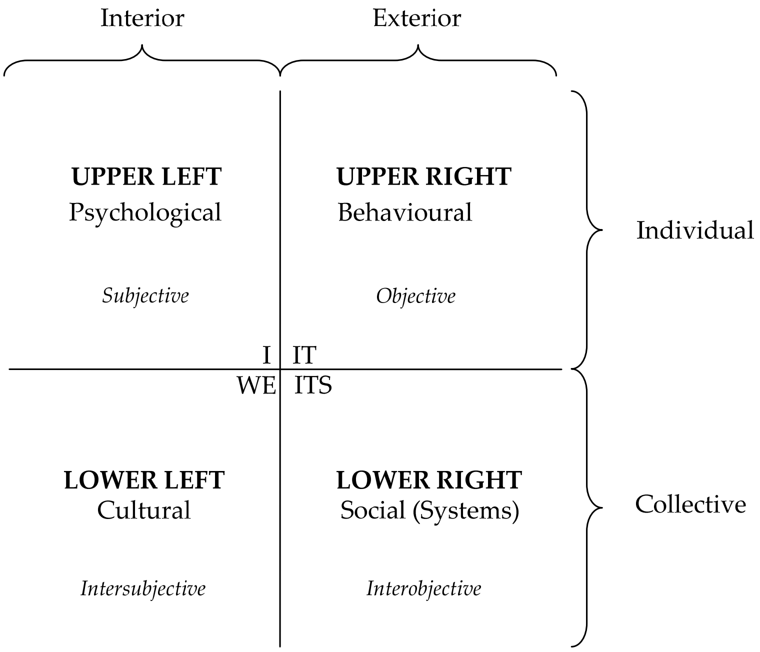

Figure 3-1 Quadrants of human knowledge
Source: adapted from Wilber (2000c)

The left hand quadrants refer to aspects of reality that are interpreted subjectively. In particular, the upper left quadrant is concerned with the interior of individuals, and is therefore considered the psychological quadrant. The lower left quadrant refers to shared cultural values, norms, worldviews and ethics, and is considered the cultural quadrant. The right hand quadrants encompass aspects of reality that are observable. The upper right refers to the exterior of individuals that may be observed objectively, such as behaviours and biological functions. It is also termed the behavioural quadrant. The lower right quadrant focuses on the exterior of collectives, such as techno-economic structures and social systems, and is termed the social quadrant.

The second element of Wilber's AQAL framework is levels or stages of development. Each quadrant's levels are correlated with levels in the other quadrants. Through an evolutionary process, the levels increase in complexity and integrate the wisdom from the lower levels, to form emergent properties as the process unfolds in the upper levels. An important tenet of Integral Theory is that one cannot reach the higher levels without first attaining wisdom in the lower levels, but once a level is reached, it is achieved permanently.

Figure 3-2 describes this element in simple terms, as it relates to human development. The psychological quadrant charts the development of values. It is based on the works of Clare Graves, which was refined by Don Beck and Christopher Cowen in their Spiral Dynamics concept. Beck (2005) later expanded this to Spiral Dynamics Integral, which incorporates aspects of Wilber's Integral Theory. In the cultural quadrant, developmental levels follow worldviews that have evolved over the course of history and is based on the works of Jean Gebser, Jurgen Habermas and Wilber himself (Wilber 2005b). Corresponding levels are identified for the right hand quadrants. Alternative levels of development may be adopted, depending on the focus of the inquiry (Wilber 2000c).

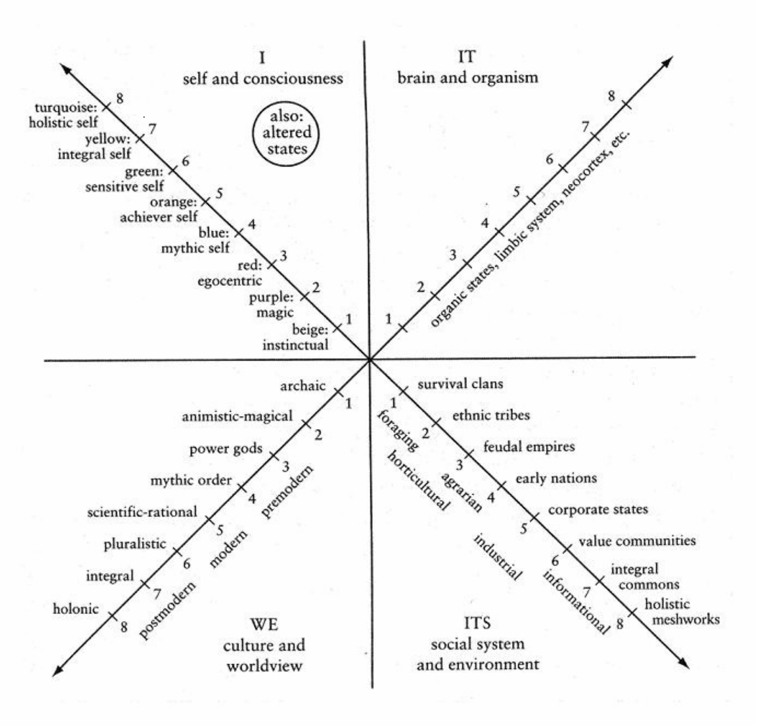

Figure 3-2 The AQAL framework and human development
Source: adapted from Wilber (2000c)

The third element in the AQAL framework refers to lines of development. In Figure 3-2, these lines include values (psychological quadrant), worldviews and cultural eras (cultural quadrant), biological and neurophysiological evolution (behavioural quadrant), and socio-political systems (social quadrant). Similar to the levels of development, alternative lines may be adopted, depending on the focus of the research. For the social quadrant for example, alternatives include techno-economic development and development of institutions.

The fourth element refers to states of consciousness, such as waking, meditative and deep sleep. In the West, knowledge is largely derived from the waking state, yet meditation is an extremely powerful tool for accessing wisdom and insights in Eastern traditions, such as Buddhism and Hinduism. Unlike levels of development, states are temporary in nature. The last element of the AQAL framework is types. Examples include personality types, such as those defined by Carl Jung (1875~1961) and the Myers-Briggs Type Indicators. Gender styles is an alternative typology that views reality from masculine and feminine perspectives (Wilber 2000c).

The five elements described above form the basic structure of the AQAL framework. The basic explanatory unit of this framework is called a holon, which is considered simultaneously a whole and a part of another whole. For example, a human is an individual (whole) and also a member (part) of his or her community. Arthur Koestler (1905~1983) first proposed the concept of holons and holarchies in his work, *The Ghost in the Machine* (1967). Wilber (2000b) adapted Koestler's holon theory, which formed the basis for the 'twenty tenets' of Integral Theory. These tenets are outlined in Appendix 1 .

3.1.2 Integral methodological pluralism

The four quadrants of the AQAL framework offer different perspectives on reality. These quadrants may also be viewed as comprising different epistemic communities, with their distinct practices and methodologies. Academic praxis tends to focus on one quadrant, or one side of the AQAL framework. Theories in the right hand quadrants generally follow a positivist epistemology, which gained prominence during the Enlightenment period (this is discussed in greater detail in Appendix 2). In contrast, some of the major theories in the left hand quadrants developed as a reaction to the positivist epistemology. Instead, these theories purport that reality is contextual and is understood through interpretation. Left hand quadrants therefore follow an interpretivist epistemology. More recently, researchers have attempted to reconcile the 'explanation' of positivism with the 'understanding' of interpretivism, yet such positions still fall short in integrating the methods of inquiry or methodologies from all four quadrants.

Wilber (2000c) contends that methodologies from all four quadrants are valid and necessary to comprehend reality. In order to guide the integration of methodologies from the four quadrants, Wilber developed integral methodological pluralism (IMP). IMP proposes that each quadrant may be understood from the inside and outside, which combined represent eight indigenous perspectives. Further, each perspective is accessible through particular methods of inquiry or methodological groups and discloses insights that other perspectives cannot (Esbjorn-Hargens 2005). Figure 3-3 uses zones to represents the eight perspectives. A discussion on the major methodologies associated with each of the zones follows.

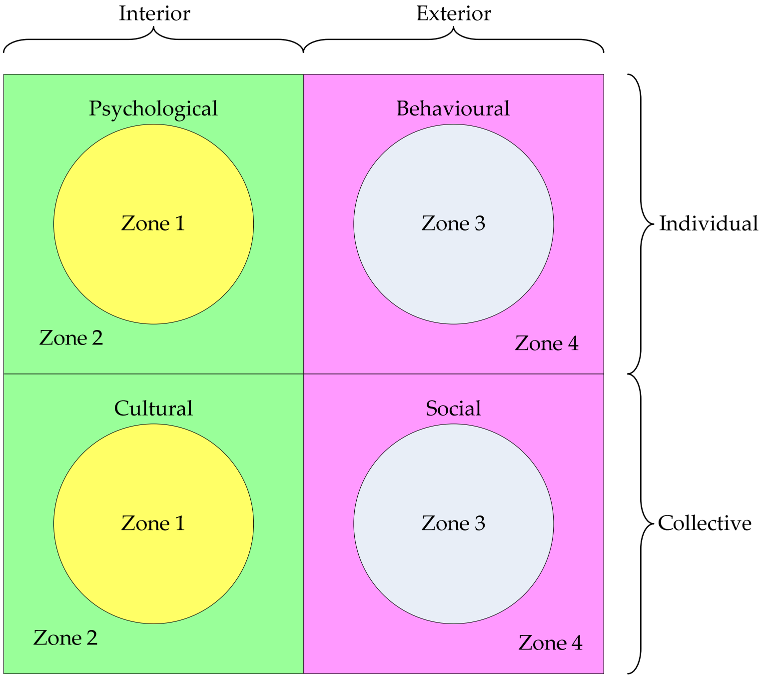

Figure 3-3 Major methodologies associated with the four quadrants
Source: adapted from Wilber (2000a)

Psychological quadrant

Zone 1 in the psychological quadrant refers to the inside of individual interiors. The major methodology is phenomenology, which explores direct personal experiences through reflection, introspection or meditation. In the context of this research, it refers to the personal experiences of this author. Zone 2 refers to the outside of individual interiors. The major methodology is structuralism, which offers a third-person perspective on the inside workings of another. This is realised through methods such as psychoanalysis and psychotherapy. This zone would also include a third-person perspective on an individual's own interiors, in order to identify their own patterns and responses to phenomena.

Cultural quadrant

Zone 1 in the cultural quadrant refers to the inside of collective interiors. The major methodology is hermeneutics, or more broadly the study of culture. An important aspect of hermeneutics is to study a group by becoming a part of it through mutual understanding. In doing so, meaningful human action may be interpreted (Abercrombie, Turner & Hill 2006). Zone 2 refers to the outside of collective interiors and includes cultural studies, such as cultural anthropology, archaeology and genealogy. The main focus of these methodologies is to explore patterns of mutual understanding.

Behavioural quadrant

In the behavioural quadrant, Zone 3 refers to the inside of individual exteriors. The major methodology is autopoesis, which examines self-regulating behaviours (such as the development and functioning of biological cells). Zone 4 refers to the outside of individual exteriors and in particular measurable behaviours. The main methodology is empiricism, which covers behaviourism and the hard sciences, such as physics, biology, and chemistry. Microeconomics would also fall into this group, as it focuses on individuals as economic agents.

Social quadrant

Zone 3 in the social quadrant refers to the inside of collective exteriors. The main methodology is social autopoesis, which examines the self-regulating dynamics of systems. Zone 4 represents the outside of collective exteriors. The concern here is how parts fit within a complex whole, and therefore systems theory is the main methodology. Ecology, macroeconomics, and chaos and complexity theories would also fit within this group.

Three principles of IMP

In order to facilitate the practice of IMP, Wilber (2005a) proposes three principles: nonexclusion, enfoldment and enactment. Nonexclusion refers to the acceptance of methodologies and practices that are considered valid by their epistemic communities in their respective fields. This implies, therefore, that methodologies or practices cannot be used to make statements in other fields that hold different perspectives. For example, an economist cannot make assertions about an archaeological phenomenon using a macroeconomic model. The second principle, enfoldment, states that some methodologies and practices are more comprehensive and inclusive than others, and that the level of inclusiveness may change as knowledge and circumstances evolve. The third principle is enactment, which states that the 'phenomena brought forth by various types of human inquiry will be different depending on the quadrants, levels, lines, states, and types of the subjects bringing forth the phenomena' (Wilber 2005a).

3.1.3 Influence of Integral Theory on this research

A significant finding of the review in Chapter 2 is that the nexus is multidimensional in nature, and that these dimensions influence each other. This research contends, therefore, that methods of inquiry from all four quadrants need to be enacted where possible, in order to develop a comprehensive understanding of the water-energy nexus. From the perspective of Integral Theory, all of the studies in Chapter 2 are derived from methods that fit in the right hand quadrants. For example, several studies measure 'behaviours', such as the numerical modelling of engineering data for buildings. Others quantify the behaviour of water and electricity consumers – either in the residential sector or agricultural sector – using methods such as econometrics, price elasticities and productivity analysis. The remaining studies focus on the use of water and electricity in a larger system, and therefore fit in the social (systems) quadrant. These methods include optimisation models and lifecycle assessments. Only Kumar (2003) offers some discussion on the social and cultural realities of the group under examination, in terms of the group's receptivity to policy recommendations derived from the results of the quantitative analysis. This aspect of the study would fit in Zone 2 of the cultural quadrant, that is, the outside of collective interiors.

Based on these observations, this research adopted the broad concept of IMP in order to guide the development of the methodological framework and the selection of research methods. In doing so, it became clear that not all of the eight perspectives – the inside and outside of the four quadrants – and corresponding methodologies could be represented. Such an approach would require the researcher to be skilled in a diverse range of methods, which is better suited to a team of researchers with complementary skills. Secondly, this author's understanding of Integral Theory and IMP deepened in a gradual manner throughout the course of the research and therefore IMP was not applied in a rigorous manner from the onset. However, the resulting methodological framework for this research is designed to effectively capture the multidimensional nature of the nexus, and does so by drawing upon the overarching perspectives from the four quadrants in the AQAL framework.

Integral Theory became the basis upon which to explore western philosophy and alternative philosophical perspectives, and how these perspectives relate to modern society and contemporary issues, such as the water-energy nexus. These explorations did not directly inform the development of the methodological framework, but indirectly influenced and strengthened the researcher's understanding of the legacies of western philosophy that are present today and the need to acknowledge alternative perspectives. This need to acknowledge alternative perspectives is captured by Einstein's assertion that 'we can't solve problems by using the same kind of thinking we used when we created them' (Einstein). Appendix 2 documents this philosophical exploration.

3.2 Methodological framework

The methodological framework is multidisciplined, in order to capture the many dimensions of the nexus that emerged from the review in Chapter 2. These dimensions are reflected in the research objectives and in turn the research methods. As stated previously, the AQAL framework served as a guide to determine which perspectives were captured by the research framework. The intent was not to explore the relationship from all eight indigenous perspectives, for reasons given above. This research instead recognises that an important first step towards an integral approach is acknowledgement of the different perspectives.

The following complementary research methods form the basis of the methodological framework: historical analysis, input-output analysis, elasticities, scenario analysis, and assessment of policy implications. Figure 3-4 identifies the quadrants and zones to which each of the methods broadly belong. The following discussion in this section provides some explanation of how these methods address the various perspectives represented by the zones.

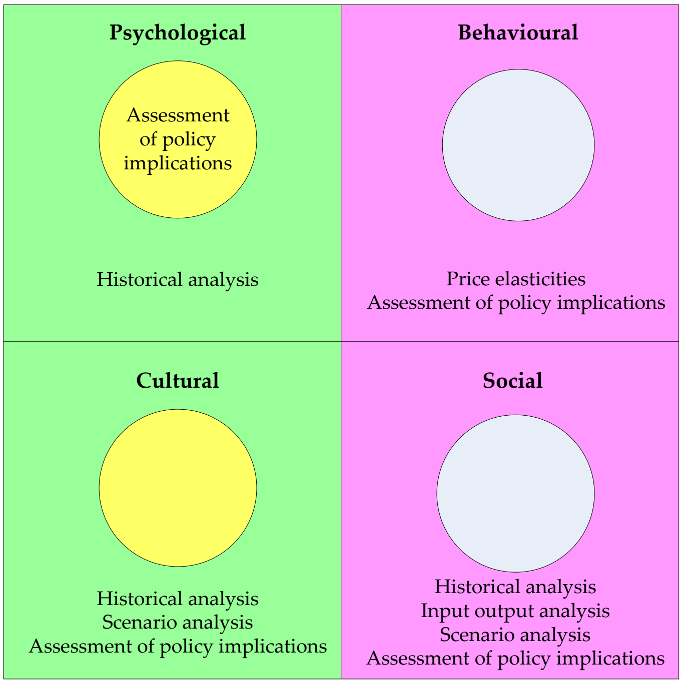

Figure 3-4 Position of research methods in the AQAL framework

Historical analysis is undertaken largely from the outside perspective of the social quadrant. It comprises an examination into the evolution of the water and electricity industries – and in turn the water-energy nexus – in terms of technological, economic, political and social systems, as well as environmental influences. The outside perspective of the cultural quadrant is also captured, in terms of the influence both on and of culture during the development of the water and electricity industries. Some aspects of the outside perspective of the psychological quadrant are also addressed during the latter periods of the historical analysis, in particular the personal experience of Australians impacted by reforms in the electricity industry.

Input-output analysis assists in quantifying the links between water and electricity and the wider NSW economy. It therefore offers an outside perspective of the social quadrant. Several lines of development are pursued with input-output analysis, including technological, economic, political and environmental, which represent many of the dimensions of the nexus.

Price elasticities are useful for determining the responsiveness of the price of a good to changes in the quantity demanded. This research focuses on cross price elasticities for water and electricity, that is, the responsiveness of water demand to electricity prices and vice versa. Own price elasticities, that quantify the responsiveness of demand for a particular good to incremental changes to its price, are also calculated. Essentially, price elasticities capture the behavioural choices of water and electricity end users and therefore offer an outside perspective of the behavioural quadrant.

Scenario analysis is adopted to explore future technological choices under alternative settings. The basis for the development of the scenarios – which is discussed later in Section 3.6 – is the UK's Environment Futures Program, which frames scenarios according to social values and governance systems. The scenarios therefore capture the outside perspective of the cultural quadrant, informing the selection of water and electricity technologies and policies. The impact of these technologies on the NSW economy are subsequently modelled using input-output analysis for the year 2031. The resulting scenario models would therefore offer an outside perspective of the social quadrant for the future year.

Assessment of policy implications refers to the process of synthesising the outcomes from all the methods and putting forward recommendations that reflect the socio-political realities of society, as well as future aspirations. In this way, the outside perspectives of the social, cultural, behavioural and psychological quadrants are captured. The future aspirations may also be influenced by the personal views of this author – the inside of the psychological quadrant – as an informed citizen engaged in the debate over water and energy, with an interest in improving how water and energy are valued, and more broadly how the Earth is valued.

The following sections describe in detail the five methods and their application to this research.

3.3 Historical analysis

The first specific objective aims ***to analyse the evolution of the water energy nexus, with a particular focus on New South Wales***. This research contends that a better understanding of the water-energy nexus may be gained by reviewing the influences that have shaped the development of the nexus in the past, by undertaking an historical analysis.

This research develops, in Chapter 4, an historical time profile of the nexus for Australia, with a particular focus on NSW. This is undertaken by first constructing time profiles for the urban water industry, rural water industry and electricity industry separately. The division of the water industry into its urban and rural components recognises their distinct histories and purposes; rural focuses on irrigation, whereas urban focuses on town water supply and sewage.

A water-energy nexus profile is subsequently developed, based on these three profiles. Further, each profile comprises the following four time periods:

1. Early developments in water and electricity (pre 1890)
when water schemes shifted from small scale/decentralised systems to larger-scale/centralised systems and important technological developments took place to facilitate the uptake of electricity in subsequent periods;

2. Building on the foundations (1890 to 1939)
when there was growing State government control over water and electricity supply, and the industries were viewed as important for nation building;

3. Expansion and pressures for change (1940 to 1979)
when there was rapid expansion of water and electricity supply systems, increase in Federal government involvement in recognition of the national development role of both industries, and later greater scrutiny over the performance of both industries;

4. Initial and contemporary reforms (1980 to 2007)
when internal and widespread reforms took place to improve the economic performance of both industries, during a time of greater environmental and social accountability, and later recognition of global issues such as climate change.

The time periods represent significant phases in the development of the industries in Australia, in terms of major shifts in water and energy policies. Each time period is analysed in terms of the influences on the industries, and in turn the nexus. In this research, these influences represent the various dimensions of the nexus identified in Chapter 2, which are environmental, technological, economic, social and political. Due to the nature of Australia's past as a British colony and its continuing affiliation with the western world, these influences have both domestic and international origins.

3.4 Input-output analysis

The second specific objective aims ***to empirically investigate the links between water, electricity and other economic sectors in New South Wales***. As shown previously in Figure 1-3, input-output analysis forms the basis of this empirical investigation.

Input-output analysis is a widely-used analytical tool that identifies the interdependencies between various economic sectors and therefore lends itself well to examining the links between water, electricity and the wider economy. Its foundations stem back to the 18th century, however, Russian-born economist Wassily Leontief (1941) developed the tool to its current form in the mid 20th century. Several researchers since Leontief have made important theoretical contributions to input-output analysis (for example Ghosh 1958; and Lahr & Dietzenbacher 2001) and many more have applied the tool to a range of policy areas, including water and energy. Table 3-1 lists a selection of water and energy input-output studies. This research represents the first study known to the author that applies input-output analysis to explicitly examine the water-energy nexus.

Table 3-1 Selection of water and energy input-output studies

Author	Sector	Region	Topic
Bullard & Herendeen (1975)	Energy	United States	Embodied energy (intensities)
Proops (1977)	Energy	N/A	Comparison of energy intensity methods
James (1980)	Energy	Australia	Energy accounts
Karunaratne (1981)	Energy	Australia	Trade offs between energy, income, employment, capital and pollution
Proops,. Faber & Wagenhals (1992)	CO_2	Germany and UK	Effects of changes to final demand, energy efficiency and interfuel substitution on CO_2 emissions
Peet (1993)	Energy	N/A	Method to calculate embodied energy (intensities)
Lenzen (1998)	Energy and GGEs	Australia	Embodied energy and GGEs in final consumption
Lenzen (1999)	Energy and GGEs	Australia	Embodied energy and GGEs in the transport sector
Yoo & Yang (1999)	Water	Korea	Impact of investment, price increases, and shortages in the water sector
de Miera (2000)	Water	Spain	Water intensities and water scarcity pricing using a hybrid model
Hondo, Moriizumi & Uchiyama (2000) (in Japanese)	Energy	Japan	$C0_2$ lifecycle assessment of power generation technologies
Lei (2000)	Energy and GGEs	PR China	Energy forecasts to 2020?
Hondo (2001) (in Japanese)	Energy	Japan	$C0_2$ lifecycle assessment of nuclear power technologies

Table 3-1 Selection of water and energy input-output studies (Cont'd)

Author	Sector	Region	Topic
Kim, Jin & Yun (2001)	Water	Korea	Water quality
Lenzen & Foran (2001)	Water	Australia	Water multipliers (intensities) for various sectors
Cruz (2002)	Energy	Portugal	Energy scenarios to 2010
Duarte, Sanchez-Choliz & Bielsa (2002)	Water	Spain	Water intensities based on the hypothetical extraction method
Pachauri & Spreng (2002)	Energy	India	Household consumption
Lenzen (2003)	Various, incl water and energy	Australia	Linkage, structural path and key sector analyses
Han, Yoo & Kwak (2004)	Energy	Korea	Impact of investment, price increases, and shortages in the electric power sector
Foran, Lenzen & Dey (2005)	Various, incl water and energy	Australia	Triple bottom line analysis of economic sectors
Wei et al. (2006)	Energy	PR China	Long-term energy scenarios
Marriott (2007)	Energy	USA	Lifecycle assessment of future electricity generation scenarios

Note: GGEs = greenhouse gas emissions, CO_2 = carbon dioxide

Section 3.4.1 begins with a theoretical description of input-output analysis, in particular the basic Leontief demand model and its diametrical opposite, the Ghosh supply model. Section 3.4.2 describes the set of water-energy oriented models developed for this research for NSW. Section 3.4.3 describes the input-output analysis techniques adopted by this research to examine specific water-energy nexus issues. Lastly, Section 3.4.4 discusses how to assess the validity of input-output models and the results.

3.4.1 Theoretical background

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** shows 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 referred to as intermediate demand. **Primary inputs** are payments to factors of production. In a standard model, primary inputs include payments to Households such as salaries and wages, gross operating surplus and mixed income and taxes less subsidies. In this research, imports follow the convention of direct allocation, and are therefore considered as primary inputs[8]. **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 Figure 3-5. Note that the elements in the input-output table represent physical quantities of goods and services, such as tonnes of steel, petajoules (PJ) of energy or megalitres (ML) of water. Many input-output studies adopt dollar values (such as $000), in which case the resulting model is called a monetary model. Where both physical quantities and monetary values are used, the resulting model is called a 'hybrid' model.

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 (*k*)	(v_{kj})	GNP	
Total input	(X_j)		

Figure 3-5: Basic structure of an input-output table

In Figure 3-5, x_{ij} represents the flow of outputs from sector *i* to sector *j* where it is used as inputs; Y_i represents final demand for sector *i* outputs; X_i is the total output of sector *i*; X_j is the total input to sector *j*; and v_{kj} represents the flow of production factor inputs to sector *j*. The following basic relationships may be derived from these elements:

$$X_i = \sum_{j=1}^{n} x_{ij} + Y_i \qquad \text{Eqn. 3-1}$$

$$a_{ij} = \frac{x_{ij}}{X_j} \quad \Rightarrow \quad x_{ij} = a_{ij} X_j \qquad \text{Eqn. 3-2}$$

$$f_{kj} = \frac{v_{kj}}{X_j} \qquad \text{Eqn. 3-3}$$

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[8] Imports may also be indirectly allocated, in which case the imports are assigned to their corresponding supply sector in the inter-industry table and allocated across the supply row to the using sectors.

where a_{ij} in Eqn. 3-2 is the amount of inputs required from sector i to produce 1 unit of output in sector j. The a_{ij} elements are commonly referred to as the technical or direct coefficients (hereafter referred to as direct coefficients). In the case of a hybrid model, X_j comprises mixed units and cannot be summed. The direct coefficients a_{ij} are therefore calculated using the corresponding row sum of X_j (that is, X_i for the same sector). In Eqn. 3-3, f_{kj} represents the amount of primary inputs v_{kj} required to produce 1 unit of output in sector j.

The input-output table is transformed into an analytical model using the basic relationship in the equations above to form three sub-models represented by the following equations:

$$X = (I - A)^{-1} Y \qquad \text{Eqn. 3-4}$$

$$P = (I - A')^{-1} F' \pi \qquad \text{Eqn. 3-5}$$

$$P' Y = F \pi' X \qquad \text{Eqn. 3-6}$$

Eqn. 3-4 represents the quantity sub-model where X and Y are column vectors of total output and final demand respectively, and A is the matrix of direct coefficients. The inverse matrix, $(I - A)^{-1}$ represents the total (direct and indirect) requirement for sector i outputs (X) to satisfy one unit of final demand in sector j (Y). It is commonly referred to as the Leontief inverse matrix.

Eqn 3-5 represents the price sub-model, where P is a n x 1 vector of unit prices. If monetary values are used in the inter-industry table, the corresponding unit price is \$1.00. The matrix F in this equation represents the k production factors per unit of output. The price vector for the k production factors, π, may refer to royalty payments, licensing fees or the unit price of imports. As with the P vector, if monetary values are used in the original V matrix, the corresponding unit price for the production factors is \$1.00.

Eqn. 3-6 is the income model and is derived from Eqns. 3-4 and 3-5. The income model ensures that the total value of final demand equals to the total value of primary inputs. Collectively, Eqns. 3-4 to 3-6 form the standard Leontief demand-driven input-output model, simply referred to in this research as the Leontief model. It is demand-driven because final demand (Y) determines the production output (X) in the economy.

The Leontief model exhibits a linear production function, because the inputs and outputs in the model are proportionately fixed – as represented by the direct coefficients – which excludes the possibility of substitution between inputs. Further, it is assumed that each sector produces one output and that the output is only produced in one sector. In reality, however, sectors often represent more than one product or service, particularly when the input-output table is highly aggregated. In such cases, the direct coefficient represents the average technology mix of the aggregated sector. Lastly, it is assumed that investment and production occur simultaneously (Cichocki & Wojciechowski 1988; Miller & Blair 1985). Despite these inherent assumptions, the Leontief model offers a simple and insightful analytical tool, which is useful for capturing the links between the water and electricity sectors and the wider economy.

The diametric opposite of the Leontief model is the Ghosh model. Ghosh (1958) suggested that fixed output coefficients, rather than fixed input coefficients found in the Leontief model, may be more suitable to describe monopoly markets or centrally planned economies with scarce resources . Fixed output coefficients essentially suggest that if the supply of primary inputs *(V)* increases for sector *i*, then the final demand - consumption and investment for that sector - will increase by the same proportion. That is, final demand is perfectly elastic. The Ghosh model is therefore considered supply-driven. The corresponding equations for this model are:

$$\vec{a}_{ij} = \frac{x_{ij}}{X_i} \qquad \text{Eqn. 3-7}$$

$$X' = (I - \vec{A})^{-1} F' \pi \qquad \text{Eqn. 3-8}$$

where $\vec{a}_{ij}$ is the Ghosh allocation coefficient and $(I - \vec{A})^{-1}$ is the Ghosh inverse matrix. The Ghosh inverse matrix represents the direct and indirect requirements of sector *j* per unit of primary inputs in sector *i*. Recent studies have used the Ghosh model to examine the impacts of supply shortages (see for example Davis & Salkin 1984; Han, Yoo & Kwak 2004; and Rose & Allison 1989). Such use has come under scrutiny, largely because of the resulting economic assumptions that are deemed implausible. In particular, the Ghosh model takes final demand as perfectly elastic, which means consumption and investment will change according to the changes in supply. Oosterhaven (1988) suggests that inter-industry linkage analysis is a more appropriate use of the Ghosh model.

3.4.2 Input-output models for NSW

In order to quantitatively examine the links between water and electricity, this research has developed a set of water-energy oriented input-output tables for NSW for 1995-96 and 2000-01 (for brevity, these years will be referred to as 1996 and 2001 for the remainder of the thesis). The original tables were developed by researchers at the Centre for Agricultural and Regional Economics (CARE), the University of New England. Using the Generation of Regional Input-Output Tables (GRIT) method, the original NSW tables were formed from parent national tables for Australia that were sources from the Australian Bureau of Statistics (refer to (1986) for further information about the GRIT method). The parent tables were the latest at the time of preparation of the NSW tables, and were of the industry by industry type. Both parent tables follow Australian and New Zealand Standard Industrial Classification (ANZSIC) 1993.

This research has developed a Leontief hybrid model, a Leontief monetary model and a Ghosh monetary model for both 1996 and 2001. The two years of analysis were selected according to the availability of water and energy data and input-output tables for NSW. Both years also represent different phases of reform, and therefore may provide some additional insights into changes to the nexus during this period. Additional notes regarding the construction of the models for the purpose of this research are provided in Appendix 3. The three main elements of the models – **inter-industry table**, **primary input** and **final sectors** – form the building blocks of the Leontief hybrid, Leontief monetary and Ghosh monetary models and are now described in more detail.

Inter-industry table

The inter-industry tables have been aggregated to 32 sectors from 107 sectors in 1996 and 106 sectors in 2001, based on the availability of water and energy data. Where possible, water- and energy-intensive sectors remained disaggregated; many were from the manufacturing sectoral group. The manufacturing sectors largely followed the ANZSIC subdivisions or groups. In one instance – the Wood Paper & Printing Products (WPP) sector, the lack of data precluded the separation of water-intensive sub-sectors (such as Wood & Paper) from sub-sectors that used much less water (such as Printing). This does not, however, compromise the overall results of the models, nor the general insights offered by the results.

The water sector – which is labelled Water Sewerage and Drainage in the ANZSIC classification system – is disaggregated into Irrigation & Drainage Water, Bulk & Retail Water, and Sewerage sectors. This disaggregation essentially separates the rural water industry (irrigation) from the remaining two urban water industry functions of water supply and sewage service provision, and therefore enables a useful comparison of the energy implications of each water sector.

The electricity sector is disaggregated into generation sectors, in line with the existing technology types in NSW, namely Coal-Fired, Gas Turbine, Internal Combustion (1996 only), Combined Cycle Gas Turbine (2001 only), Cogeneration, Hydropower and Other Renewables. This level of disaggregation enables one to compare the water implication of each generation sector, which is of critical importance, given the recent water shortages experienced in the state.

The row vectors for both the water and energy sectors show how their respective output is distributed in the economy. In the case of the electricity sectors (the main energy sector being considered in this research), this is dependent on the generation mix. For example, if sector *i* consumed 100MWh of electricity and Coal-Fired power stations generated 85 per cent of electricity in the state, then sector *i* was deemed to have received 85 MWh of electricity from the Coal-Fired sector. The models also consider the contribution of embedded generation in the state. In such cases, the electricity generated by the embedded power plants are directly allocated to the receiving sectors. Any additional electricity that such sectors source from the grid is then supplied by all the electricity sectors, based on the generation mix. The column vectors of the water and energy sectors show their required inputs, and is based on operation and maintenance data.

Table 3-2 lists all the production sectors in the inter-industry table, and the sector abbreviations adopted in this research. This table also contains the units adopted in the Leontief hybrid model. For the Leontief and Ghosh monetary models, all units are in monetary terms ($000). Appendix 4 contains detailed direct and total coefficient matrices derived from the input-output models for both 1996 and 2001.

Table 3-2 Production sectors, abbreviations and hybrid units

Production Sector		Abbreviation	Hybrid model Units
1	Agriculture	AG	$000
2	Coal mining	COAL	PJ
3	Other mining & services to mining	OMS	$000
4	Food, beverages & tobacco	FBT	$000
5	Textile, clothing, footwear & leather	TCFL	$000
6	Wood, paper & printing products	WPP	$000
7	Petroleum refining	PR	PJ
8	Petroleum & coal products NEC	PCP	PJ
9	Chemicals	CHEM	$000
10	Non-metallic mineral products	NMMP	$000
11	Basic metals & products	BMP	$000
12	Fabricated metal products	FMP	$000
13	Transport equipment	TE	$000
14	Other machinery & equipment	OME	$000
15	Miscellaneous manufacturing	MM	$000
16	Electricity – Coal-fired	CF	PJ
17	Electricity – Gas turbine	GT	PJ
18a	Electricity – Internal combustion (1996 only)	IC	PJ
18b	Electricity – Combined cycle gas turbine (2001 only)	CC	PJ
19	Electricity – Cogeneration	CG	PJ
20	Electricity – Hydropower	HYDRO	PJ
21	Electricity – Other renewables	OR	PJ
22	Retail gas supply	GAS	PJ
23	Water – Irrigation & drainage water	IDW	ML
24	Water – Bulk & retail water	BRW	ML
25	Water – Sewerage	SEW	ML
26	Construction	CONST	$000
27	Wholesale & retail trade	WRT	$000
28	Transport & storage	TS	$000
29	Finance, property & business services	FPBS	$000
30	Government administration & defence	GAD	$000
31	Education, health & community services	EHCS	$000
32	Other commercial services	OCS	$000

Primary inputs

The original tables generated by the Centre for Agricultural and Regional Economics (CARE) at the University of New England comprise three primary input categories of Labour, Other Value Added and Imports. Labour refers to payments to Households, such as salaries and wages. The Other Value Added category is an aggregate of three primary input categories normally found in the standard national input-output tables generated by the Australian Bureau of Statistics. As previously mentioned, these are gross operating surplus, mixed income, and taxes less subsidies. The Other Value Added category also serves as a balancing term for the tables. In this research, the Imports category is divided into non-energy imports and energy imports.

This research treats natural resources, such as primary energy and water resources, as primary inputs. Following this convention, three additional primary inputs, namely Raw Coal, Raw Water and Instream Use have been included in the input-output tables. Raw Coal refers to coal that is extracted from the Environment by the Coal Mining sector. Raw Water refers to extraction of water from the Environment for consumptive use. Instream Use refers to non-consumptive use of water, such as water for hydropower generation and aquaculture.

Table 3-3 lists primary input categories and corresponding units in the Leontief hybrid model. Similar to the production sectors, the monetary units of $000 are adopted for the Leontief and Ghosh monetary models.

Table 3-3 Primary input categories and hybrid units

Primary input category		Hybrid model Units
1	Labour	$000
2	Other value added	$000
3	Imports – Non energy	$000
4	Imports – Raw coal	PJ
5	Imports – Crude oil	PJ
6	Imports – Refined petroleum products	PJ
7	Imports – Petroleum & coal products NEC	PJ
8	Imports – Electricity	PJ
9	Imports – Gas	PJ
10	Primary energy – Raw coal	PJ
11	Water resources – Raw water	ML
12	Water resources – Instream use	ML

Final sectors

The final sector categories in the original CARE tables comprise Household Consumption, Other Final Demand and Exports. Similar to Other Value Added in the primary inputs category, Other Final Demand is an aggregate of final sectors that are ordinarily represented in a standard input-output table. These include public expenditure, capital stock and investment. Aggregation of these sectors into Other Final Demand limits the potential to convert the standard static model to a dynamic model, which includes a time lag variable to account for staged investment of capital. The scope of modelling is therefore also limited.

In addition to the three final sectors above, this research also includes Environment and Miscellaneous categories. The Environment category enables water flows to be balanced in the tables, as it is assigned water that is discharged to the Environment, either as environmental flows from the Irrigation & Drainage Water, and Bulk & Retail Water sectors, or as treated effluent from the Sewerage sector. This category also balances Instream Water use in the primary inputs category, so that this water is not registered as a 'consumed' quantity in the input-output table. In this case, the balancing amount is simply equal to the negative value of all Instream Water use. The Miscellaneous category comprises water and energy losses, and therefore similar to the Environment category, assists in balancing water and energy quantities in the table. This category also records statistical differences encountered during data compilation. Table 3-4 lists the final sector categories for input-output models.

Table 3-4 Final sector categories

Final sector category	
1	Household consumption
2	Other final demand
3	Exports
4	Environment
5	Miscellaneous

3.4.3 Input-output analysis of the water-energy nexus

Input-output analysis is well suited for quantifying the various links between water and electricity using the following techniques, as illustrated in Figure 1-3: linkage analysis, dependency analysis and multiplier analysis. Table 3-5 summarises the models used for each of the techniques and identifies where the analysis is located in this thesis. The sections that follow describe the three techniques and the corresponding equations in more detail.

Table 3-5 Summary of input-output techniques

Techniques	Model	Thesis location
Linkage analysis	Leontief monetary model Ghosh monetary model	Section 5.1
Dependency analysis	Leontief hybrid model	Sections 5.2, 5.3, and 6.1
Multiplier analysis	Leontief monetary model	Section 6.2

Linkage analysis

Linkage analysis was introduced in the 1950s by Rasmussen's 'power of dispersion' and 'sensitivity of dispersion' concepts and Hirschman's 'backward' and 'forward' linkages[9] (Hirschman 1958; Rasmussen 1956). Backward linkages (or powers of dispersion) are an indication of the dependence of sector *j* on inputs from other sectors. Represented by L_j, backward linkages may be calculated as follows from the Leontief monetary model:

$$L_j = \frac{\sum_{i=1}^{n} \alpha_{ij}}{n} \qquad \text{Eqn. 3-9}$$

where L_j is the average of the α_{ij} elements in column *j* of the Leontief inverse matrix.

Conversely, forward linkages (or sensitivities of dispersion) indicate the extent to which sector *i* outputs are used by other sectors and are commonly calculated from the Ghosh monetary model in the following manner:

$$\vec{L}_i = \frac{\sum_{j=1}^{n} \vec{\alpha}_{ij}}{n} \qquad \text{Eqn. 3-10}$$

where $\vec{L}_i$ is the average of the $\vec{\alpha}_{ij}$ elements in row *i* of the Ghosh inverse matrix.

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[9] Hirschman's terminology is more commonly adopted in input-output parlance.

In order to allow linkages to be compared across sectors, Hazari (1970) suggests standardising L_j and $\vec{L}_i$ by the overall average, defined as:

$$\overline{L} = \frac{\Sigma_{ij} L_{ij}}{n^2} \qquad \text{Eqn. 3-11}$$

$$\overline{\vec{L}} = \frac{\Sigma_{ij} \vec{L}_{ij}}{n^2} \qquad \text{Eqn. 3-12}$$

This results in the following backward and forward linkage equations, respectively:

$$U_j = \frac{L_j}{\overline{L}}, \quad U_i = \frac{\vec{L}_i}{\overline{\vec{L}}} \qquad \text{Eqn. 3-13}$$

A sector is considered to exhibit a strong backward linkage if $U_j > 1$. In this case, an increase in final demand for its outputs would create an above-average increase in economic activity overall. Similarly, a sector is said to have strong forward linkages if $U_i > 1$, which means that an increase in final demand of all sectors would result in an above-average increase in its production activity.

A key sector is identified when both U_j and U_i are greater than one. Both indices, however, are based on averages and are therefore susceptible to a small number of extreme values in their corresponding inverse matrices. For example, a sector may still exhibit a strong backward linkage despite drawing heavily on just one or two sectors, with little dependency on the others. Therefore, in order to identify key sectors, Hazari (1970) and Bharadway (1966) further recommend measuring the spread effects or variability of the indices, using the following coefficients of variation (CoVs):

$$V_j = \frac{\sqrt{\frac{1}{n-1} \sum_{i=1}^{n} \left(\alpha_{ij} - \frac{1}{n} \sum_{i=1}^{n} \alpha_{ij} \right)^2}}{L_j}, \quad V_i = \frac{\sqrt{\frac{1}{n-1} \sum_{j=1}^{n} \left(\vec{\alpha}_{ij} - \frac{1}{n} \sum_{j=1}^{n} \vec{\alpha}_{ij} \right)^2}}{\vec{L}_i} \qquad \text{Eqn. 3-14}$$

The numerators in Eqn. 3–14 are the standard deviations of the Leontief column elements and Ghosh row elements, respectively. The denominators are the averages of these column and row elements. A relatively high CoV is an indication of an uneven spread. In contrast, a relatively low CoV indicates that linkage effects are spread evenly among all sectors. It is therefore considered an additional criterion for key sectors.

Dependency analysis

This research uses dependency analysis to calculate water and energy intensities for each production sector for 1996 and 2001. Direct and total intensities are derived from two fundamental input-output relationships using the Leontief hybrid model: the direct coefficients of the A matrix and the total coefficients of the Leontief inverse matrix, $(I-A)^{-1}$. The intensities therefore refer to water and energy that is supplied by the water and energy sectors in the economy. The advantage of total intensities is that the indirect demand for water and energy sector outputs is captured. This indirect demand refers to the water and energy embedded in the flow of goods and services between the sectors.

These coefficients, however, do not capture all water and energy demand in the economy. The primary inputs matrix, V, comprises Raw Water (which is extracted directly from the Environment by the production sectors), Instream Use of water, primary energy sources and energy imports. These water and energy primary inputs must be considered in any analysis of water and energy demand. The coefficients that represent the water and energy primary inputs are contained in Table 3-6. Briefly, the coefficients of the F matrix defined in Eqn. 3-3 represent the direct intensities. Total intensities are derived by multiplying the F matrix with the Leontief inverse matrix, $(I-A)^{-1}$.

Table 3-6 Water and energy intensity equations

	Coefficient	Equation	Matrix	Intensities
Production sectors	Direct	$a_{ij} = \frac{x_{ij}}{X_j}$	A	Water sectors: IDW, BRW and SEW Energy sectors: ELEC, PR and GAS
	Total	α_{ij}	$(I-A)^{-1}$	
Production factors	Direct	$f_{kj} = \frac{v_{kj}}{X_j}$	F	Water: Raw Water and Instream Use Primary energy: Raw Coal Energy imports: Raw Coal, Crude Oil, Refined Petroleum, Electricity and Gas
	Total	ω_{kj}	$F(I-A)^{-1}$	

A further point of clarification is required to understand the relationship between the water intensities for IDW, BRW and Raw Water. The total Raw Water coefficient for sector *j* ($\omega_{raw\ water,j}$) comprises both the direct Raw Water coefficient ($f_{raw\ water,j}$) and indirect Raw Water use. A portion of the indirect use is water that is extracted by the IDW and BRW sectors to supply sector *j* – either directly (a_{ij}) or indirectly (part of α_{ij}) – with irrigation and urban water, respectively. That is, sector *j*'s a_{ij} and α_{ij} coefficients for the IDW and BRW water sectors are embedded in its $\omega_{raw\ water,j}$ coefficient.

For the energy intensities, some additional adjustments are required, because of the direct allocation of energy imports. In particular, the electricity and refined petroleum intensities for sector *j* are a summation of domestic energy sources (such as electricity generation and petroleum refined in the state) and imports, where: direct intensities = $a_{ij} + f_{kj}$ and total intensities = $\alpha_{ij} + \omega_{kj}$.

Similar to the energy sector intensities, the primary energy intensities require additional adjustments to account for imports. For example, the adjusted direct and total intensities for Raw Coal include coal that is mined domestically and the small amount of coal imported into NSW. Adjusted Crude Oil intensities include crude oil that is imported for domestic refining, and the crude oil equivalent of imported refined petroleum. This last figure is calculated based on the conversion efficiencies of NSW refineries.

The conversion efficiencies quantify the amount of primary energy required to produce final energy. On average, the NSW electricity industry requires 100 PJ of coal to generate 36 PJ of electricity, resulting in a conversion loss of 64 PJ. The primary energy intensities would therefore offer a better indication of energy use, because it includes the energy lost in the conversion process.

As previously mentioned, this research considers energy imports when calculating energy intensities. However, water and energy are also embedded in other imported goods and services, and a more thorough measure of the water and energy intensities of the sectors would therefore include the water and energy embedded in imports. There are obviously some inherent challenges in calculating this embedded or indirect water and energy use, because it would require knowledge of the production processes and electricity generation mixes of the places of origin. An alternative approach is to assume similar intensities as if the imports were domestically produced. This research does not include the water and energy embedded in imports due to time constraints, but may consider doing so in future work.

Multiplier analysis

A multiplier measures the impact on the total economy of a change in final demand (ΔY) for sector *j's* output. In particular, it represents a ratio of the total effect to the initial effect caused by this exogenous change. The three most common types of multipliers are output, income and employment.

Output multipliers may be defined as:

$$O_j = \frac{\sum_{i=1}^{n} \alpha_{ij}}{\Delta X_j} \Rightarrow \frac{\sum_{i=1}^{n} \alpha_{ij}}{1} \Rightarrow \sum_{i=1}^{n} \alpha_{ij} \qquad \text{Eqn. 3-15}$$

where the numerator is the total effect represented by the Leontief inverse matrix coefficients and the denominator is the initial effect represented by the change in total output of sector *j* ($\Delta X = 1$).

Using the same initial effect of $\Delta X = 1$, income multipliers may be defined as:

$$H_j = \sum_{i=1}^{n} h_j \alpha_{ij} \qquad \text{Eqn. 3-16}$$

where h_j represents the household coefficient, which are payments to households (represented by the Labour primary input category) per unit of sector *j* output, X_j. Income multipliers calculate the additional income generated as a result of this initial increase to the total output of sector *j* that is required to satisfy the final demand changes.

Similarly, employment multipliers may be defined as:

$$E_j = \sum_{i=1}^{n} m_j \alpha_{ij} \qquad \text{Eqn. 3-17}$$

where m_j represents the employment coefficient, defined as the number of employees per unit of total output in sector j. The employment multiplier therefore calculates the additional employment generated as a result of this an initial increase to the total output in sector j that is required to satisfy final demand changes.

Eqns. 3-15 to 3-17 represent simple multipliers, because they are calculated using an open input-output model, where household activity is considered exogenous to the economic interactions captured by the inter-industry transactions. In reality, however, households use their income to purchase outputs from the different economic sectors. These feedback loops may be captured by creating a 'household sector' within the inter-industry table. The row and column vectors of this new sector are the Labour vector under primary inputs and the Household Consumption vector under final sectors. The model is now considered closed with respect to households. New direct and total coefficients – denoted by a_{ij} and $\overline{\alpha}_{ij}$ respectively – may be calculated using the closed model.

Total multipliers may be calculated by substituting α in Eqns. 3-15 to 3-17 with $\overline{\alpha}$. Further, the initial output effect (ΔX) for the simple income and employment multipliers may also be substituted with the h_j and m_j coefficients, respectively, to form Type 1 multipliers. Type 2 multipliers are derived when the same initial effect substitution is carried out using the total multiplier equations.

There are therefore several approaches to calculate output, income and employment multipliers. Miller and Blair (1985) indicate that the differences in the multipliers between the sectors are relative, regardless of which multiplier equation is adopted; that is, the ranks of the sectors remain unchanged. Simple multipliers are therefore considered sufficient for the purpose of this research.

In this research, income, employment and output multipliers are calculated for each (non-water and non-energy) sector, in order to examine the potential trade-offs between these macroeconomic indicators and their total water and energy requirements. Karunaratne (1981) similarly used multiplier analysis to explore the trade-offs between energy, income, employment, capital and pollution.

3.4.4 Model validation

There are no equivalent statistical tests to assess the validity of input-output models. Rather, the accuracy of a model – and therefore the results – is determined by the extent to which it accurately represents the economy under examination. The original tables used by this research were developed using the GRIT method, which is accepted as an holistically accurate method to generate input-output tables (Jensen & West 1986). Secondly, the tables were extensively modified with the best available water and energy data from Australian Bureau of Agricultural and Resources Economics (ABARE) and the Australian Bureau of Statistics (ABS). Other data was obtained from company annual reports, and direct requests to organisations. In instances where data was unavailable for commercial in confidence reasons, the researcher sought expert opinions, or used proxies from equivalent national data. Powell (1991) also suggests that the plausibility of the results is another way to validate an input-output model.

3.5 Analysis of substitution possibilities

The third specific objective aims ***to further validate the findings of the empirical investigation by determining the extent of substitution between water and electricity*** by quantifying price elasticities of demand. The elasticities are also useful for developing an understanding of the consonance of the findings based on input-output analysis and therefore offer an indirect validation of the input-output modelling.

Recent studies into the water-energy nexus indicate that the demand for water is sensitive to changes in the price of electricity (see for example Hansen 1996; and Schuck & Green 2002). Under certain conditions, water and electricity may be substitutes or complements, and such relationships may be quantified by calculating cross price elasticities of demand. In addition, own price elasticities of demand may be calculated, which measure the responsiveness of demand to changes in price for one good only. This research calculates both cross and own price elasticities for water and electricity, in order to explore these quantity-price relationships for the NSW economy.

Several methods may be used to calculate elasticities. This research adopts the classical price elasticity approach, due to the limited availability of historical water data that precludes the adoption of more complex methods. These methods – such as the Allen's partial elasticities of substitution (AES) and Morishima elasticities of substitution (MES) – generally require the use of regression analysis to fit historical data to a demand function, from which elasticities may be calculated.

Eqns. 3-18 and 3-19 depict the own and cross price elasticities adopted by this research, respectively. The elasticities are based on the geometric, rather than arithmetic mean. Phillips (1994) suggests that the geometric mean would give equal weight to equal proportional changes and would therefore better suit the calculation of elasticities compared to the arithmetic mean, which gives equal weight to equal absolute changes.

$$\eta_{ii} = \frac{\Delta q / \sqrt{q_1 q_2}}{\Delta p / \sqrt{p_1 p_2}} \qquad \text{Eqn. 3-18}$$

$$\eta_{ij} = \frac{\Delta q_i / \sqrt{q_{i1} q_{i2}}}{\Delta p_j / \sqrt{p_{j1} p_{j2}}} \qquad \text{Eqn. 3-19}$$

In the above two equations, q and p denote price and quantity, respectively, and i and j represent two goods. In the case of own price elasticities (Eqn. 3-18), a good or service is considered to be relatively price inelastic if the absolute value η_{ii} is between 0 and 1; conversely, an absolute value of greater than 1 indicates that it is relatively price elastic. In the case of cross price elasticities (Eqn. 3-19), the two goods are considered substitutes if η_{ij} is greater than zero; conversely the two goods are considered complements if η_{ij} is less than zero. The two goods are considered independent if η_{ij} is equal to zero.

Both own and cross price elasticities are calculated for households, and for key production sectors that are found to be water- and/or energy-intensive in the dependency analysis results. This is undertaken for time periods where sufficient water and electricity data is available for NSW, which include the following: 1993-94 to 1996-97, 2001 and 2004-05.

3.6 Scenario analysis

The findings in Chapter 2 clearly establish that there are inherent links between water and electricity. The first three specific objectives of this research focus on exploring the historical and empirical links. The importance of these links is unlikely to diminish in the future, but rather intensify and potentially require policy trade-offs. Such trade-offs may be demonstrated using scenario analysis.

The fourth specific objective aims ***'to identify the potential trade-offs that will need consideration in order to satisfy the future demand for water and electricity'***. This objective will investigate alternative scenarios to meet the demand for water and electricity in 2031, with a view to determining the potential trade-offs that may occur. This is undertaken by quantifying the water required to satisfy electricity demand, the energy required to satisfy water demand, and the resulting carbon emissions from energy use in the water industry.

Scenarios represent possible futures that have developed along different pathways. As a tool, they have been used extensively for military and commercial purposes to facilitate strategic planning and risk management. Today, scenario analysis is routinely applied to water, energy and climate change issues in Australia and abroad. Appendix 5 lists some of the more significant scenario studies undertaken in Australia in these areas.

The purpose of this section is to outline the process used to develop and model the scenarios in this research. In particular, Section 3.6.1 describes the key drivers and variables that distinguish the different scenarios, and Section 3.6.2 discusses the use of input-output analysis to model the scenarios for the year 2031.

3.6.1 Development of water and energy scenarios

One of the first steps when developing scenarios is to determine the key **drivers** that will influence how the future will unfold. These drivers provide a framework within which to identify the variables that are relevant to the issue under investigation. **Scenario narratives** – which are qualitative descriptions or storylines – may then be developed from these variables.

Scenario drivers

The scenarios developed for this research closely align with the scenario matrix developed by the UK Foresight Program on Environmental Futures (Eames & Skea 2002). It is the product of an extensive review into environmentally-relevant scenario studies, which aimed in part to identify the primary dimensions or drivers of change that were most commonly used to frame scenarios. These drivers – the review concluded – were governance systems and social values.

Governance systems describe the structure and scale of political authority, from globalisation to regionalisation. At the globalisation end, political authority is distributed away from the nation-states towards global organisations. At the regionalisation end, national sovereignty is retained or even strengthened. **Social values** describe patterns of economic activity, consumption and policy-making. At one end is consumerism, which is characterised by individualism and short-termism. At the other end is community, which encompasses values of social equity and long-term sustainability. The scenario matrix is created when the two drivers are used as axes, which intersect at right angles to form four quadrants. The four quadrants represent the four scenarios, as illustrated in Figure 3-6.

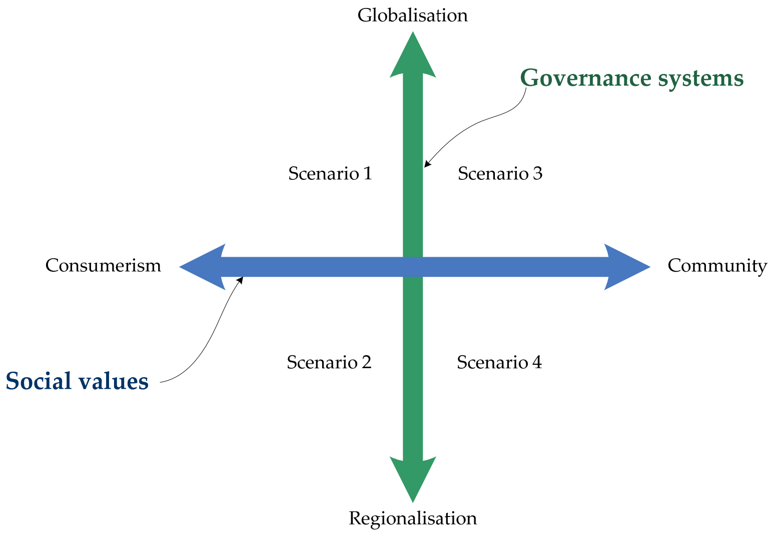

Figure 3-6 Scenario matrix adopted in this research

This research adopted the UK Foresight Program's scenario matrix because it enables the incorporation of social and cultural dimensions, and in doing so, acknowledges the lower left and lower right hand quadrants of the AQAL framework (refer to Figure 3-4). Further, it has the flexibility to accommodate a range of issues in the water and electricity industries and has proven application in water, energy and climate change scenarios (see for example Environment Agency 2001; Performance and Innovation Unit (PIU) 2001a, 2001b). Lastly, a similar scenario taxonomy has been adopted by the IPCC in their Special Report on Emissions Scenarios, which is well recognised worldwide (Nakicenovic & Swart 2000).

Scenario variables

The next step in developing scenarios for this research is to determine which variables will influence the supply and use of water and electricity in NSW in 2031. These variables were identified based in part on the outcomes of Chapter 2, a review of existing water and energy scenario studies for Australia, and discussions with industry experts.

The variables in this research may be summarised as: Environmental, Economic, Technological and Security of Supply. **Environmental** refers to the following factors: the priority accorded to environmental protection, the extent of water and energy conservation; and the influence of drought and climate change. **Economic** describes the extent to which cost determines decisions in the industries, which is influenced by the extent of private investment and the impact of an emissions trading scheme. **Technological** describes the propensity for innovation and for adopting new technologies, and the influence of emissions trading on the selection of and level of dependency on various technologies. **Security of Supply** refers to the importance of domestic energy resources in contrast with relying on energy imports from interstate and abroad. It also refers to the importance of non-rainfall dependent water supplies.

Scenario narratives: a brief description

Based on the two drivers and four variables, narratives have been developed for each of the scenarios identified in Figure 3-6. These scenarios have been labelled World Markets, Provincial Enterprise, Global Sustainability, and Local Stewardship, in line with the four Environmental Futures scenarios. A brief description of these scenarios now follows.

Scenario 1 World Markets: low cost technologies and efficiency improvements

The World Markets scenario is underpinned by consumerist values. The main priority in the water and electricity industries is efficiency improvements insofar as costs are reduced, and therefore the Environment is accorded a low priority. There is a tendency towards private investment and international trade, which facilitates technology transfer and fosters a high degree of innovation.

Scenario 2 Provincial Enterprises: water and energy security of supply

The Provincial Enterprise scenario is underpinned by individualist values. The main priority in the industries is security of supply, which favours technological diversity, although the inward-looking focus hampers some technology transfer. Resource independence is emphasised at the expense of the Environment, except for environmental issues of regional significance, such as drought.

Scenario 3 Global Sustainability: technologies for global sustainable outcomes

The Global Sustainability scenario is characterised by strong international co-operation in dealing with environmental issues, particularly carbon emissions. Therefore, technologies that reduce the reliance on coal and oil, and optimise the use of water resources without over-exploitation are favoured. Technological innovation is high, due to the open exchange of ideas.

Scenario 4 Local Stewardship: regional resources use and environmental protection

The focus of this scenario is maximum utilisation of natural resources, with minimum environmental impact. There is a tendency towards self-reliance – due to strong local and regional governance – and conservation. The regional focus limits technological innovation, although there is a willingness to invest in local technologies.

The four scenarios form the basis for the selection of technologies and demand management strategies that are required to meet future demand for water and electricity. These technologies are reviewed in Chapter 7. The scenarios are modelled using a set of four input-output tables projected to 2031, as described in the following section.

3.6.2 Scenario modelling using input-output analysis

This research uses input-output analysis to model the different scenarios for 2030-31. Some recent scenario studies using input-output analysis in areas of relevant to this research include Faber, Idenburg & Wilting (2007), Marriott (2007), Pan (2006) and Wei et al. (2006). The advantage of input-output analysis over other scenario modelling tools outlined in Appendix 5, which includes computable general equilibrium (CGE), is that there are no inbuilt economic assumptions – such as utility or profit maximising objectives – that drive the scenario outcomes. Instead, alternative drivers, such as social values and governance structures are more easily accommodated within the input-output framework.

The input-output tables developed to model the scenarios are based on the 2001 Leontief hybrid model described previously in this chapter. The hybrid model was selected over the monetary model for the scenario analysis, because the former captures actual technological links between the water and electricity sectors. Further, the lack of long-term price data for the water sector – in contrast with future electricity price estimates that are more readily available in the literature – poses significant challenges to completing the Leontief monetary model. The adoption of the Leontief hybrid model, however, precludes the calculation of other indicators, such as economic output, employment and income multipliers.

There are several ways in which scenarios may be modelled, depending on whether a static or dynamic model is developed. This research develops static models for 2031, for the following reasons. Firstly, dynamic models require a series of input-output tables at regular intervals so that a time lag variable may be inserted. This variable captures when a capital item is produced by sector *i* and when it adds to the capacity of sector *j*. At the time of developing the scenarios for this research, such a series was not available for NSW, and again sectoral water use data was only available for a select number of years. Secondly, the final sectors of the original input-output table upon which the 2001 model is based are highly aggregated, which places restrictions on the ability to expand the final sectors to accommodate additional data (such as capital expansion and replacement requirements) required for a dynamic model (Duchin 1988a). Nonetheless, the static model is well suited to explore the potential trade-offs in the future, as a result of the net water-energy impact of decisions in both industries.

One of the key steps in using input-output analysis for scenario modelling is determining the future structure of the economy, which is essentially represented by the *A* matrix. The *A* matrix, as described previously, assumes that the technical coefficients are fixed; that is, the technical coefficients do not change over time nor allow for substitution. It has been argued, therefore, that input-output analysis is only suitable for short to medium-term analyses (Miller & Blair 1985). Despite this assumption, researchers have undertaken long term scenario analysis with minor modifications to existing technical coefficients (Cruz 2002; Lei 2000; Murthy, Panda & Parikh 1997; Proops, Faber & Wagenhals 1992)

The technical coefficients may be modified in order to better represent the future structure of the economy, and therefore improve the suitability of input-output analysis for long-term studies. There are several methods with which to undertake this modification, including development of marginal technical coefficients , use of best practice firm data, extrapolation of past tables, and expert judgment (for further information see Allen & Gossling 1975; Duchin 1988b; Miller & Blair 1985; and Wilting, Faber & Idenburg 2004).

The **RAS method** is an alternative to those mentioned above, which is much used by government statistical offices across the globe, including the Australian Bureau of Statistics. This method iteratively adjusts the technical coefficients of the base year, using actual or estimated data for a future year, for which the input-output table is being created. Some advantages of the RAS method is that it is mathematically straight forward, and when used in conjunction with exogenous data – such as engineering data or expert judgment – for sectors of significance, the accuracy of the method improves (Allen & Gossling 1975; Miller & Blair 1985).

This research uses the RAS method to update the 2001 A matrix, in conjunction with exogenous data to develop new water and electricity sectors in 2031. The process comprises three steps, which are illustrated in Figure 3-7 and further explained in Figure 3-8. A description of the three steps follows below.

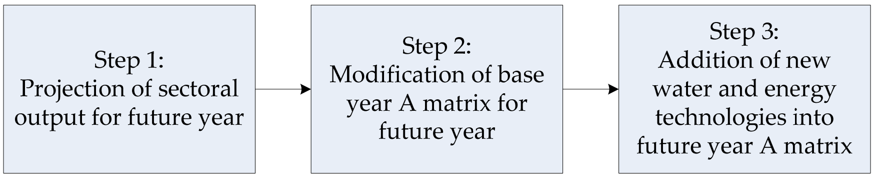

Figure 3-7 Steps to update the input-output model for a future year

Step 1: Projection of sectoral output for the future year

In order to project the total output for each sector for 2031 $X_i(31)$, this research assumes that the NSW economy will follow a medium growth path from 2001 to 2031 and assumes that the growth of each sector is relative to economic growth. The total output for each sector may then be calculated using Eqn 3-20.

$$X_i(31) = X_i(01) \cdot \prod_{t=02}^{31} \left(1 + g(t) r_i\right) \qquad \text{Eqn. 3-20}$$

where $X_i(01)$ is the total output for sector *i* in 2001, r_i is the relative growth rate for sector *i*, and $g(t)$ is the economic growth rate for year *t*. Tables 3–7 and 3-8 list the rates assumed by this research. These rates are based on reports published by the Australian Bureau of Statistics, the Australian Bureau of Agricultural and Resource Economics, and the National Electricity Market Management Company (see tables for sources). Once total output $X(31)$ has been derived, the modification of the *A* matrix may proceed using the RAS method. Section 7.2.1 describes the calculation of total output for the water and electricity sectors in 2031.

Table 3-7 Relative sectoral growth rates (r_i)

Sector		Relative growth rate
1	Agriculture (Ag=G)	1.0
3	Other mining & services to mining (OM&S)	0.9
4	Food, beverages & tobacco (FBT)	1.0
5	Textile, clothing, footwear & leather (TCFL)	1.0
6	Wood, paper and printing (WPP)	0.4
9	Chemicals (CHEM)	0.4
10	Non-metallic mineral products (NMMP)	1.0
11	Basic metals & products (BM&P)	1.0
12	Fabricated metal products (FMP)	1.0
13	Transport equipment (TE)	1.0
14	Other machinery & equipment (OME)	1.0
15	Miscellaneous manufacturing (MM)	1.0
26	Construction (CONST)	1.0
27	Wholesale & retail trade (WRT)	1.0
28	Transport & storage (TS)	1.1*
29	Finance, property & business services (FPBS)	1.2
30	Government administration & Defence (GAD)	1.1*
31	Education, health & community services (EHCS)	1.1
32	Other commercial services (OCS)	1.3

Source: Cuevas-Cubria & Riwoe (2006), *Researcher's assumption

Figure 3-8 Illustration of the three steps used to develop input-output models for 2031

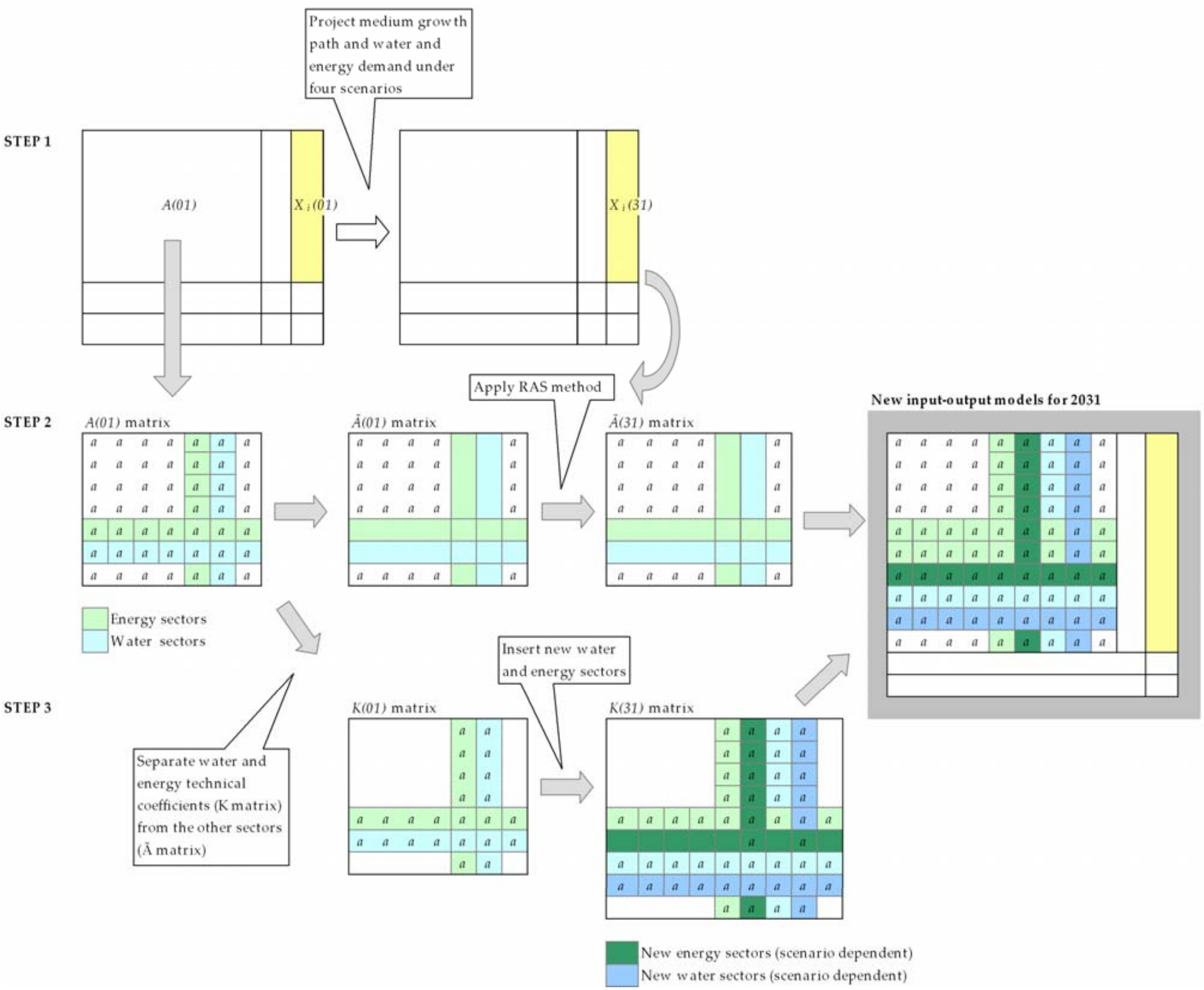

Table 3-8 Medium economic growth rates *g(t)* for NSW

Year	Economic growth (%)	Year	Economic growth (%)
2001	3.0	2017	3.5
2002	1.9	2018	2.1
2003	2.5	2019	2.1
2004	1.5	2020	2.1
2005	0.8	2021	2.1
2006	1.4	2022	2.1
2007	1.3	2023	2.1
2008	2.5	2024	2.1
2009	1.4	2025	2.1
2010	1.7	2026	2.1
2011	3.6	2027	2.1
2012	3.0	2028	2.1
2013	3.0	2029	2.1
2014	2.7	2030	2.1
2015	3.1	2031	2.1
2016	3.0		

Source: 2001-2006: ABS (2006b); 2007-2017: NIEIR (2007); 2018-2031: Cuevas-Cubria & Riwoe (2006)

Step 2: Modification of A matrix using the RAS method

The RAS method was first proposed by Stone (1961) as a way to generate an *A* matrix for years where minimum data is available, in order to shorten the time between the release of statistical data and the formation of input-output tables. The method requires the total output for the future year *t*, which was calculated in Step 1 above, as well as the intermediate supply *U(t)* and demand *V(t)*. Both *U(t)* and *V(t)* for the future year may be estimated by substituting *U* and *V*, respectively in Eqn 3-20, as depicted in the following equations:

$$U_i(31) = U_i(01) \cdot \prod_{t=02}^{31} \left(1 + g(t) r_i\right) \qquad \text{Eqn. 3-21}$$

$$V_i(31) = V_i(01) \cdot \prod_{t=02}^{31} \left(1 + g(t) r_i\right) \qquad \text{Eqn. 3-22}$$

The aim of the RAS method is to develop a set of technical coefficients comprising the *A* matrix that satisfy the future intermediate supply and demand for each sector. This is undertaken by multiplying the *A* matrix from the base year *(t = 0)* with the total output for the future year (*t*), which derives an initial estimate of *U(1)* and *V(1)*. This estimate is then compared with the projected future values *U(t)* and *V(t)*, in order to derive '**R**'ow and '**S**'um coefficients, that are used firstly to adjust the base year *A* matrix, *A(0)*, and then subsequent *A* matrices in an alternating pattern, as illustrated in the equation sequence below:

$$R(1) = \hat{U}(t) \cdot U(1)^{-1} \qquad \text{Eqn. 3-23}$$

$$A(1) = R(1) \cdot A(0) \qquad \text{Eqn. 3-24}$$

$$S(1) = \hat{V}(t) \cdot \hat{V}(1)^{-1} \qquad \text{Eqn. 3-25}$$

$$A(2) = A(1) \cdot S(1) \ldots \Rightarrow \ldots A(2) = R(1) \cdot A(0) \cdot S(1) \qquad \text{Eqn. 3-26}$$

The *A* matrices are iteratively adjusted by *n* values of *R* and *S* in alternation until *U(n)* and *V(n)* converge to within a certain margin of *U(t)* and *V(t)*, respectively. Miller & Blair (1985) suggest a margin of a small positive number, such as 0.01; that is, |*U(t) – U(n)*| and |*V(t) – V(n)*| equal to 0.01.

In situations where some of the technical coefficients in the future year are determined exogenously – as is the case with the water and energy coefficients in this research – those coefficients are replaced by zeros in the A matrix – forming the $\overline{A}$ matrix – and are instead contained in a corresponding *K* matrix. In addition, the known amounts from these sectors (x_{ij}*'s*) are subtracted from *U(t)* and *V(t)* before the RAS procedure is carried out. This is represented by the following equation in matrix notation:

$$A(t) = K + R\overline{A}(0)S \qquad \text{Eqn. 3-27}$$

The technical coefficients of the existing water and energy sectors in the *K* matrix are based on the 2001 model. To complete the *K* matrix, an additional step is required to develop technical coefficients for the new water and electricity sectors for the future year, which is now discussed.

Step 3: Addition of new water and electricity sectors in the K matrix for year (t)

In this research, the selection of new water and electricity sectors to provide new capacity has been determined by undertaking a review of existing and emerging technologies in both industries that are likely to be developed under each of the four scenarios. The outcomes of this review are contained in Section 7.1.

Table 3-9 lists the selected technologies, and the sources used to develop the input-output data to form the technical coefficients for the new sectors. The sources form part of a vastly larger collection of literature that was reviewed, which includes engineering and financial data on operation and maintenance procedures, expert reports, research findings, and input-output studies from both Australia and abroad. This larger collection – whilst not used directly – informed the development of the technical coefficients and the selection of the most appropriate data. This became highly important, given that the new sectors represent technologies that are still under development or are not operational in Australia. In the case of Geothermal, physical engineering data from overseas studies were converted to monetary data using construction cost information for Australia. In the case of Nuclear – which is not present in Australia but is well established internationally – the latest available French national input-output table was used as the starting point for developing the input-output data for the nuclear sector. France generates 78.5 per cent of its electricity from nuclear power and therefore nuclear would dominate the input-output data for its electricity sector (Commonwealth of Australia 2006).

Table 3-9 Source of data to develop input-output sectors

Technology	Sources
Supercritical coal	Based on 2001 model
Ultrasupercritical coal	Based on 2001 model
Nuclear	Based on INSEE (2007)
Geothermal	Cooper (2008) Hondo (2001) and Rawlinson (2007)
Biomass	ECOTECT (1998) and Stucley & RIRDC (2004)
OCGT	Based on 2001 model
CCGT	Based on 2001 model
Wind	ECOTECT (1998)
Desalination	Leslie (2007), Rayan & Khaled (2002), Sydney Water (2007a; 2007c), Voutchkov (2007)
Adv. wastewater treatment	Adham & Gagliardo (1998), Ben Aim (2004), Voutchkov (2007)

In developing the technical coefficients for the new sectors, this research assumed a typical year of operation and took into account the actual costs to produce output from each of the new sectors; capital and depreciation costs were excluded. In this way, the technological input structure may be best represented. Further, it was assumed that all operational inputs are derived from within NSW, with the exception of energy sources that are not available within the state.

In summary, the scenarios developed in this research consider some of the more salient issues affecting both the water and electricity industries. They represent different yet plausible futures for NSW so that the net water-energy impact of delivering water and electricity to the NSW economy under each of these futures may be determined and compared.

3.7 Assessment of policy implications

The fifth specific objective aims ***to demonstrate how consideration of the water-energy nexus may lead to effective policy development***. Due to the fast-paced nature of changes to water and energy policies in Australia, the assessment provides an overview of the major policy developments in 2008, and summarises the main government measures (in terms of plans, programs and policies) at both the Federal and state government level. The assessment discusses the implications of the nature of the nexus on these developments under key themes that have emerged from the analysis for the previous three objectives.

Based on this assessment, this research puts forward recommendations that may assist in improving the integration of water and energy policies in NSW, with a view to reduce the potential for policy trade-offs. These recommendations comprise improvements and additions to existing institutional arrangements, government measures, and industry activities.

3.8 Summary and conclusion

This chapter outlines the development of an integrated methodological framework within which to examine the various dimensions of the water-energy nexus. This framework has been informed by Integral Theory, which aims to ‘map’ reality from eight distinct perspectives using the AQAL framework. These perspectives may also be viewed as eight epistemic communities with their own methodologies and practices. The specific objectives and methods adopted for the research aim to incorporate major perspectives of the AQAL framework as they relate to the water-energy nexus. The methods include historical analysis, input-output analysis, price elasticities, scenario analysis and an assessment of policy implications. Historical analysis is used to develop an historical profile on the nexus, in order to gain a deeper appreciation of nexus issues that are prevalent today, by identifying the forces that shaped its development in the past. Input-output analysis is used to empirically examine the links between water and electricity in NSW, and more specifically, water use in the electricity sectors, energy use in the water sectors, and water and energy use in the other economic sectors. Price elasticities measure the responsiveness of water and electricity demand to changes in price, and would complement the findings from the input-output analysis. Scenario analysis is used to identify the potential trade-offs that may ensue in the water and electricity industries in the future. Lastly, the assessment of policy implications reviews the findings from the previous research methods, in light of recent policy developments.

The above-noted framework represents a distinct advancement over existing studies, in that it effectively incorporates the various dimensions of the nexus and explores the implication of the nexus at an economy-wide level. This approach, to the best knowledge of this author, represents the first comprehensive study into the nature of the water-energy nexus for Australia, and perhaps the world. Further, the research methods would offer complementary insights into the nature of the nexus from lenses of the past, present and future. The past development of the water-energy nexus is the focus of the next chapter.

Chapter 4

Historical evolution of the water-energy nexus

If you would understand anything, observe its beginning and its development

Aristotle

The links between water and electricity are increasingly influencing how society uses both resources. The review of contemporary nexus issues in Chapter 2 suggests that the water-energy nexus is multi-dimensional in nature and that these dimensions – political, economic, technological, social and environmental – are often grounded in history. An understanding of the historical evolution of the water-energy nexus would therefore assist in understanding current nexus issues.

The purpose of this chapter is to analyse the historical evolution of the nexus for Australia with a particular focus on NSW. The analysis begins at the time of British Settlement in 1788 and concludes in 2007. The analysis also refers to events prior to 1788 that were significant for the development of the water and electricity industries in latter years.

A set of three questions guided this historical analysis: what were the key global, national and regional drivers that shaped the evolution of the nexus?; what was the influence of other sectors on the evolution of the nexus?; and how did the water and electricity industries influence the development of each other? To facilitate this analysis, the historical profile of the nexus is structured into four time periods. These time periods represent distinct stages in the history of the water and electricity industries as described below:

1. Early developments in the industry (until 1889)

Period 1 covers the events leading up to the establishment of the water and electricity industries. It also considers the role of energy in a wider context, because establishment of the electricity industry began to occur towards the end of this period.

2. Building on the foundations (1890 to 1939)

Period 2 represents a transition period in Australia, as the colonies formed a Federation of States. It describes the role of the industries in the new nation and the changes that led to improvements in coordination and planning in both.

3. Expansion and pressures for change (1940 to 1979)

Period 3 is marked by significant growth in the Australian economy. It describes the reasons for the growth and expansion in the water and electricity industries. It also identifies the growing pressures for change.

4. Initial and contemporary reforms (1980 to 2007)

Period 4 describes the recent reform phases in the industries. It explores the rationale underpinning these different phases, and examines some of the more contemporary influences in both industries and in turn the nexus.

The four time periods form Sections 4.1 to 4.4 of this chapter. Each section begins with a background discussion of significant events and influences for each time period, and follows with an examination of the urban water industry (which focuses on potable water supply and sewerage), the rural water industry (which focuses on irrigation) and the electricity industry in turn. Based on these discussions, the historical profile of the water-energy nexus is developed, as depicted in Figure 4–1. This profile adopts the classification system in Chapter 2, which categorises the links into upstream, transportation and downstream. Section 4.5 summarises the salient features of the nexus and highlights historical trends common to both industries. Readers may wish to proceed directly to the sections that discuss the water-energy nexus for each time period, and refer back to previous sections when additional explanation is required.

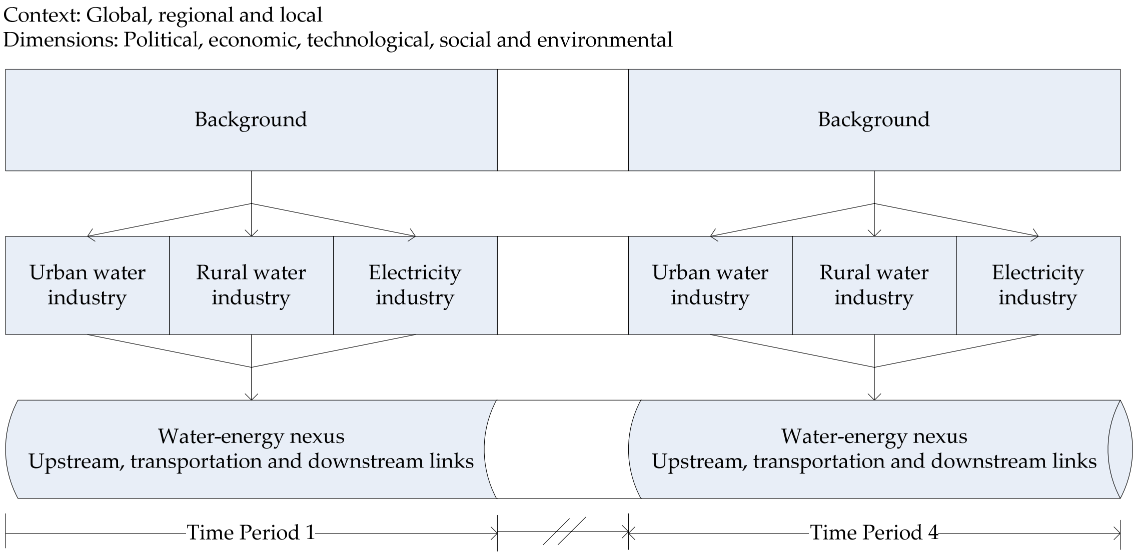

Figure 4–1 Structure of the historical profile

4.1 Early developments in the industries (until 1889)

The Australian continent has been home to the Aboriginal people for over 60,000 years. These first inhabitants adapted to environmental conditions during this extensive period, moving location according to the availability of food and water. They developed strong spiritual links with the land, which to this day they regard as a physical expression of their ancestors (Clarke 2002; Sveiby & Skuthorpe 2006).

British settlement in 1788 introduced a radically different culture to the land. At that time, the intellectual movement known as the Age of Enlightenment, which brought about significant political, economic, and social changes, and technological innovations, was influencing European thinking (refer to Appendix 2 for further discussion). The invention of the steam engine in the late 17th century, for example, resulted in a shift from both animal and water power to steam power, and had widespread ramifications for the water and electricity industries in later years (Porter 2005). Enlightenment thinking also encouraged the exploitation of the Environment for development, which became widespread during the Industrial Revolution in the late 18th and early 19th centuries. These influences abroad made their way to Australia and – together with the arrival of free settlers – contributed to the expansion of rural and urban areas in NSW and other colonies.

In rural areas beyond the Limits of Settlement in NSW, early settlers (known as 'squatters') occupied large tracts of land for sheep and cattle grazing (Clarke 2002). The discovery of gold and other minerals further bolstered development of inland areas in the 1850s. These discoveries also stimulated growth in manufacturing, banking and commerce in the major cities in the following two decades (ABS 2007). By the 1870s, manufacturing industries had expanded from simple commodities like alcohol, soap, tobacco and sugar refining, to steel and chemicals (Shaw 1966). By the 1880s, the colonies had attracted many free settlers and the population in major cities grew rapidly (NSW Water Resources Commission (NSWRC) 1984).

4.1.1 Urban water industry

At the time of British settlement, the Aboriginal people had already developed over thousands of years an intricate understanding of the land, which enabled them to adapt to the availability of water in their Environment. Being nomadic, the Aboriginal people freely moved in search of food and water according to the seasons. They possessed a deep knowledge of water in terms of availability and sources, and developed techniques to store water in arid regions (Blainey 1976; NSW Water Resources Commission (NSWRC) 1984; Sveiby & Skuthorpe 2006). Water also held an important spiritual place in Aboriginal cultures, which follow the creation myth of the Rainbow Serpent. According to this myth, the land gave birth to the Rainbow Serpent, which formed the riverbeds as it moved. These riverbeds were filled with water from frogs that were born at the request of the Rainbow Serpent. The coming of water to the land, the myth continues, enabled the creation of plants, trees, animals, birds and humans (Sveiby & Skuthorpe 2006).

The arrival of the British in the 1770s introduced radically different attitudes towards the Environment and in turn, water resources. As it remains today, water was a vital resource for the early colonies: Captain Arthur Phillip selected the area of Sydney Cove as the site of the first settlement because of its proximity to a freshwater source. Phillip demarcated a fifteen-metre greenbelt on either side of this source – later called the Tank Stream – in order to protect its water quality. The Tank Stream was soon supplemented by private wells, which were considered symbols of privilege. Poorer consumers, however, supplemented their supplies by purchasing water that was more expensive from private operators. These early operators used horse carts to transport water barrels from Lachlan Swamps and nearby lagoons (Lloyd 1988). By 1828, the Tank Stream had degenerated into an open sewer and was abandoned (Sydney

Water 2004b). Lachlan Swamps became the main source and were connected to Hyde Park via a tunnel called Busby's Bore. From Hyde Park, private operators would distribute water across the town on horse carts (Sydney Water 2004a). The NSW colonial government charged these operators a volumetric fee and an annual connection fee to access the Bore (Aird 1961).

In 1842, Sydney was incorporated as a city, and the first election was held for the Municipal Council of the City of Sydney (Sydney Municipal Council). The Council became responsible for infrastructure development, including water supply, sewerage and lighting (Golder 2001). One of its earliest activities was construction of the first network of water-distribution pipes, which transported water by gravity from Hyde Park to various parts of the city (Sydney Water 2004a).

In the early 1850s, Sydney's water supply system had reached its limit due to population growth, demands from early manufacturing industries, and a prolonged dry period. In order to ease the situation, the Botany Swamps scheme was recommended and approved. When it finally began operations in 1859, steam engines pumped water to areas served by the scheme (Beasley 1988).

In 1854, the NSW colonial government abolished the Sydney Municipal Council for general ineffectiveness in developing infrastructure in the city. This ineffectiveness, it is reasoned, was caused largely by mismanagement, lack of administrative controls and lack of funding. These problems stemmed from the Victorian tradition of an aversion to public spending, particularly when the economic benefits were not immediately obvious or tangible (NSW Water Resources Commission (NSWRC) 1984). The government transferred administrative control of water supply and sewerage schemes to three Commissioners. In their first year of office, the Commissioners erected a small steam pump to increase the transfer of water from Lachlan Swamps into Busby's Bore. By 1856, control was subsequently returned to Sydney Municipal Council, when the Commissioners themselves were accused of failing to deliver water infrastructure services (Aird 1961; Sydney Water 2004a).

The discovery of gold in the 1850s resulted in economic growth for NSW in the 1860s and 1870s, particularly in the banking, commerce and manufacturing industries. Manufacturing industries in particular had become dependent on steam power for energy and began petitioning for water supplies that were more reliable. Domestic users who remained unconnected to the water distribution network continued to source water from wells or paid private operators for more expensive water (NSW Water Resources Commission (NSWRC) 1984). In 1867, a Royal

Commission was established to investigate possible catchment areas to ease the water supply problems. One of its recommendations was to develop the Upper Nepean Scheme, which was completed in 1889. To this day, the Scheme diverts water from the Nepean River and its tributaries to Prospect Reservoir (Aird 1961; Beasley 1988; NSW Water Resources Commission (NSWRC) 1984). From Prospect, water is transported via canals and pipelines to consumers in Sydney. When the Scheme began, consumers paid for this water according to the number of rooms in their building (Aird 1961).

Sewage disposal presented another issue for the early water industry. In the early years, sewage was discarded in open sewers and street canals. Cesspits were soon excavated to contain sewage. Essentially holes in the ground, the cesspits would be filled with soil once full and replaced by another nearby. Later, pan closets were constructed to reduce contamination. A pan closet consisted of a toilet seat on top of a removable pan, which would be emptied by nightmen at regular intervals. Population growth in the cities, however, soon made this arrangement untenable. In wealthier areas, water closets were installed which used water to carry waste to the sewer mains (Lloyd 1988).

In 1832, the idea of a centralised sewerage system was first mooted, but was abandoned due to poor administration, limited technical expertise, and lack of funds – the same issues that hampered the development of water supplies (Beasley 1988; NSW Water Resources Commission (NSWRC) 1984). Sydney Municipal Council finally constructed the first sewerage scheme in 1857. The Scheme comprised outfall pipes that discharged sewage and stormwater into Sydney Harbour at Bennelong Point and later Ultimo and Woolloomooloo (NSW Water Resources Commission (NSWRC) 1984). Augmentation of this system took a further three decades, because resources were largely channelled into meeting the immediate need for water. By this time, public discontent over the harbour outfalls was strong, and there was growing recognition of the link between infectious diseases, such as cholera and typhoid, and contaminated drinking water (Butlin in Beasley 1988; NSW Water Resources Commission (NSWRC) 1984).

In 1875 the Sydney City and Suburban Sewage and Health Board was created to deal with these growing public health concerns. During its tenure until 1877, the Board prepared detailed reports on sewage collection, disposal and other public health issues, which led to a spate of legislation governing such issues (Shergold & Allen 2003). The Board also recommended the construction of larger-scale sewerage schemes to replace the harbour outfalls. The Bondi Ocean

Outfall System (Northern System) and Botany Bay Sewage Farm (Southern System) were soon developed and completed in 1889 (Aird 1961; Beasley 1988). Expansion of the sewerage scheme also increased the demand for water, because water was – and continues to be – considered a transportation medium for waste (NSW Water Resources Commission (NSWRC) 1984).

The Sewage and Health Board laid the foundations for the formation of the Board of Water Supply and Sewerage (Board) in 1888, which assumed responsibility from Sydney Municipal Council. This new Board's jurisdiction covered a larger area than its predecessor and enabled long-term planning to be carried out. Formation of the Board represented a significant shift in water management, from unplanned responses that dealt with immediate storage needs and public health concerns, to better planning (NSW Water Resources Commission (NSWRC) 1984). The Board also enabled professional groups – in particular engineers – to claim specialised knowledge in the industry (Beder 1990). Environmental impacts of water projects were not considered, due to the attitude at the time of exploiting natural resources for development.

4.1.2 Rural water industry

During this period, agriculture was limited to fertile areas immediately surrounding city centres, such as the Cumberland Plain in Sydney. Similar to elsewhere in the colonies, these landowners were granted riparian rights[10] to adjacent water bodies, in accordance with the English Common Law principle. Landowners diverted water from nearby streams by gravity and later by steam engine pumps (Hallows et al. 1995).

The invention of new harvesting machines, development of new drought-tolerant wheat strains and refrigeration provided important stimuli for the development of large-scale agriculture towards the end of this period, and with it irrigation projects (Lougheed 1988; Shaw 1966). Victoria led the way in irrigation developments and influenced irrigation in NSW from the 1890s. The first major development in rural water management occurred in 1881, when Victoria transferred water ownership to the Crown under its *Water and Conservation District Act, 1881*. Whilst existing riparian rights were maintained, no additional rights were granted. Many independent waterworks and irrigation trusts developed in rural Victoria because of the Act of 1881. They were a government attempt to promote self-reliance in outlying areas, and thereby reduce the drain on state funds (Powell 2002; Smith 1998).

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[10] A landowner's right to access adjacent water bodies for reasonable use. Where there is insufficient water, it is allocated proportionately according to frontage on the water body.

The Victorian Royal Commission on Water Supply of 1884, headed by Alfred Deakin, gave further impetus for Crown ownership. The Commission compared irrigation practices from around the world, and concluded that

> responsibility, care and custody of water can only be invested in the state, the state's right to water must not be compromised by riparian rights to anyone else, and the rights of the individual and the state need to be properly defined in order to avoid lengthy and costly legislation (Smith 1998, p. 152).

The Commission also recommended that water grants be tied to specific allotments of land, after Deakin observed that 'land in the western states of America was plentiful but almost worthless without water' (Tan 2002, p. 17). As a result of these findings, the Victorian government passed the *Irrigation Act, 1886.* Several irrigation projects followed in Victoria and South Australia, including two private schemes developed by the Chaffey Brothers from California. In NSW, the Lyne Royal Commission (1884-1887) recommended the replacement of Common Law riparian rights with rights defined by statutory law. During this time, private interests and municipal councils developed small-scale schemes in the state. The first state-funded intensive scheme in NSW – the Murrumbidgee Irrigation Scheme – did not appear until 1912 (Lloyd 1988).

The inland rivers supported early attempts at irrigation, and where the quality was suitable, groundwater was used for irrigation and town supply. The Great Artesian Basin, which was discovered in 1879, became an important source for stock watering, especially during drought (Lloyd 1988). In NSW, the Public Works Department operated artesian bores along the travelling stock routes in the Western Division, using windmills to pump the groundwater to the surface. Oil engines and steam pumps were later used for this purpose (Hallows et al. 1995; NSW Water Resources Commission (NSWRC) 1984).

4.1.3 Electricity industry

At the time of British settlement, electricity was still in an experimental phase. Human knowledge of electricity, however, has existed since ancient times. Ancient Greek philosopher Thales (585 BC) observed that amber attracted light objects after being rubbed, a phenomenon which has since become known as static electricity (McNeil & NetLibrary Inc. 2002). The word 'electricity' itself is derived from the Greek word for amber (*elektron*).

Static electricity, in the form of lightning, is also evident in Aboriginal mythology from Northern Australia. According to the Dreamtime[11] from the region, *Namarrgon* – an important Creation Ancestor commonly known as 'Lightning Man' – is responsible for the violent lightning storms that occur on the Arnhem plateau every wet season. Using the stone axes that are mounted on his head, elbows and knees, *Namarrgon* splits dark clouds and strikes the ground, creating thunder and lightning (Balderstone 1995).

In the modern era, important experiments were undertaken that characterised the behaviour of static electricity during the 17th and 18th centuries. By the start of the 19th century, concepts in electrochemistry had been developed, and the first modern battery was invented. Key principles regarding electric currents were also advanced during this period, including a discovery in 1820 by Danish scientist Hans Christian Oersted that electricity produces a magnetic field. Oersted's discovery was explored by English scientist Michael Faraday, who established the principle of electromagnetic induction in 1831, and subsequently developed the first electric motor (McNeil & NetLibrary Inc. 2002).

These advancements in electrochemistry and electromagnetism during this period facilitated the invention of communication technologies, such as the telegraph and later the telephone (Scholz 2006a). The electric arc lamp became the first use of electricity as an energy source. As with the communication technologies, these early lamps relied on current produced from large wet-cell batteries, such as the Voltaic battery. These technological developments overseas soon made their way to Australia (Godden Mackay 1995).

In 1863, Australia held its first demonstration of the electric arc lamp at Observatory Hill, in order to celebrate the marriage of the Prince of Wales. In 1879, electric arc lamps enabled round the clock construction of the Garden Palace in Sydney, in preparation for the International

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[11] Aboriginal belief system

Exhibition. Electric arc lamps became used for street lighting and stage theatre lighting in many cities around the world. Due to their brilliance and emission of fumes and heat, however, these lamps were only suitable for large spaces and outdoor use. Inventors soon began working on alternatives (Wilkenfeld & Spearritt 2004). By the late 1870s, the incandescent carbon filament lamp had been invented by Englishman Joseph Swan and American Thomas Edison almost simultaneously (Scholz 2006b). The incandescent lamp offered the advantage of consuming less electricity, and could be installed inside buildings.

Technological advancements in the electric motor and generator in the mid 1870s facilitated the electrification of many cities in the 1880s, primarily for electric lighting. In Sydney, electric lighting was installed in various locations, including the Sydney Town Hall, Redfern Terminal (now Central Station) and the General Post Office at Martin Place. Sydney had invested heavily in gas street lighting, which was managed by the Sydney Municipal Council, and electric street lighting was therefore not installed in the city until two decades later. The northern NSW town of Tamworth became the first in Australia to install permanent street lighting as part of the centenary celebration of British settlement in 1888. This accomplishment also reflected the wealth and power of the pastoralists during this period, who were keen to keep up with advancements occurring elsewhere in the world.

Due to the proximity of the coalfields, many of these early lighting networks were powered by coal-fired steam generators. Hydropower generation technology, which was developed in Great Britain in the 1880s, also made its way to Australia by the end of this time period, and in 1889 a small hydropower station was built at Jenolan Caves to provide power for lighting (Wilkenfeld & Spearritt 2004).

4.1.4 Water-energy nexus

This first period of Australian history marked the beginning and early developments of the urban and rural water industries. It also laid the foundation for the development of the electricity industry in subsequent years.

Prior to the introduction of electricity, the water industries – like other early industries – were already reliant on energy. Similar to pre-industrialised Europe, animal power was used in the early years of the colony. In the water industry, for example, horse carts transported water across the town. Technological advancements in Europe – such as the development of the steam engine – soon made their way to the Australian colonies. Other energy technologies used in the colonies included oil engines, windmills and gas engines. The use of water for steam power and later electricity generation assisted in diversifying the energy mix. Due to the importance of these technologies to the water industry, this section considers energy in more general terms.

Upstream

There were numerous private operators in the early years of the water and electricity industries. As the colony and its industries developed, the colonial government assumed greater control over these services. There was still, however, an underlying aversion to public spending. This was evident in the apparent mismanagement and lack of investment in the urban water industry – which was largely dictated by public health and drought concerns – as well as the prevalence of private operators in the rural water industry. In the case of the electricity industry, private operators first supplied electricity for lighting in various buildings across the city. Electric street lighting in Sydney did not eventuate until another two decades due to the heavy investment in gas lighting. Instead, Tamworth became the first town in the colony to generate electricity for permanent street lighting using steam engines in 1888. This first public electricity supply system reflected the social and political aspirations of the pastoral economy at the time.

During the early transition towards government control, both water and energy (lighting) services in Sydney were at one time under the jurisdiction of the same utility, namely the Sydney Municipal Council. As the transition continued, however, professional groups such as engineers extended their influence in the ongoing management of the industry. In addition, the jurisdictional boundaries of the water utility expanded. This trend was replicated by the electricity industry in the subsequent period.

Transportation

The transportation category comprises links between energy and the movement of water. As previously identified in Chapter 2, these links include energy for groundwater extraction; energy for surface water transfers; and energy for water distribution and wastewater collection.

Groundwater extraction began in the early days of the colony, when free settlers excavated wells to supplement the water supplied by the Tank Stream. Later, Lachlan Swamps, which were fed by groundwater, became the primary water supply for the town after the Tank Stream. Water was transferred from Lachlan Swamps to Hyde Park by means of gravity via Busby's Bore. Sydney later took advantage of steam pumps to increase the rate of transfer when the demand for water increased.

The ability to harness steam pumps to transfer surface water saved the NSW colony, and in particular Sydney, from water shortages. Steam pumps facilitated the transfer of water from further a field, such as the Botany Swamps scheme and later the Upper Nepean Rivers. In rural areas, steam pumps enabled early irrigators to transfer surface water from nearby rivers to their farms.

Sydney's first water distribution system used animal power – in the form of horse carts – to transport water across the city. The first piped distribution network that connected to Busby's Bore at Hyde Park was gravity-fed. Sewage collection in the early years also relied on horse carts to collect waste at night. The sewerage schemes developed later in this period relied on gravity to transport the sewage to the Harbour for discharge, and later to the Bondi Ocean Outfall and the Botany Sewage Farm.

Downstream

Cross subsidies between water and energy is one of the downstream links identified in Chapter 2. It could be argued that the water industry subsidised the cost of generating energy, when petitioning by manufacturing industries prompted investment into more reliable water supplies. In this instance, the need for energy by other economic sectors significantly shaped the development of the water industry during this period. In other words, water was not only a constraint on development but also on energy security.

During this period, there appears to be little focus on treating water and wastewater. In fact, the quality of the water supplies was largely dependent on controlling pollution activities adjacent to the water source. In the case of sewerage, raw sewage was disposed of without prior treatment.

4.2 Building on the foundations (1890 to 1939)

Significant national and global events occurred during this period that influenced the development of the water and electricity industries. During the 1890s, issues of common concern began to unite the Australian colonies and provided the impetus for the formation of a Federation of states, which took place on 1 January 1901. Under the new constitution, the Federal government took control over areas of national significance such as defence and immigration, and the states retained residual power. Importantly, Section 96 of the Constitution conferred power to the Federal government to make grants to states for specific purposes (Clarke 2002; Shaw 1966). The Federal government has since exercised this power in the water and electricity industries.

The period between Federation and the onset of World War 1 was a time of rapid development. Population increased substantially and factories expanded rapidly under the umbrella of protection from imports, with implications for the water and electricity industries (Clarke 2002). In early 1914, Great Britain was at war and Australia was called to her defences. Trade was severely disrupted, which prompted the development of manufacturing and metal industries to service domestic demand (Lougheed 1988). After the war in 1918, in a new era of Closer Settlement, the Soldier Settlement Schemes encouraged returned soldiers to work on the land. Soldier Settlement funding became part of a larger program of investment into infrastructure industries in rural and urban areas (Clarke 2002).

During the 1920s, the economy grew strongly as a result of tariff protection and favourable conditions for primary industry exports. However, when the New York stock exchange collapsed in October 1929, the impacts reverberated around the world and the Great Depression began soon after. The Australian economy was one of the most seriously affected, because of its high dependence on primary exports (Lougheed 1988). Construction of many infrastructure projects was put on hold, due to a lack of funds (NSW Water Resources Commission (NSWRC) 1984). By 1933, the economy began to recover. In 1939, however, Great Britain declared war on Germany and Australia was again called to her defence (Clarke 2002).

As with the previous period, natural resources were considered commodities to be harnessed for development. There was little appreciation of the intrinsic value of the Environment, nor of its needs. The growing population and expansion of agriculture, grazing and resource-intensive industries such as mining and manufacturing, had lasting repercussions for the state of the Environment in subsequent periods.

This period also marked a shift towards greater public ownership and coordination in the infrastructure industries. Underpinning this shift was the belief that the government was in a better position to undertake risky infrastructure projects that were considered beyond the financial resources and expertise of private companies. Rather, it was perceived that the government's role was to develop infrastructure industries that would in turn encourage private investment in other sectors of the economy (Booth 2003; Rosenthal & Russ 1988).

4.2.1 Urban water industry

From the outset of this period, water was perceived as a constraint on development. Prolonged drought conditions in the 1890s in south-eastern Australia ensured that water became a key issue in the lead up to Federation in 1901. States were keen to maintain control of their water resources, and succeeded in doing so under Section 100 of the Constitution (Commonwealth of Australia 2003a).

The Federation Drought, as it was subsequently called, continued until 1903. During the 1900s to 1930s, numerous water storage dams and storage reservoirs were constructed in an effort to secure bulk supplies and cope with variations in demand. Pumping stations driven by steam, gas and later electricity transported the water from the dams to the reservoirs scattered across Sydney. In 1931, the Board of Water Supply and Sewerage adopted the practice of using steam pumps in winter, in order to reduce electricity consumption (Aird 1961).

Whilst the Board managed and operated water infrastructure, the Public Works Department was responsible for its construction. This dual system of control was not without problems. Financial and administrative difficulties ensued between the two authorities, resulting in complete transfer of authority over construction to the Board in 1925 (Beasley 1988). That same year, the Board was renamed the Metropolitan Water Sewerage and Drainage Board (MWSDB). In 1935, the MWSDB was reconstituted, in order to streamline its administration (Aird 1961).

In the 1920s, urban expansion and another drought placed new pressures on water supplies. In Sydney, the MWSDB struggled to cope and suffered severe criticism from the public (Beasley 1988). The onset of the Great Depression in the early 1930s further compounded this condition, as construction in the industry largely ceased due to a lack of funds. In 1934, the Australian economy began to recover, by which time another drought had commenced. By the late 1930s, Sydney's water supply was on the brink of total failure. In order to provide short-term relief, the Warragamba Emergency Scheme was developed in 1937. This scheme composed of a weir along the Warragamba River and an underground pumping station to transport the stored water to Prospect Reservoir (Aird 1961).

Sewerage expansion during this period suffered a worse fate, due to limited funds and priority accorded to augmenting the water supply system. Sewerage services therefore struggled to keep up with demand. Disease and sickness were not uncommon, and sewer ventilation shafts were blamed for blanketing neighbourhoods with odorous vapours. Swimmers were also exposed to the pollution created by the Bondi Ocean Outfall System. The Botany Sewage Farm – which was completed at the start of this period – had also become overloaded. The farm would screen sewage and transport the sludge using a steam locomotive to a designated farming area, where it was dug into the soil to grow crops (Beasley 1988).

In the early 1900s, the Public Works Department constructed small-scale sewerage schemes in Sydney. Planning for additional large-scale ocean outfall systems soon followed in the 1910s (Aird 1961). In 1919, the Southern and Western Suburbs Ocean Outfall Sewer was completed and replaced the Botany Sewerage Farm. Fractures in a section of the sewer main two years after completion and an increasing demand for sewerage led to the construction of a second phase from 1936 (Beasley 1988). In 1930, a second system called the Northern Suburbs Ocean Outfall Sewer was completed. The ocean outfalls soon absorbed many of the local systems, thereby furthering the industry trend towards large-scale centralisation (Aird 1961). Inspite of this expansion, fifty per cent of Sydney's population still used pan closets by the outbreak of World War 2 in 1939 (Beasley 1988).

An important element in both the ocean outfalls and minor systems was the construction of pumping stations in low-lying areas. Some of the early operation methods of these pumping stations included the steam engine, oil engine, electric-motor drive and compressed-air ejection. As electricity networks extended through the city, sewage pumping stations were connected to the mains power and were provided with individual automatic control systems (Aird 1961). Electric machinery was also used to dissipate odorous vapours from some sewer ventilation shafts (Beasley 1988).

During this period, the pricing structure for both water supply and sewerage underwent several changes. Until 1904, water charges followed a sliding scale that depended on annual property values. From 1905 onwards, the Board adopted the British pricing policy of a flat rate charge per property. For sewerage services, a flat rate charge was applied until 1890, after which time unoccupied land was charged at a lower rate. In 1899, sewerage charges were dependent on which sewerage scheme serviced the property. In 1905, a flat rate structure was again adopted (Aird 1961). This flat rate charge assisted the Board in estimating its annual revenue, however because it was not representative of water consumed by end users, it did not promote water conservation.

4.2.2 Rural water industry

By the 1890s, independent irrigation trusts that were established in Victoria in the previous decade foundered for financial reasons. A weakened pastoral economy – caused by a decline in overseas wool and wheat prices – were partly to blame (Dovers 1994). The Federation Drought significantly affected rural areas, rendering many areas unproductive, and as in urban areas, water began to impose a constraint on development (NSW Water Resources Commission (NSWRC) 1984).

In NSW, the *Water Act, 1912*, further consolidated the Crown's control established by the *Water Rights Act, 1896*, and introduced a system of licenses to access the water, subject to availability. This Act also established a hierarchy of use during water shortages. The Water Conservation and Irrigation Commission was established the same year to oversee irrigation development and operations, and to administer water rights. Development of irrigation schemes continued in subsequent decades, largely funded by the State government (Broughton 1999; Haisman 2005; Powell 2002; Smith 1998).

The first major instance of Federal government involvement in irrigation was the ratification of the River Murray Waters Agreement in 1915 between the Federal and State governments of NSW, Victoria and South Australia. The governments also agreed to establish the River Murray Commission, which became responsible for arranging construction of water infrastructure and allocating Murray waters between the three participating states. Under the agreement, capital costs were borne by the governments and water sales covered operating costs (Hallows et al. 1995). Water supply became the main priority of the Commission in the early years;

environmental management and efficiency measures were not implemented until the 1970s (NSW Water Resources Commission (NSWRC) 1984).

After World War 1, the states developed irrigation as part of the Federal government's policy for Soldier Settlement. This policy included populating inland areas and rewarding returned servicemen. Many of these settlements had limited success, as settlers were poorly skilled for life on the land. Farm allotments were too small to produce an adequate yield, which was exacerbated by drought. Prices on the overseas market declined rapidly by the 1920s and many soldier settlers faced severe hardship (Hutton & Connors 1999; Lougheed 1988). During the Great Depression, funding for infrastructure projects such as irrigation stopped, as access to overseas capital ceased.

In terms of groundwater, artesian bores in the NSW Western Division continued to supply water along the travelling stock routes, for pastoral properties, and for a limited amount of irrigation on experimental farms (Lloyd 1988). Improved well drilling techniques imported from the oil industry, and cheap oil and gas prices encouraged rapid expansion of drilling programs. This expansion, however, reduced the pressure and flow of groundwater in some locations (McNeill 2000).

During this period, the rural water industry fulfilled important social and political objectives. Licensed water users were not charged for water, despite the investment of public money into storage dams of questionable economic viability, and other water infrastructure (Haisman 2005). Rather, storage dams were considered impressive symbols of progress and instilled the romantic notion of 'making the deserts bloom' (NSW Water Resources Commission (NSWRC) 1984). Irrigation was seen as key to overcoming drought, and was supported by the subconscious belief that the community had a duty to alter the Environment for useful purposes, if it had the capability to do so (Hallows et al. 1995). Such was the strength of the legacies from Aristotle, Bacon and Descartes and the belief in the great engineering and technological advances of the time that the Environment was accorded little or no priority, despite the emergence of environmental problems towards the end of this period (refer to Section A 2.3 in Appendix 2). Excess water from inadequate drainage in irrigated areas, for example, caused local watertables to rise, bringing salt to the surface (Dovers 1994; Proust 2008).

4.2.3 Electricity industry

Electrification of cities and towns proceeded rapidly during the early years of this period, largely due to the demand for lighting. By 1891, the NSW towns of Young, Penrith, Moss Vale, Broken Hill and the Sydney suburb of Redfern had established their electricity supply systems. Electrification continued during the 1890s in major cities across the colonies. In 1896, Sydney Municipal Council passed the *Electric Lighting Act*, although as mentioned previously, Sydney had invested heavily in gas lighting and therefore remained gas-lit until 1904 (Jobson 2004).

Many of the power stations constructed during the 1890s comprised direct current (DC) generators driven by reciprocating steam engines, and therefore required reliable sources of water. DC technology was cheap to establish for small areas of supply. Coal became the dominant fuel source due to its abundance in NSW, but timber was also burnt directly in boilers. Larger-scale hydropower generation schemes were developed in the 1890s, such as the Gara River hydropower station near Armidale in NSW that was completed in 1895. This power station provided power for lighting to nearby mines (Davies 2006).

In Europe, long-distance transmission and the three phase alternating current (AC) motor was developed during the 1890s, which had a major influence on the evolution of the electricity industry in the twentieth century (Godden Mackay 1995). The Australian electricity industry, however, was still in its infancy at the time of Federation in 1901, and there was little need for coordination at a national level. This was further reinforced by the large distances between major cities in the newly-formed states. Development of the electricity industry therefore remained under the jurisdiction of State governments in the Australian Constitution (Rosenthal & Russ 1988).

In the early 1900s, the number of electricity undertakings increased in order to meet the growing demand for lighting. Industrial and residential use of electricity was still minimal. Many of these early undertakings were private companies that supplied to local premises, or government departments such as the Department of Railways in Sydney (Rosenthal & Russ 1988; Wilkenfeld & Spearritt 2004). Municipal councils generated electricity for street lighting and developed distribution networks into adjacent council areas. Importantly, the shift from gas to electricity for street lighting gave municipal councils independence from gas companies (Wilkenfeld & Spearritt 2004). By 1913, the early private companies had largely been taken over by municipal councils. Underlying this shift was the belief that governments were in a better position to undertake the task of electrification, as private companies neither had the experience nor financial resources (Booth 2003; Rosenthal & Russ 1988).

Concomitantly, many of the early power stations were replaced by stations of larger capacity, due to improvements in the generation technology. By the end of the 1930s, NSW was supplied by four major generation and supply organisations and several regional networks. In more remote areas, isolated power stations operated independently (Godden Mackay 1995).

World War 1 affected the development of the industry, which relied heavily on imported equipment from Great Britain and elsewhere in the western world. As the war progressed, international trade became exceedingly limited, thereby halting the import of equipment necessary for electrification to continue (Wilkenfeld & Spearritt 2004). Australia's isolation from international trade prompted the development of mineral and manufacturing industries, which were energy-intensive (Lougheed 1988). By war's end, demand for electricity had increased exponentially, largely due to the establishment of these industries. A minerals and manufacturing boom during the 1920s continued to drive the demand for electricity. To meet this demand, additional capacity was installed in existing stations in metropolitan NSW (Booth 2003; Rosenthal & Russ 1988).

In the years after World War 1, institutional arrangements in the industry were further developed. In 1919, the NSW Government passed the *Local Government Act* which described the rights and responsibilities of municipal councils that supplied electricity to end users (Electricity Supply Association Australia (ESAA) 1973). The Electricity Advisory Committee was established in 1934 and became the official link between the NSW Government and the electricity industry (NSW Government 2008a). The following year, the Government introduced the *Gas and Electricity Act, 1935*. This Act led to the establishment of the Electricity Advisory Committee and the Sydney County Council in 1936 (Burger 2004). The Sydney County Council took over the functions of the Sydney Municipal Council and other adjacent municipal councils, and effectively gave the State government discretionary control over the organisation of electricity supply in the state (Godden Mackay 1995; Wilkenfeld & Spearritt 2004).

Demand for electricity also increased after the war, as many homes became electrically-wired. The use of domestic appliances such as the clothes iron fed this demand. Sydney's electricity supplies were augmented by installing additional capacity at the Pyrmont Power Station and constructing the Bunnerong Power Station (Wilkenfeld & Spearritt 2004). Hydropower stations were also constructed in the NSW country towns of Nymboida and Mullumbimby, and at Burrinjuck Dam in the 1920s (Davies 2006). By the end of this period, electricity had shifted from its beginning as a novelty, to an indispensable part of life (Godden Mackay 1995).

4.2.4 Water-energy nexus

This period incorporates major historical events of global and national significance that influenced how the water and electricity industries developed and in turn the evolution of the nexus. The Australian colonies formed a Federation of States in 1901, and under the new Australian Constitution, the Federal government assumed control over issues of common concern, such as defence. States retained residual powers, including control over their water and energy industries, but Section 96 conferred powers to the Federal government to grant special purpose funding to states. In the 1940s, the Federal government used defence as a primary reason to develop the hydroelectric component of the Snowy Mountains Scheme. More recently, the Federal government exercised this power in order to implement its reform of the water and electricity industries since the 1990s.

This period also coincided with increased government involvement with the water and electricity industries. In both industries, it was argued that governments were in a better position to invest in risky infrastructure compared to the private sector. This represented a significant shift from the first time period, which was characterised by an aversion to public spending that was prevalent in the Victorian era. This period consolidated – through the formation of the Metropolitan Water, Sewerage and Drainage Board and the Sydney County Council – the role of professional engineers in both industries, which gave a technological focus to both industries. In addition, technological advancements favoured the development of more large-scale centralised systems by the end of this period. Other links between the water and electricity industries are now discussed.

Upstream

The formation of the electricity industry began in earnest during this period, as the demand for lighting and other services increased. In NSW, power stations were constructed close to areas of demand in cities. These power stations were built and operated by private operators, government departments and municipal councils. Many of these power stations used steam engines to generate electricity and therefore – similar to the use of steam in the previous period

– required a reliable source of water. The early power stations were thus built close to a water source. The municipal power stations in Sydney sourced water from the inlets of Sydney Harbour, and did not share the same water source as the urban water industry. By the 1890s, hydropower technology had made its way from England, and several stations were constructed to supply lighting to mines in remote areas. In the 1920s, additional hydropower plants were developed in NSW and some water storage dams, such as Burrinjuck Dam, served dual purposes of generating electricity and providing water (for town supply and irrigation). More generally, dams were considered symbols of nation building, progress and modernity.

Transportation

Groundwater extraction in rural areas increased during this period, because of cheap energy and improved well drilling techniques that were adopted from the energy industry. As with the previous period, groundwater was a significant source of water along stock routes and for domestic supplies, particularly during times of drought. An increase in the reliance on groundwater during drought, however, coupled with the rapid expansion of drilling programs, reduced the pressure and the flow of groundwater in some locations. Despite these problems, the concern for the environmental implications of using groundwater was overshadowed by the desire to develop inland areas.

In terms of surface water transfers, increases in the demand for water and recurring drought led to a spate of dam and storage reservoir constructions during this period in both urban and rural NSW. These projects increased energy demand in the water industry, because of the additional pumping required to transfer water. Whilst pumping stations during this period were largely powered by electricity, from 1931 the Board of Water Supply and Sewerage used steam pumps in winter, in order to reduce its electricity consumption, and therefore the cost was passed on to users. In other words, price was a determinant for the choice of energy.

In the early part of this period, sludge was transported within the Botany Sewage Farm using steam locomotion. Steam-powered pumping stations also transported water and sewerage to high- and low-lying areas respectively and were critical for the spread of these services in urban areas. Other operation methods were also utilised, including the oil engine, electric-motor drive and compressed-air ejection. With the spread of electricity in cities and towns, electricity became the modus operandi. The advent of electricity in the water industry improved operations by enabling automated and individual control of pumping stations. The increasing use of technology in the urban water industry also paralleled the establishment of the Board of Water Supply and Sewerage and the move towards engineering specialisation in the industry.

Downstream

Manufacturing industries continued to adopt steam power in the early part of this period and continued to require reliable sources of water to meet their growing energy needs. In addition, the electrification of households and the increased availability of household appliances increased water demand in the electricity industry.

4.3 Expansion and pressures for change (1940 to 1979)

During World War 2, investment in infrastructure was largely suspended as resources – including labour, expertise and funds – were channelled into defence projects (Aird 1961). When the war ended in 1945, the Federal government embarked on a program of national development. Keynesian economics underpinned much of this vision, and is based on the belief that government spending induces private spending, because it circulates money in the economy (Stilwell 2002). Soldier Settlement schemes were once again pursued as part of this program in an attempt to increase population and to develop inland areas (Clarke 2002). Infrastructure services including water and electricity were considered key to the success of this program. In order to cope with the backlog of projected demand for these services, the Federal government launched an ambitious immigration policy in 1947, targeting British and other migrants from war-torn Europe (Shaw 1966).

In the 1950s and 1960s, the economy grew strongly under protectionist policies. High employment levels and standards of living ensued, and urban centres expanded rapidly as a result of major housing developments (Cousins 2005). By the 1970s, economic instability began to set in. Unemployment and inflation increased significantly, ending thirty years of prosperity (Clarke 2002). Two global oil crises occurred in 1974 and 1979 and resulted in a five-fold and two-fold increase in the price of oil, respectively. Both crises exacerbated inflation and dampened economic growth in industrialised countries, including Australia (Lougheed 1988).

As before, exploitation of nature underpinned development in the early half of this period. In particular, nature was seen as having value only when manipulated, tamed or changed by humans (Doyle 2000). A shift in thinking began to develop in the 1960s that challenged this western worldview on development. Many have attributed this shift to American biologist Rachel Carson (1962) and her seminal work *Silent Spring*, which documented the environmental effects of pesticides. The subsequent decade brought greater awareness of the impact of development on the local Environment (Dovers 1994; Doyle 2000; Shaw 1966). Later, an international group of concerned scientists called the Club of Rome (1972) published *Limits to Growth*. The report concluded that Earth's resources were insufficient, if consumption and population growth rates at the time continued. This shift grew out of decades of material wellbeing post World War 2, after which time sections of society began to search for a higher meaning to life (Dovers 1994). Improving human interaction with the Environment became subsumed in this search. The implication for the water and electricity industries was greater public scrutiny of their environmental performance and construction projects, such as water storage dams.

4.3.1 Urban water industry

After World War 2, construction activity in the water industry increased significantly to deal with the backlog created by the war, and to service new housing areas that were being developed for the influx of immigrants. Projects to augment the industry's storage capacity were also initiated. In Sydney, construction of a new storage reservoir called Warragamba Dam began in 1946. Completed in 1960, Warragamba Dam has become Sydney's primary water source (Beasley 1988). This dam also produces hydropower from a 50-MW station when water levels are one metre below full storage (Sydney Catchment Authority (SCA) 2007). Within a decade of its completion, however, the water industry became concerned about Warragamba Dam's ability to meet demand by the mid 1970s. In preparation for this expected demand, work on the Shoalhaven Water Supply and Power Generation Scheme commenced in 1971. As the name suggests, the Scheme incorporates a hydro-electric power station, which generates electricity during times of high flow (Beasley 1988).

As with the previous two periods, water supply took priority over sewerage (Beasley 1988). Many areas, therefore, remained unsewered, causing extensive environmental damage and deterioration of water quality in metropolitan waterways (NSW Water Resources Commission (NSWRC) 1984). The introduction of developer charges[12] in the 1960s improved the situation.

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[12] A charge passed on to property developers to cover the cost of augmenting infrastructure in unserviced areas

By the 1970s, the ocean outfalls – the backbone of Sydney's sewerage system – were viewed as a public health and environmental threat. It was not until the early 1990s that the water industry modified the outfalls in an attempt to improve their environmental performance. Outfall pipes were extended by two to four kilometres so that the outlets were submerged in deep water (Beasley 1988). These improvements, however, were still opposed by members of the public, who viewed the projects as dumping toxic waste into the oceans without proper treatment (Beder 1992). In other parts of the country, treated effluent became an alternative source of water for outdoor non-potable uses. In South Australia, for example, treated effluent was used from the 1950s to irrigate playing fields, golf courses, and caravan parks (Hallows et al. 1995).

Despite the significant amounts of government funding injected into water projects during this period, the industry was not expected to cover all its costs. It was argued that the industry fulfilled important economic and social functions – such as improving public health and supporting national development – that justified public ownership. The external benefits derived from these functions, it was argued, would outweigh the costs (Johnson & Rix 1993; Powell, 1989 in Smith 1998, p. 166). This established costing practices, including subsidy provision. Subsidies were considered desirable by governments and 'generally reinforced the public perception that water is an essential commodity that should be readily available to all at low cost and in unlimited quantities, without any appreciation of the real cost of supply' (Department of Resources and Energy 1983, p. 73).

By the end of this period, three types of institutional arrangements had evolved in the water industry. The first, which emerged in NSW, comprised a mix of statutory and local government agencies. This arrangement also developed in Victoria and Tasmania. The second type comprised single jurisdiction agencies responsible for all water-related services within the state. South Australia, Western Australia, the Northern Territory and the Australian Capital Territory adopted this arrangement. The third type comprised predominantly local government administration, which occurred in Queensland (Johnson & Rix 1993).

4.3.2 Rural water industry

Similar to water supply and sewerage, developments in irrigation ceased during World War 2, as the nation's resources were channelled into defence projects. After the war, the Federal government once again established Soldier Settlement schemes with the states as part of the national development vision. Irrigation was viewed as critical to the success of these schemes.

From 1945 to 1950, post-war conditions were favourable for the expansion of irrigation, because of shortages of food and raw materials in Europe (Lougheed 1988). Water storage dams were constructed as part of this expansion until the 1970s and continued to symbolise progress and modernity (Hallows et al. 1995).

The Snowy Mountains Scheme represents one such dam project of national significance. Developed foremost as a hydropower project, discharge water from the Scheme enabled the creation of new irrigation areas and intensification of existing irrigation areas along the Murrumbidgee and Murray Rivers in NSW and Victoria (refer to Section 4.3.3 for further discussion). Diversions to the Murrumbidgee and Murray Rivers began in 1959 and 1966, respectively (Hallows et al. 1995). The economic benefits of irrigation alone would have been inadequate to justify the investment into the diversions, but the project received strong political and social support because of its role in furthering the national development program (Dovers 1994; McColl 1976; NSW Water Resources Commission (NSWRC) 1984). Irrigation infrastructure was therefore provided at no charge.

By the 1960s, water resources management – which had largely remained within state boundaries – began to take on a more national focus. In 1963, federal and state ministers formed the Australian Water Resources Council (AWRC) because of increasing concerns over the nation's water resources. One of the AWRC's first tasks was the commissioning of a comprehensive assessment of Australia's water resources, which was published in 1965. A year later, the AWRC established the National Water Development Program, in response to a severe drought in eastern Australia at the time. Additional water storage dams were constructed as part of this program, in order to provide security against this latest drought and to facilitate further agricultural expansion (Hallows et al. 1995).

Attitudes towards water projects began to change significantly in the 1970s. The public began to question the economic viability and environmental impacts of irrigation schemes, which were once considered symbols of progress and modernity. Salinity, water logging and the deterioration of ecosystems downstream of water storage dams prompted the public's environmental concerns. AWRC addressed these and other concerns in its second assessment report released in 1975, under a new water quality component. This marked an important step in recognising the environmental impacts of the water industry.

In 1977, the Federal government formed the National Water Resources Development Program. Under this program, projects to mitigate salinity and other environmental problems were established. Similarly, in 1973, the River Murray Commission had resolved to incorporate a water quality component into the River Murray Agreement. The revised Agreement came into effect in 1984 (Hallows et al. 1995).

The expansion of irrigation schemes during this period paralleled the expansion of groundwater use, particularly in South Australia and Queensland. Establishment of electricity networks – particularly after World War 2 – facilitated this growth, by providing access to grid power for pumping (Hallows et al. 1995).

4.3.3 Electricity industry

The electricity industry played a pivotal role in the Federal government's national development program after World War 2, which included the provision of cheap and reliable power. This role is epitomised by the joint development of the iconic Snowy Mountains Scheme by the Federal government and State governments of NSW and Victoria. This landmark project represented the Federal government's first significant involvement in the electricity industry, as described in more detail in Box 4–1.

Box 4–1 The Snowy Mountains Scheme

The idea of harnessing waters from the Snowy River was first mooted in the 1880s for irrigation, and later in 1915 for hydropower; nevertheless proposals for developing the river were only seriously considered after World War 2. At that time, the Federal government became concerned about the vulnerability of coastal thermal power stations to attack; the experience of war was still fresh in the minds of the populous (Collis 1990). The final proposal focused on hydropower generation; irrigation was considered a bonus (McColl 1976).

Construction of the Snowy Mountains Scheme commenced in 1949 and was completed in 1974. To this day, the Scheme comprises seven power stations with a total capacity of 3,740 MW, sixteen dams, one pumping station, and 225 kilometres of tunnels, pipelines and aqueducts (Australian Government 2007f). The Federal government financed its construction and electricity sales in NSW and Victoria contribute to recuperating the operating costs (Collis 1990).

By default, the Snowy Mountains Scheme became the first inter-state connection in Australia. Electricity is shared between NSW and Victoria in a two-to-one ratio, after the Australian Capital Territory's receives its allocation. In the early years, the cost of generating electricity from the Scheme was half the generation costs from thermal power stations in NSW and Victoria. Because of time differences, the interconnection also enabled peak demand in one state to be met by the other.

In addition to its key water and electricity functions, the Snowy Mountains Scheme played a pivotal role in shaping Australian society after World War 2. The project attracted many continental European migrants that left war-torn countries in search of better prospects. It is generally considered Australia's birthplace of multiculturalism, albeit of Caucasian origin (Clarke 2002). The coming together of new migrants and existing Australians helped – along with two World Wars – to forge an identity for Australia that until then had largely deferred to Anglo-Celtic Britain.

It can be argued that the conditions were conducive to the development of the Snowy Mountains Scheme, which would be difficult to replicate: a large workforce keen to establish itself in a new country; a national development vision underpinned by Keynesianism with Federal and State government support; general appreciation of the role of engineering in harnessing natural resources for development; and little understanding of the environmental impacts of large-scale infrastructure projects. Further, the Scheme developed a large technical skills base in Australia. To this day, companies associated with the construction of the Scheme continue to practice in the electricity and water industries.

The influx of immigrants from post-war Europe in the 1950s significantly increased the demand for electricity, which continued well into the following decades. High economic growth, improvements in the standard of living, and the spread of household electrical appliances furthered the demand for electricity in the 1960s. Newly established mineral processing industries such as aluminium smelting, and declining electricity prices until the mid 1970s also contributed to the growth in demand.

The oil shocks in 1974 and 1979 fuelled electricity demand further. Whilst Australia's total energy demand dropped significantly, demand for electricity increased because it became a substitute for expensive oil – electricity displaced oil for space heating and industrial power. The electricity industry itself was largely buffered from the effects of the oil shocks, because of its heavy reliance on coal and therefore limited exposure to oil prices (Electricity Supply Association of Australia (ESAA) 2003).

An important concept to emerge from the oil shocks was 'energy efficiency' (Bennett 1990). Even today, energy efficiency programs are integral to the electricity industry's demand management strategies and efforts to limit the growth of carbon emissions. The efficiency concept has also been adopted and widely applied in the water industry.

The increases in electricity demand during this period prompted investments to augment generation capacity. After World War 2, new investment was generally channelled into larger-scale power stations that were interconnected – partly for defence purposes – and located close to coal fields (Booth 2003). Long-distance transmission made this arrangement possible, which contrasted with previous investments in smaller-scale power stations located in high-demand metropolitan areas.

This change reflected changes to the structure of the electricity industry. In 1945, the Electricity Authority of NSW was constituted under the *Electricity Development Act*. The main responsibilities of this Authority were to develop electricity supplies and promote the use of power, which resulted in greater co-ordination in the industry. At that time, both state and local bodies generated electricity, whilst municipal councils almost exclusively distributed electricity (NSW Government 2008b). In 1950, however, the Authority established the Electricity Commission of NSW (ELCOM), which took over the generation and transmission functions of Sydney County Council. Development of new power stations was no longer limited to the jurisdictional boundaries of Sydney County Council. ELCOM, which supplied Sydney County Council and other municipal councils across the state, continued to distribute electricity to end users (Wilkenfeld & Spearritt 2004). The Authority was abolished in 1979 and replaced by the Energy Authority (NSW Government 2008c).

The change in investment was also prompted by improvements in the economies of scale and thermal efficiencies of larger generating units. By locating power stations close to the coalfields, coal transportation costs were greatly reduced, and these factors provided relatively low and stable electricity prices until the mid 1970s (McColl 1976).

The larger-scale power stations and coalmines diversified water usage in the electricity industry. Due to their location, the additional water demand created by the power stations began to compete with demands from agriculture. In addition, dewatering activities in coalmines became an additional source of water. However, these activities raised concerns over the contamination of existing water sources in adjacent areas (NSW Water Resources Commission (NSWRC) 1984).

By the late 1970s, the interconnected power stations had developed into statewide networks. The electricity industry began to plan for additional capacity, in preparation for an expected minerals boom in the subsequent decade, and at the same time, pressures for reform began to emerge. From the mid 1970s, the unit cost of electricity increased faster than inflation, due to increases in the cost of capital, fuel and labour. The industry had also maximised the economies of scale offered by the larger generation units (Electricity Supply Association Australia (ESAA) 1973). Lastly, the environmental movement – which had gained considerable momentum since the 1960s – challenged the environmental performance of the industry across the country. In 1973, the Hydro-Electric Commission of Tasmania flooded Lake Pedder in the South West National Park for the Upper Gordon Power Development project. The flooding sparked protests from environmental and community groups, who were outraged by the limited public consultation that took place, despite the natural significance of the location (Dovers 1994). These influences and others that emerged in the subsequent decade prompted initial reforms in the electricity industry.

4.3.4 Water-energy nexus

The water and electricity industries expanded rapidly during this period, because of the national development program pursued by the Federal government after World War 2. During this expansion phase, several factors influenced the evolution of the water-energy nexus, including the structure and pricing policies of the industries, technological choices, population growth and drought.

In terms of structure, both industries were largely controlled by the state, although some local government control existed in the water industry. Government ownership continued to be favoured over private ownership, because of the overriding belief at the time that governments were in a better position to make investment decisions in what were deemed risky infrastructure projects.

The water and electricity industries were viewed as critical for national development and therefore cost recovery was not a priority for either industry. This was reflected in the pricing policies that favoured cross-subsidies between customer groups and even between the water and electricity industries. The main priority of both industries was to augment supply in order to meet growing demand, as a result of the burgeoning domestic industries, and later the influx of immigrants after World War 2.

Advancements in technology – such as long distance transmission, larger generation units and water pumping – facilitated this expansion and further centralised the supply of both water and electricity, which complemented the state control. The role of the engineer was further entrenched, resulting in little consideration of the environmental impacts of water and electricity technologies, nor their end uses. Towards the end of this period, however, the environmental impacts of relentless development became apparent and the public soon made the industries accountable for their environmental performance.

The upstream, transportation and downstream links are now discussed in further detail.

Upstream

Construction of water-storage dams peaked during this period, in an effort to secure water supplies during drought and to meet the demands of the growing population. As before, many water storage dams fulfilled dual functions of water supply (both irrigation and town water) and hydropower generation. Both functions were viewed as critical for national development. Water storage dams were seen as fulfilling wider social and political objectives: in rural areas, Soldier Settlement schemes went hand-in-hand with the irrigation projects, and the expansion of urban areas as a result of the Federal government's migration policies after World War 2 required adequate supplies of water and electricity.

An iconic example is the Snowy Mountains Scheme which also represents the first involvement of the Federal government in the electricity industry. The Scheme was designed to supply hydropower to NSW, Victoria and the Australian Capital Territory and to provide irrigation water to NSW and Victoria (McColl 1976). The sale of electricity subsidised the cost of the irrigation infrastructure, and therefore masked the true value of the water provided for agriculture. Farmers who benefited from the irrigation infrastructure were only charged a water-usage fee, calculated by meters located at the farm gate (Lloyd 1988).

By the end of this period, segments of society began to protest against the construction of water storage dams, such as the Gordon Power Development in Tasmania, because of the environmental damage that they caused. This dissent sowed the seeds for an environmental movement in Tasmania that subsequently spread to the Australian mainland.

Earlier in 1952 when the NSW Government – under ELCOM – took control over the generation and transmission functions of the industry, investment in generation shifted from power stations in municipal areas to larger-scale units close to the coalfields. These power stations relied on a continual supply of water for steam production and cooling and were therefore located near water bodies. Whilst links between electricity and the rural water industries already existed – in terms of the use of energy to transfer surface water and extract groundwater – some of the inland locations of the power stations placed them in competition with irrigators. As long as there was sufficient water flowing in the rivers to meet the needs of all users, this competition lay dormant. Drought and environmental flow commitments have since led to trade-offs between both these coal-fired power stations and hydropower generators, irrigators and the Environment. In addition, the water produced from dewatering activities in coal mines adjacent to the power stations was identified as an alternative water source for reuse, but raised concerns over contamination of surrounding water supplies (NSW Water Resources Commission (NSWRC) 1984).

Transportation

The immigration policies of the Federal government post World War 2 expanded housing developments in NSW and in other states. These new housing developments increased the demand for infrastructure services, such as water supply, sewerage and electricity. Electrification of cities and towns greatly facilitated the expansion of water and sewerage networks, particularly for pumping water and sewage in high- and low-lying areas, respectively. Similarly, electrification facilitated the expansion of groundwater use in rural areas, as more areas became connected to the electricity grid, allowing for pumping.

Downstream

The oil shocks in 1974 and 1979 resulted in electricity displacing oil for space heating and industrial power. This additional demand for electricity would have been met by the large-scale coal-fired power stations that consumed water for steam generation and cooling. This demand therefore indirectly increased water consumption in the electricity industry. The oil shocks also introduced the concept of efficiency to the energy industry, which has since been adopted by the water industry. Efficiency programs have been instrumental in driving down demand for water and electricity, with direct and indirect effects for both industries (in terms of water embedded in electricity and electricity embedded in water).

4.4 Initial and contemporary reforms (1980 to 2007)

By the start of this period, there were emerging concerns about the state of the Australian economy which, it was argued, were due to structural problems. These structural problems, the argument continued, were the result of protectionist policies pursued by Australian governments in the post-war years to support the national development program (Productivity Commission 1999). This prompted the Federal government to evaluate the performance of the Australian economy overall, and in turn the role of infrastructure industries. The solution, it was reasoned, resided in the opening up of the economy based on free market principles. This entailed a move away from centralised, controlled structures to decentralised, market-based structures operating on commercial principles.

A further fillip to this thinking was provided by the ascent of market-based philosophies in the developed world, in particular in the United Kingdom (UK), New Zealand and the United States (US). The governments in these countries, especially the UK, had embarked upon a radical program to restructure their economies, including infrastructure industries; the water industry in the UK, for example, was privatised in 1989 (see Vickers & Yarrow 1988).

Against this backdrop, the Australian Federal and State governments embarked on a program of macroeconomic reform. This program emphasised the application of market-based principles, as enunciated in the National Competition Policy (NCP) in 1993. The Australian Competition and Consumer Commission (ACCC) and the National Competition Council (NCC) were formed to regulate and oversee implementation of the NCP. Significantly, the Federal government tied state funding to adequate progress in implementing the NCP (Productivity

Commission 2002). In doing so, it exercised its power under Section 96 of the Constitution, and for the first time began to exert considerable control over infrastructure industries, including water and electricity.

For the water and electricity industries, the move towards market-based measures entailed changes in their structure, ownership and regulatory arrangements (Industry Commission 1995). In terms of structure, the industries were functionally unbundled; competition was introduced in the competitive generation and retail segments and the monopoly segments became regulated to allow third party access. Ownership shifted towards the private sector, as many utilities were corporatised. Independent regulatory arrangements were also established for price, service delivery and environmental performance, in addition to existing health regulations for the water industry. In NSW the Independent Pricing and Regulatory Tribunal was established in 1992 to regulate price and service delivery of infrastructure industries, including water and electricity. In 2004, the Council of Australian Governments (COAG) reinvigorated the reform program, with the belief that further efficiency and productivity gains were possible.

Concomitant to the internal and wider reforms was a shift in the environmental movement, which began to take on a more global focus. Increasing concern about environmental problems, such as the state of world water resources, ozone depletion, global warming, and resource depletion culminated in the formation of the World Commission on Environment and Development (the Brundtland Commission) in 1987. Importantly, the Brundtland Commission's report, *Our Common Future*, introduced the concept of sustainable development, which has since been widely cited and applied. This definition, as stated in the report, is 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (1987 p. 43).

In 1988, the World Meteorological Organization and the United Nations Environment Program established the Intergovernmental Panel on Climate Change (IPCC) to assess the risk of human-induced climate change, its potential impact, and options for adaptation and mitigation. The First Assessment report of the IPCC (2004) formed the scientific basis for an international treaty titled the United Nations Framework Convention on Climate Change (UNFCCC), which was adopted in 1992. In 1997, many countries agreed to an addition to the treaty – the Kyoto Protocol – which introduced more powerful and legally binding measures. The Kyoto Protocol came into effect in February 2005 (United Nations Framework Convention on Climate Change (UNFCCC) 2007).

Since the adoption of the UNFCCC, scientific opinions have differed greatly about the validity of claims that human-induced climate change is occurring. In February 2007, IPCC's Working Group 1 Fourth Assessment Report quelled much of the scepticism, when it unequivocally concurred that global warming is occurring, and that the probability of it being caused by human emission of carbon is over 90 per cent (Working Group 1 IPCC 2007). A year earlier, the UK Government's Stern Review on the Economics of Climate Change and the documentary film *An Inconvenient Truth* (2006), were instrumental in raising popular interest in and awareness of climate change.

Australia did not initially ratify the Kyoto Protocol, because of the absence of the world's largest carbon emitters – China and India – from the treaty and concern over the wider impacts on the Australian economy. However, the Federal government under John Howard still committed to meet its target of 108 per cent of 1990 levels between 2008 and 2012 (ABS 2007). In 1998, the Federal and State governments agreed to a *National Greenhouse Strategy*, which became the primary mechanism through which this and other international commitments would be met. This agreement replaced the earlier *National Greenhouse Response Strategy* from 1992 (ABS 2007). In 2007, the Federal government passed the *National Greenhouse and Energy Reporting Act*, which established a single national framework for corporations to report their carbon emissions, abatement actions, and levels of energy production and consumption (Australian Government 2007c). This Act came into effect on 1 July 2008 and applies to corporations that exceed thresholds for carbon emission, energy consumption and energy production. It therefore is likely to apply to electricity generators and larger water utilities.

In January 2006, the Howard Federal government – in partnership with China, India, Japan, Republic of Korea and the United States – launched the Asia-Pacific Partnership on Clean Development and Climate (AP6), as an alternative to the Kyoto Protocol. Activities under AP6 were soon implemented[13] (Australian Government 2007a). Australia finally ratified the Kyoto Protocol when the Rudd Labor Government took office on 3 December 2007 (Rudd 2007).

In April 2007, the State and Territory governments commissioned Professor Ross Garnaut to examine the impact of climate change on the Australian economy, and to put forward policy

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[13] Canada joined AP6 on 15 October 2007 and AP6 was subsequently renamed APP.

recommendations to improve the 'prospects of sustainable prosperity'. The terms of reference for the Garnaut Review were to report on: the likely effect on the economy, Environment and water resources in the absence of effective strategies to reduce carbon emissions; the possible effects of international and Australian policy reforms and interventions and associated cost and benefits; Australia's potential role in developing and implementing effective international policies on climate change; and to recommend medium to long-term policy options based on the above research (Commonwealth of Australia 2008c).

The report recognises the links between water and energy, stating that 'water and energy are joined at the hip' (p496) and that future power stations could be air-cooled, or that future supplies could use seawater desalination from renewable supplies. This is an important acknowledgement, yet it does not reflect the complexity and trade-offs inherent in balancing the demand for water and electricity in a carbon-constrained world. The Garnaut Climate Change Review released its final report in September 2008.

This period of reforms coincided with some of the most severe droughts on record, including those of 1982-83 and 1994-95. Australia had experienced an extended dry period that commenced in 2001 and peaked in 2002-03, but during this peak period, almost the entire State of NSW – and much of the continent – was drought-declared (ABS 2007). In mid to late 2007, La Niña conditions – which are typically associated with increased rainfall – developed over the Pacific Ocean. The impacts of La Niña were initially countered by a climate pattern from the Indian Ocean, but by November 2007, NSW had experienced above-average rainfall (Bureau of Meteorology (BOM) 2008). This assisted in reducing the drought-declared areas in the state from 81.9 per cent in November 2007 to 69.4 per cent in December 2007 (State of NSW 2008). This latest drought has been particularly severe, because it was accompanied by record high average temperatures and consequently increased evaporation in many areas (ABS 2007).

4.4.1 Urban water industry

In the 1980s, the efficiency of the water industry was being questioned in terms of its financial, service and environmental performance (Broughton 1999). Firstly, water authorities, particularly statutory boards, were perceived to be overstaffed and subject to political pressures from State governments to maintain subsidy patterns and pricing structures. In the residential sector, price levels were tied to property values rather than water consumption. Furthermore, this sector was subsidised by the commercial and industrial sectors. It was also argued that the pricing structure offered little incentive for water conservation (Shadwick 2002).

Secondly, the industry was characterised by aging infrastructure and declining water quality. New infrastructure and improvements in maintenance were needed to reduce leaks and pollution incidents. Governments were, however, a less ready source of income (Productivity Commission 1999). The problem was compounded by the pricing structure, which did not charge for the full cost of water. The decline in water quality was also attributed to the vertical integration structure of water authorities – utilities regulated themselves and were thus less likely to punish or take action when quality levels declined.

Thirdly, environmental concerns necessitated a change from traditional supply-side to more demand-side solutions. It was argued that decades of supply-side solutions and a lack of understanding of environmental needs had led to severe degradation of land and water resources. Waterways were highly polluted, flow regimes had changed significantly and aquatic ecosystems were being degraded (Broughton 1999).

State governments realised that the water industry was in need of change and began to address the perceived shortcomings of the industry. This constituted the first phase of water industry reform (see Broughton 1999; Smith 1998). In 1984, the NSW Government commissioned the NSW Water Management Audit as part of the internal reform program. Implementation of the Audit recommendations was later reviewed in 1988 (NSW Department of Water Resources 1988). These recommendations signalled a shift towards more holistic water management to include economic, environmental and social goals, recognition of environmental requirements for water resources; and a more commercial focus for water service providers.

Despite these internal reforms, the Federal government began to evaluate the performance of the water industry as part of its wider program of microeconomic reforms being implemented by COAG. In 1994, COAG established the High Level Steering Group on Water and commissioned the Group to develop a national approach to water reform. The resulting report for the Water Reform Framework came under the umbrella of the NCP in 1995. That same year, Sydney's Water Board became corporatised and was renamed Sydney Water Corporation (Sydney Water). In 1998, Sydney Water's bulk water supply functions were transferred to the newly-formed Sydney Catchment Authority, after traces of *cryptosporidium* and *giardia* were found in Sydney's water supply that year and attributed to polluted runoff entering the catchment dams (Sydney Water 1999). This restructure – which separated the bulk and retail functions of the water industry – also complemented the goals of the Water Reform Framework.

In 2003, COAG reasoned that additional efficiency and productivity gains were possible in the water industry (Council of Australian Governments (COAG) 2003). It agreed to the National Water Initiative (NWI) the following year and established the National Water Commission to oversee the implementation of the NWI. Some of the key issues addressed by the NWI include establishing permanent water trading, securing access entitlements, ensuring water planning is cognisant of the interaction between surface water and groundwater systems, addressing over-allocation, and ensuring more efficient water management decisions in urban areas, such as increased use of recycled water and stormwater. A significant component of the NWI is the five-year $2 billion Australian Water Fund, which commenced in 2004. Three programs receive an allocation from the fund: Water Smart Australia, Raising National Water Standards, and Australian Water Fund Communities (Australian Government 2007e).

As mentioned previously, the reform of the water industry in recent years has been accompanied by widespread drought. While Australia's extensive water storages can tolerate drought conditions, the protracted dry period that accompanied the latest drought reduced water levels to record lows. In order to slow the draw-down rate of storage dams, State governments across the country began to implement mandatory water restrictions. These restrictions prohibited or limited water-intensive activities, such as watering gardens.

Drought and climate change have shifted the industry's emphasis from long-term conventional planning to adaptive management. In contrast to conventional planning, adaptive management entails a regular review of demand- and supply-side measures, to take account of best available knowledge and changing circumstances (NSW Government 2006).

This approach has been adopted in the NSW Government's Metropolitan Water Plan (MWP), which was released in 2004 and updated in 2006. The 2006 MWP outlines a range of measures to meet expected demand from the growing population, including: accessing deep water from existing dams; groundwater readiness; desalination readiness; water recycling; and water savings from demand management and efficiency programs (NSW Government 2006). On 25 June 2007, the NSW Government agreed to commence construction of the desalination plant, and double the capacity outlined in the 2006 MWP from 125 ML/day to 250 ML/day. The plant is expected to be complete by 2010 and will provide up to 15 per cent of Sydney's water supply

(Anon. 2007b). It is estimated that it will consume approximately 4 kWh/ML and will be powered by wind (Sydney Water 2007d).

These current influences – drought, climate change and population growth – are likely to increase the electricity demand of the water industry, because of the need to treat 'new' sources of water using advanced technologies that are typically more energy-intensive. Adoption of these technologies would therefore further contribute to climate change. Some carbon emissions may be offset by utilities adopting carbon neutral policies. Sydney Water, for example, plans to achieve carbon neutrality by 2020 (Sydney Water 2007b). However, fugitive emissions from sewage treatment plants such as methane and nitrous oxide have a higher global warming potential and are harder to control (Foley, Lant & Dolon 2008).

4.4.2 Rural water industry

In the 1980s, concerns were being raised about the efficiency of the water industry as a whole. In rural areas, assumptions underpinning the support for irrigation schemes were challenged. In particular, it was argued that the price of rural water was well below cost or free, and therefore revenue was inadequate for proper maintenance of irrigation schemes (Shadwick 2002). Pricing policies were also viewed as aggravating environmental problems, as they offered little incentive for irrigators to use water efficiently. Issues such as a decline in water quality, rise in watertables, increase in salinity, toxic algal outbreaks, degradation of ecosystems, and loss of biodiversity were viewed as consequences of inappropriate agricultural practices that were carried out over decades (High Level Steering Group on Water 1999). Problems in the industry were further compounded by a severe drought that affected eastern Australia in 1982-83. In addition, there was concern over the availability of water for the next 20 years, in the light of forecasted growths in urban population, agricultural production and development of major thermal power stations (Hallows et al. 1995).

As a result of these concerns, the Federal government commissioned a study to identify the major issues facing the water industry to the end of the 20th century. Titled *Water 2000* and released in 1983, the resulting report represented a shift in the management of the industry towards integrated water resource management. Efficiency of existing systems and multipurpose planning gained precedence over increasing water storage dam capacity (Hallows et al. 1995; NSW Water Resources Commission (NSWRC) 1984). In addition, the drought provided the impetus for the creation of limited water trading in NSW under the *Water*

Act, 1912, so that scarce water resources could be pooled to maintain the viability of irrigation districts. This represented a significant shift in the perception of water management, as initially, many viewed this trading as an end to equitable sharing policies, in order to further economic goals (Haisman 2005).

In the Murray-Darling Basin, changes were made to the River Murray Agreement, in recognition that environmental problems transcended state boundaries. In 1985, the Murray Darling Basin Commission replaced the River Murray Commission and the Murray-Darling Basin Ministerial Council was formed. In 1987, the new Council made amendments to the River Murray Agreement. This Agreement was subsequently replaced by a new Murray-Darling Basin Agreement in 1992 that put in place management of water, land and other environmental resources at a basin-wide level (MDBC 2007).

In 1994, COAG introduced the Water Reform Framework, which led to significant changes to the rural water industry. In particular, the Framework recommended allocating water for the Environment, separating land and water entitlements and establishing water markets to facilitate trading of entitlements. Proponents of this Framework believed that market mechanisms would lead to an efficient allocation of water, as water would shift to crops of a higher value (High Level Steering Group on Water 1999).

In 1998, a pilot interstate water trading project was established between NSW, Victoria and South Australia within the Murray-Darling Basin, in preparation for a permanent water market. Existing licences were honoured in the pilot project. In the past, however, irrigation schemes had over-allocated water, based on the premise that not all irrigators would make use of their licences every year. When the pilot scheme was implemented, dozer licences that had remained dormant over many years were reactivated and sold. Over-allocation became a significant hurdle, particularly because it coincided with appeals for water for environmental flows during the drought years (Young & McColl 2003).

This period therefore marked significant changes in the management of water, which culminated in the creation of the *Water Management Act, 2000*. This Act introduced a new framework within which to allocate water to the Environment and to entitlement holders. Under the Act, Water Sharing Plans were developed for each region, in order to set out allocation rules. The Act further separated access rights with use rights in order to facilitate trading; that is, water use approvals could be granted, even if there were no current access rights to the water (Haisman 2005).

In 2004, COAG attempted to refresh reforms in both the urban and rural areas with the introduction of the NWI. The NSW Government amended its new water management framework, in line with the NWI (NSW Government 2004). The NWI reaffirmed the commitment to establish permanent interstate water trading, to implement full-cost recovery policies, and to address over-allocated systems. COAG also agreed to a new Murray-Darling Basin Water Agreement, which set out arrangements for investing $500 million over five years, commencing 2004-05. The aim of the Agreement is to reduce the level of water over-allocation and achieve specific environmental outcomes in the Murray-Darling Basin. Water-recovery projects will receive first priority under the funding arrangements, and it is expected that recovered water will be set aside to improve environmental flows (Council of Australian Governments (COAG) 2001).

The Federal government pledged additional funding for the rural water industry when it introduced the National Plan for Water Security in January 2007. Under this plan, $10 billion has been allocated to further improve irrigation practices, to purchase water for environmental flows, and to improve the governance structure of the Murray-Darling Basin, among other initiatives (Australian Government 2007d).

4.4.3 Electricity industry

The 1980s were a turning point in the electricity industry. In the early 1980s, a massive construction program was pursued to meet demand from an expected mineral boom which did not occur. This program, it is argued, was carried out with little co-operation between states, leading to suboptimal investment decisions and overcapacity in the system. Cost overruns on several major construction projects and relatively low prices were blamed for the poor financial state of utilities (Booth 2003). The industry had established a policy of maintaining low prices that only covered operating costs, and therefore profit-making was not an imperative. As part of this policy, cross-subsidies occurred between customer groups, and commercial and small businesses, for example, heavily subsidised domestic customers in rural areas. Price cuts were also offered to encourage new industrial customers (Rosenthal & Russ 1988). In addition, a spate of industrial disputes in the early 1980s kept generators out of service after maintenance, resulting in power shortages and contributing to poor labour productivity. Many of these issues contributed to an increase in electricity prices in the mid 1980s and led to criticisms of inefficiency and 'goldplating'.

Against this backdrop, the State governments, particularly NSW and Victoria, began to address the perceived shortcomings of the industry, which constituted the first phase of reform. In NSW, the Energy Administration Act, 1987 established the Department of Energy to promote energy development in the state and to provide advice on pricing. This Department was restructured several times in the decade that followed (NSW Government 2008c).

ELCOM was reconstituted in 1982, and further changes were instigated in 1987 and 1989 (IEEE 2007). Improved performance and productivity was reported for the few years that followed (Booth 2003). In the retail end, the NSW Government took control of Sydney County Council from the municipal councils in 1989 and formed Sydney Electricity, which became a state-run corporation. In 1996, Sydney Electricity was renamed Energy Australia (IEEE 2007).

Despite these internal reforms in the 1980s, the electricity industry soon became an integral part of COAG's microeconomic reforms in the 1990s when it came under the banner of the NCP. In 1992, ELCOM was separated into six operating units, was corporatised and began trading as Pacific Power (IEEE 2007). This new structure facilitated competition in the wholesale and retail segments of the industry. To promote further competition, Pacific Power's three generation operating units were split in 1995 into three separate entities: Delta Electricity, Macquarie Generation and Pacific Power. The transmission operating unit was also separated and renamed Transgrid. In the retail end, the 25 county councils that supplied retail electricity across the state were amalgamated into six entities (IEEE 2007).

Whilst the states were reforming their electricity industries under the direction of the NCC, the Federal government in 1993 formed the National Grid Management Council (NGMC) to commence operation of a simulated national electricity market. In 1997, the National Electricity Management Company (NEMMCO) replaced the NGMC and the National Electricity Code Administrator (NECA) was established to enforce the newly-approved National Electricity Code (NEC) (Rann 1998). Finally in 1998, a full National Electricity Market (NEM) commenced, but not without opposition to the complex process that preceded its design and establishment (see Booth (2003) and Spoehr (2003) for further details).

Earlier in 2001, COAG attempted to refresh the reform program, by outlining the development of a national energy policy framework and establishing the Ministerial Council on Energy (MCE). The MCE was set a series of priority tasks, including examining future energy scenarios, opportunities for increasing interconnection and system security for electricity and gas, and potential for harmonising regulatory arrangements (Council of Australian Governments (COAG) 2001). In 2004, the Federal Government released its energy policy white paper titled *Securing Australia's Energy Future* that continued to promote the benefits of a national electricity market, such as 'price signals' to encourage new supply investment and energy efficiency. The Australian Energy Market Commission and the Australian Energy Regulator were established to oversee this priority (Energy Task Force 2004).

In late 2004, the NSW Government released its *Energy Directions Green Paper,* in an effort to facilitate public discussion about aspects of energy policy and further reform proposals. Greenhouse gas emissions, planning requirements, price regulation and government investment were identified as important areas requiring clear policies, in order to minimise uncertainty, and thereby encourage private investment in the industry (New South Wales Government 2004). More recently the NSW Government commissioned an inquiry (Owen Inquiry) into electricity supply in the state in May 2007. The purpose of the inquiry was to determine the need and timing for baseload generation, and to assess technological options to provide this additional baseload capacity (New South Wales Government 2007). The findings of the Owen Inquiry, released in September 2007, recommend improvements to the commercial and policy signals in the industry, in order to facilitate private investment in baseload generation, which the Inquiry suggests will be required from 2013-14 (Owen 2007).

The objectives of improving efficiency and productivity in infrastructure industries underpinned much of the reform program in the last decade or so, but the massive restructuring and down-sizing of utilities that ensued came with a social cost. From conversations with several employees or their family members, this period represented a time of great instability and uncertainty and appears to have placed great stress on employees across the operating units of the previous Pacific Power. The widespread reform program initiated by COAG is reported to have increased GDP by $1.5 billion per annum (Energy Task Force 2004), although independent studies, however, have challenged this claim and instead offer alternative arguments for GDP growth unrelated to the reform program (see Fathollahzadeh (2005) for example). Sharma (2003) further argues that the market-based structures introduced by reforms have emphasised the economic dimension of the industry, at the expense of other dimensions, such as social and environmental. The NCC nevertheless maintains that the public interest – such as social welfare, the Environment and regional development – is considered when reviewing competition laws (National Competition Council (NCC) 2007).

A shift in environmental awareness also impacted the industry during this period. The Hydro-Electric Commission's (HEC) decision to dam Lake Pedder in south west Tasmania in 1973 for hydroelectric power generation created significant dissent amongst local environmentalists (The Wilderness Society 2007; Walker 1994). When Stage 2 of the project – the Franklin Dam – commenced in the early 1980s, the environmentalists launched a 'No Dams' campaign that reached the Australian mainland and subsequently the international stage. Work on the Franklin Dam project ceased when the Hawke Labor Government took office in 1983 (Dovers 1994; Hutton & Connors 1999).

In more recent years, the Federal and State governments have implemented policies to reduce carbon emissions in the industry. The national Mandatory Renewable Energy Target (MRET) came into effect on 1 January 2001. Under MRET, 9500 GWh of electricity (approximately two per cent) must be generated from renewable energy sources by 2010 (Commonwealth of Australia 2003b). In December 2007, COAG agreed to extend MRET to 20 per cent of electricity from renewable energy by 2020 (Commonwealth of Australia 2008d). In 2003, NSW began implementing the world's first mandatory carbon emissions trading scheme, called GGAS. It is envisaged that GGAS will transition to the National Emissions Trading Scheme (NETS) in 2010 (Department of Water and Energy (DWE) 2008).

Concomitant to the increase in awareness of climate change has been the occurrence of an extended drought which began in 2001. The drought had significant implications for electricity generators across the country. Water shortages reduced the generation output from several power plants across the country, and significantly influenced investment decisions in the industry, as well as the wholesale price in the NEM.

4.4.4 Water-energy nexus

The water and electricity industries underwent significant changes during this period. The NSW Government set out to reform both industries in the 1980s. In the 1990s, these internal reforms were subsumed under the Federal government's wider microeconomic reform agenda. The reforms lent a more economic focus: both industries were functionally unbundled;

competition was introduced in competitive segments in order to encourage private investment; and monopoly segments were opened to third-party access. The reform of both industries continues under the auspices of COAG at the Federal level, whilst implementation occurs at the state level.

In more recent years, environmental concerns of a more global nature – that emerged over two decades ago – began to permeate the reform agenda. Climate change is now widely recognised as the single most important issue for the future of the water and electricity industries. The recent drought and mandatory water restrictions have reinforced the profound impact that climate change may have in the future. Collectively, these issues have also reinforced the links between water and electricity. The water industry has shifted towards adaptive management in order to cope with uncertainty inherent in climate change and drought. More energy-intensive technologies are becoming important elements of such strategies, but counter carbon neutral and other policies to mitigate the water industry's contribution to climate change. In the electricity industry, mandatory renewable energy targets and carbon trading schemes have been established and are examples of climate change mitigation measures. When introduced, the *National Greenhouse and Energy Reporting Act* will apply to medium and large-scale organisations, including water and electricity utilities. This Act will focus the attention of businesses on their contribution to carbon emissions. Embedded generation technologies are enabling water utilities to generate electricity, to participate in carbon trading schemes in the future, and to contribute to renewable energy targets.

Chapter 2 comprehensively discusses the links that have emerged between the water and electricity industries in recent years. The section below reintroduces links that are relevant to NSW for the benefit of the reader.

Upstream

Water is critical for electricity generation. Drought, particularly in 2007, has severely impacted generation output in the electricity industry. In order to cope with the drought, generators have transferred their output from inland power stations in regions experiencing drought, to coastal plants that source water from estuarine lakes. Generators have also diversified their water sources in order to secure their water supplies. These sources included water from nearby mines, treated effluent, and extraction of additional river water normally reserved for periods of high flows.

A related issue is shared water resources and the potential for trade-offs during drought. Increases in river extractions by generators reduce the amount of water available for downstream users, such as irrigators. The case of the Snowy Mountains Scheme – as discussed in Chapter 2 – demonstrates this clearly. Drought has reduced the amount of water available to improve the health of the Snowy River, to supply irrigation schemes in the Murray and Murrumbidgee Rivers, and to ensure adequate environmental flows for these rivers. Drought has also reduced the amount of water that Snowy Hydro can use for hydropower generation to fulfil its contractual obligations to customers, as well as provide peak power to the NEM. There have also been claims that in 2007, Snowy Hydro released irrigation water to rice farmers in NSW, at the expense of future hydropower generation in Victoria (Egan & Dowling 2007). As stated in Chapter 2, despite the veracity of these claims, they highlight potential tensions between water users. In another case in 2007, despite water restrictions in Queensland, cheaper electricity was imported from Queensland to NSW via the NEM, tapping into already low drinking-water supplies in Queensland. NSW, however, had sufficient electricity generation capacity to meet its own demand.

Electricity prices in the NEM reached record highs in 2007, which is attributed in part to the drought. Whilst it can be argued that these high prices are the normal workings of the market and would stimulate investment in technologies to secure water supplies, an alternative argument is that more integrated planning between the water and electricity industries may lead to more sustainable outcomes.

In terms of other upstream links, alternative energy generation, such as hot dry rock technology, is currently under investigation in NSW. This technology recycles surface water through an engineered aquifer in order to capture heat from rocks. This technology therefore requires sufficient water to initially start the system and make up for normal losses, which are estimated at ten per cent of water volume (Boyle 2004).

Seawater desalination became part of Sydney's water management strategy in the early 2000s. Initially it was only a drought-readiness strategy, but in 2007 the NSW Government decided to proceed with the project, and awarded the construction contract for the plant. Whilst it will be powered by wind, the energy consumption of the plant is significantly more than other treatment technologies, including conventional wastewater-treatment processes.

Transportation

The energy cost of moving water is also likely to increase because of drought, and, in the longer-term, climate change. In 2005, it was reported that the price of groundwater in the Australian rural water market was cheaper than surface water. This would have increased the demand for groundwater, and in turn electricity. Similarly, over the last five years approximately 70 per cent of Sydney's water supplies have originated from the Shoalhaven and Kangaroo River in southern NSW. These surface transfers have increased the amount of electricity consumed by the water industry for pumping.

In terms of water distribution, the increasing use of rainwater tanks – as part of demand management and integrated water-cycle management strategies – increases electricity consumption, because household pumps are generally less energy-efficient than commercial models used in pumping stations (refer to Table 2-3). Therefore, efforts to harvest rainwater may have the unwanted consequence of increasing carbon emissions.

Downstream

Technological choices determine the amount of electricity consumed to treat water and wastewater. These choices in turn are influenced by environmental policies and water supply strategies. For example, increasing the use of treated effluent – in order to reduce the reliance on drinking water supplies – requires advanced treatment processes such as membrane bioreactors and reverse osmosis. These advanced processes are more energy-intensive than conventional processes and would require utilities to further their efforts to reduce carbon emissions, in order to achieve carbon neutral goals. Use of clean energy however, may assist in offsetting these increases in emissions; for example, Sydney Water is combusting methane that is produced from the anaerobic digestion of sludge and is installing microhydro turbines.

Changes to pricing structures in both the water and electricity industries may influence consumption patterns of end users. Compared to international prices, water and electricity prices in Australia have been historically low. In the case of water, prices were tied to the size or value of properties. The recent reforms have introduced volumetric pricing which – at a price elastic level – is likely to reduce consumption of water and electricity, with indirect flow on effects for the other resource. Demand management programs and efficiency programs being implemented in both industries will have a similar effect. As previously mentioned, the efficiency concept was first introduced in the energy industry after oil shocks in the 1970s and was later adopted by the water industry.

4.5 Summary and conclusion

The water and electricity industries are historically intertwined. Each has been critical for the development of the other and for the wider Australian economy. Table 4-1 summarises the historical links for each time period according to the dimensions that they represent.

In summary, it is observable that:

- The various dimensions of the nexus do not act in isolation, but instead their interaction has influenced the evolution of the nexus. This is particularly the case for the technological, political, economic and social dimensions. Australia continued its strong affinity with Mother England after the establishment of the Federation in 1901, and this cultural affinity was also apparent in both the water and electricity industries, which adopted technologies from the UK and relied heavily on the expertise of British engineers. By the mid to late 1900s, Australia had begun looking towards the US in a similar manner. The recent microeconomic reforms that have underpinned many of the changes in both the water and electricity industries drew inspiration from the philosophies of the UK and US governments in the 1980s.

- There have been similarities in the institutional development of both industries: small private companies operated in the early years of both industries, which later transitioned to government ownership, largely at state level. This paralleled the development of large-scale centralised systems that extended beyond local or municipal boundaries. In the early periods, intergovernmental agreements over water resources, in particular the Snowy River and the Murray-Darling Basin, represented the first forms of intergovernmental cooperation in both industries. In the last period, the microeconomic reform agenda cemented Federal government involvement in both industries. In the latest period, the reforms instigated by the Federal government through the Council of Australian Governments have brought about interstate trade of electricity and water via the NEM and the rural water market.

Table 4-1 Summary of the water-energy nexus profile

Dimension	**Period 1: Until 1888**	**Period 2: 1890 to 1939**	**Period 3: 1940 to 1979**	**Period 4: 1980 to 2007**
Political	Regulated private operators and government-owned utilities prevalent.	Shift towards public ownership and coordination: the role of government was to develop infrastructure industries that would in turn encourage private investment in the economy. Section 96 of the Constitution confers power to Federal government to make grants to states for specific purposes – exercised later. **T:** Soldier Settlement schemes post WW1 encourage irrigation and increase reliance on groundwater.	Increasing Federal government intervention. Soldier Settlement schemes post WW2 form part of Post-War Reconstruction Scheme and the national development program. Infrastructure development is key to their success. Immigration policies prompt expansion in both industries. **U:** Snowy Mountains Scheme further reinforces the link between electricity and rural water industry. It brings together Federal and State governments of NSW and Victoria.	Entrenchment of Federal government involvement. Implementation of similar microeconomic reforms in both industries under Section 96 of the Australian Constitution. Towards the end of the period, regulated private operators again deliver water and energy services. Mandatory renewable energy targets and carbon trading schemes change the operating Environment of both industries.
Economic	Early private operators with a trend towards government ownership. Early dominance of market economics and Victorian aversion to public spending. ***D:** Energy security needs prompt investment in the water industry.*	Increased government ownership paralleled increase in protectionism in the economy at large. ***T**: Cheap oil and gas prices increase groundwater extraction.* ***T**: Urban water industry uses steam for winter pumping to save on electricity costs.*	Keynesianism adopted to stimulate economy and develop water and electricity infrastructure: subsidies politically desirable, cost recovery not a priority. **U:** Snowy electricity sales subsidise irrigation diversions. **D:** Subsidy patterns develop in both industries for similar social and political reasons. **D**: Electricity displaces expensive oil after Oil Shocks and indirectly increases water demand.	Return of market mechanisms as part of microeconomic reform, in order to improve competitiveness of the Australian economy. Mandatory renewable energy targets and carbon trading schemes make it cost effective for water industry to reduce carbon emissions. **U:** Electricity industry suffers significant financial losses as water shortages cut generation. **U:** Wholesale electricity prices increase due to water shortages. **U:** Cheap energy diverts water from water-scarce regions via market and impacts on urban water industry. **U:** Use of recycled water set to increase electricity generation costs. **T:** Groundwater cheaper than surface water in rural water market. **T:** Drought increases water transfers.

Notes: *Italics: non-electric energy sources*; U: Upstream; T: Transportation; and D: Downstream (Continued on the next page)

Table 4-1 Summary of the water-energy nexus profile (continued)

Dimension	**Period 1: Until 1888**	**Period 2: 1890 to 1939**	**Period 3: 1940 to 1979**	**Period 4: 1980 to 2007**
Technological	From decentralised to small-scale centralised systems. Emergence of the role of engineers towards the end of the period. ***T:*** *Steam pumps distribute urban and rural water and save the colony from shortages.* ***T:*** *Windmills pump groundwater in rural areas.* ***D****: Use of steam power in manufacturing provides impetus for improving security of water supply.*	Shift towards centralised systems concomitant with increased government control and ownership. Role of engineer is entrenched. **U:** Early power stations are built adjacent to demand centres and do not share same water source as urban water industry. **U:** Hydropower technology enables water storage dams to serve dual purposes, establishing links between electricity and rural water industry. ***T:*** *Steam pump, and oil and gas engines installed in water supply and sewerage schemes.* **T:** Electric pumps eventually replace steam pumps and allow for automated control of pumping stations. ***T:*** *Groundwater use expands due to import of improved drilling techniques from energy industry.* **D**: *Steam power* and electricity demand by end users increases rapidly, requiring water.	Technological innovation enables large-scale centralised systems. **U:** Water storage dams continue to serve dual purposes. **U:** Snowy Mountains Scheme links two important infrastructure services – electricity and irrigation and provides first inter-state connection. **U:** State government builds power stations close to coal fields and places power generation in competition with rural water industry. **U:** Coal mines provide alternative water source. **T:** Groundwater use expands as more areas obtain grid connection. **D:** Electricity industry adopts energy efficiency concept after Oil Shocks. Water industry adopts it later.	Large-scale centralised systems continue to play a role, along with the ascent of decentralised systems. Shift from engineering domain to more multi-disciplined, dominated by economics. **U:** Generators diversify water supplies to guard against drought. **U/D:** Adaptive management strategies such as desalination and water-recycling are energy-intensive. **T/D:** Both industries pursue efficiency and demand management programs. **D:** Integrated water cycle management strategy of using rainwater tanks likely to increase electricity consumption.

Notes: *Italics: non-electric energy sources*; U: Upstream; T: Transportation; and D: Downstream (Continued on the next page)

Table 4-1 Summary of the water-energy nexus profile (continued)

Dimension	Period 1: Until 1888	Period 2: 1890 to 1939	Period 3: 1940 to 1979	Period 4: 1980 to 2007
Environmental	Enlightenment attitude of harnessed resources for development. Focus of concern is public health impacts.	Environmental exploitation for development continues. **T**: Rapid expansion of groundwater use facilitated by energy industry creates environmental problems.	Environmental performance of the industries questioned towards the end of this period. Environmental issues are local in nature. **U:** Environmental impact of the industries is scrutinised, e.g. damming of Lake Pedder in Tasmania. **U:** Concern over contamination of water supplies from coal mines.	Environmental issues – such as drought and climate change – are more regional and global in nature and reinforce the links between water and energy. Parallels the entrenchment of Federal government involvement, which may be more suited to handle such issues. Water industry adopts 'adaptive management' to cope with drought and climate change. This entails the use of more energy-intensive technologies. **U:** Franklin Dam stopped in .1983 **U:** Environmental flows compete with electricity generation and irrigation.
Social	Water supply and electricity a status symbol, with the latter also a novelty.	**U:** Water storage dams for water supply and electricity generation fulfil important social and political objectives.	**U:** Snowy becomes an important symbol of a new Australia after war. Birthplace of multiculturalism.	Social attitudes towards resource consumption changing with the ascent of the 'sustainable development' paradigm and climate change. Decentralised systems offer community more opportunity to determine water and energy supply.

Notes: *Italics: non-electric energy sources;* U: Upstream; T: Transportation; and D: Downstream

- The pricing policies of both industries have followed similar trends; from regulated private operators, subsidised supply by government-owned utilities, to a return to regulated private operators with a focus on full cost recovery. There are links between the use of one resource and the price of the other; for example, the water industry has in the past resorted to steam power for winter pumping in an effort to save electricity; the cheap price of groundwater relative to surface water increased pumping costs; and drought dramatically increased electricity prices in the NEM in 2007.

- Each industry greatly facilitated the development and expansion of the other, particularly in the first three time periods: water was critical for steam power and later for electricity generation; electricity facilitated the transportation of water and therefore assisted in expanding water supply and sewerage networks. The water industry adopted many ideas that first developed in the energy industries, such as well drilling techniques and the 'efficiency' concept.

- The expansion of both industries has strong political connections. In the case of the electricity industry, coal-fired generation became the technology of choice, due to the abundant indigenous reserves of black coal in NSW. Governments developed transmission networks to support the development of these stations, with the effect of 'locking in' coal-fired generation in the electricity industry to this day. Similarly, the rural water industry received significant government support, because of the importance of developing agriculture in inland areas, as part of national development efforts. This had the additional affect of moving a portion of the population to inland regions from major coastal cities.

- Drought has been a common factor in all four time periods. It has stimulated investment in both industries, as they sought to secure their water supplies. Historically, electrification enabled drought proof measures to be pursued in the water industry by transporting water from further afield and from below ground. In contrast, the recent drought has widely affected electricity generation which also needs to compete for water with other users, including the water industry itself.

- The recognition of climate change has lent an environmental focus to recent forms in both industries. Government policies and programs that promote renewable energy and carbon trading have increased awareness of the energy consumption within the water industry and opened up new opportunities for both industries

- There is a strong social dimension to the water-energy nexus. This is evident in the role that both industries fulfilled in the development of Australia; an iconic example is the Snowy Mountains Scheme. Social policies such as national development and immigration led to the expansion of both industries, which continued as social aspirations – including higher standards of living and increasing use of appliances – were fulfilled. More recently, decentralised systems – such as rainwater tanks and embedded generation – offer society greater input into the industries.

It is evident that the water and electricity industries do not exist in isolation: their histories parallel the development of Australia and each other, throughout which they have become further intertwined, due to common factors influencing both industries in recent years, including microeconomic reform, drought and climate change. The findings from the historical analysis presented in this chapter shed light on the broader trends and interactions between water and electricity, some of which can be validated through empirical analysis and are the subject of the next chapter. Conversely, the findings from the historical analysis could also provide points for validating the findings from the empirical analysis.

Chapter 5

Water-energy nexus: an empirical investigation (I)

Civilization has been a permanent dialogue between human beings and water

Paolo Lugari

The existing water-energy studies reviewed in Chapter 2 offer useful insights into the nature of the nexus. As discussed in Section 2.4, however, the studies do not comprehensively model the links between the water and the electricity industries, nor do they account for the interactions between the two industries and the wider economy. The purpose of this chapter therefore is to empirically investigate these links for NSW. The historical analysis in Chapter 4 complements the empirical investigation, by offering additional insights into the quantitiative findings.

The investigation is based in part on the development of water and energy-oriented input-output models for 1996 and 2001, and the calculation of price elasticities for five time periods between 1993-94 and 2004-05. Both methods – which are described in detail in Sections 3.4 and 3.5 – will provide useful and complementary insights into the links between water, electricity and the other sectors in NSW.

The investigation is divided into two chapters, of which this chapter comprises the first part. Section 5.1 presents a background to the NSW economy by examining the links between the sectors and describing some of the structural changes that have occurred in the recent past. This section also identifies the key sectors driving economic growth, and describes the role of the water and electricity industries in the economy. Section 5.2 quantifies the direct and total water intensities for the energy sectors. It also compares the water intensities for the electricity sectors more specifically with recently published reports. Similarly, Section 5.3 quantifies the direct and total energy intensities for the water sectors and compares the results with other published data.

Chapter 6 comprises the second part of the empirical investigation. It focuses on the interaction between water and energy in the remaining 19 sectors in the NSW economy, which are divided into the following six major sectoral groups: Agriculture, Mining, Manufacturing, Construction, Transport and Services. As detailed in Chapter 2, the links between water and energy extend beyond the boundaries of the industries themselves. Chapter 6 therefore aims to identify the major interactions between water and energy within these other sectors. The introductory paragraphs of Chapter 6 provide a more detailed description of its structure.

5.1 Exploring the sectoral links in the NSW economy

In order to gain a deeper appreciation of the links between water, energy and the wider economy, it is first necessary to understand the structure of the economy and to identify the role of various sectors within it. These roles may be identified using linkage analysis, which is based on the Leontief and Ghosh monetary models. Linkage analysis identifies the extent to which a sector stimulates economic production by consuming outputs from other sectors, and the degree to which a sector's outputs are used as inputs by other sectors. These relationships are termed backward and forward linkages, respectively. Together, the backward and forward linkages identify the key sectors that drive growth in any given economy, and offer insights into the roles of the different sectors. Section 3.4 provided a theoretical description of linkage analysis and the equations used to derive the backward (U_j) and forward (U_i) linkage indices, and the coefficients of variation (CoV). An important point to note is that the linkages are based on the interactions between the production sectors, and therefore do not consider the reliance on primary input categories, such as Labour, water extracted directly from the Environment, energy imports, and primary energy sources.

Table 5-1 lists the backward and forward linkages, corresponding CoVs and ranks for the sectors for both 1996 and 2001. The results are also pictorially presented in Figure 5–1, which shows the number of sectors with strong backward and/or forward linkages and the major sectoral groups to which they belong. There are three other major sectoral groups in addition to the six previously mentioned: Electricity, Water and Gas. The numbers in brackets in Figure 5–1 indicate the number of sectors that have linkages greater than one, and whose CoV value is relatively high (that is, above average). The linkages between these sectors and the economy are not evenly spread, and therefore these sectors are not considered when identifying key sectors. The sections that follow examine the results for the electricity sectors, water sectors, and lastly the other major sectoral groups. The linkages are also compared with structural trends that are evident in each of the major sectoral groups.

Figure 5–1 Breakdown of sectors with strong backward and/ or forward linkages

Table 5-1 Sectoral backward and forward linkages for 1996 and 2001

			1996						2001					
			Backward linkages (U_j)			Forward linkages (U_i)			Backward linkages (U_j)			Forward linkages (U_i)		
Sector			**Uj**	**CoV**	**Rank**	**Ui**	**CoV**	**Rank**	**Uj**	**CoV**	**Rank**	**Ui**	**CoV**	**Rank**
1	Ag	Agriculture	1.01	3.96	15	0.89	4.07	19	1.02	3.71	16	0.90	3.99	19
2	COAL	Coal Mining	0.78	4.60	25	0.87	3.60	20	0.82	4.24	26	0.84	3.82	22
3	OMS	Other mining & services to mining	1.09	3.70	10	1.06	3.26	15	1.08	3.42	11	0.95	3.62	18
4	FBT	Food, beverages & tobacco	1.18	3.38	7	0.67	5.15	28	1.12	3.43	6	0.72	4.85	28
5	TCFL	Textile, clothing, footwear & leather	0.98	4.09	20	0.73	4.77	27	0.93	4.07	23	0.76	4.57	26
6	WPP	Wood, paper and printing products	0.99	4.01	17	1.05	3.30	16	1.06	3.91	13	1.17	3.29	10
7	PR	Petroleum refining	0.77	4.98	26	1.31	3.07	5	0.76	4.92	31	1.44	2.87	2
8	PCP	Petroleum & coal products *	1.09	3.32	9	1.71	2.24	1	0.69	4.99	32	1.62	2.30	1
9	CHEM	Chemicals	1.25	3.78	4	1.17	3.47	8	1.03	4.13	15	1.04	3.73	16
10	NMMP	Non-metallic mineral products	1.20	3.36	6	1.13	3.16	12	1.08	3.66	10	1.04	3.60	15
11	BMP	Basic metals & products	1.28	3.71	2	1.09	3.76	14	1.18	3.80	3	0.99	4.14	17
12	FMP	Fabricated metal products	1.26	3.35	3	1.20	2.98	6	1.17	3.32	4	1.15	3.05	12
13	TE	Transport equipment	1.08	3.67	11	0.86	4.03	22	1.03	4.03	14	0.86	4.44	20
14	OME	Other machinery & equipment	1.10	3.68	8	0.87	3.97	21	0.86	4.40	25	0.84	4.10	23
15	MM	Miscellaneous manufacturing	1.20	3.01	5	0.64	4.84	29	1.00	3.50	18	0.73	4.39	27

Legend

🟦 Strong backward linkages 🟪 Strong forward linkages

Source: Derived from the Leontief and Ghosh monetary models as described in Section 3.4 (continued on to next page)

Table 5-1 Sectoral backward and forward linkages for 1996 and 2001 (continued)

			1996						2001					
			Backward linkages (U_j)			Forward linkages (U_i)			Backward linkages (U_j)			Forward linkages (U_i)		
Sector			Uj	CoV	Rank	Ui	CoV	Rank	Uj	CoV	Rank	Ui	CoV	Rank
16	CF	Coal-fired	0.97	4.05	21	1.15	2.92	11	1.11	3.39	7	1.18	2.90	8
17	GT	Gas turbine	1.04	3.97	12	1.15	2.89	9	1.07	3.72	12	1.17	2.84	9
18a	IC	Internal combustion (1996 only)	1.71	3.53	1	1.15	2.89	10						
18b	CC	Combined cycle (2001 only)							1.37	3.00	1	1.18	2.87	7
19	CG	Cogeneration	0.72	4.95	30	1.64	3.06	2	0.79	4.37	29	1.28	2.79	5
20	HYDRO	Hydropower	0.66	5.37	32	1.11	2.79	13	0.80	4.33	27	1.15	2.80	11
21	OR	Other renewables	0.74	4.82	29	1.18	2.65	7	0.80	4.33	28	1.19	2.73	6
22	GAS	Retail gas supply	0.68	5.40	31	1.41	2.35	3	0.98	3.81	20	1.43	2.36	3
23	IDW	Irrigation and drainage water	0.93	3.82	22	1.34	3.26	4	1.28	2.90	2	1.34	3.24	4
24	BRW	Bulk and retail water	0.76	4.67	27	0.82	3.73	23	0.98	3.59	21	0.85	3.72	21
25	SEW	Sewerage	0.74	4.79	28	0.57	5.37	31	0.94	3.70	22	0.58	5.48	32
26	CONST	Construction	1.00	3.58	16	0.78	4.10	24	1.10	3.17	8	0.62	5.18	30
27	WRT	Wholesale & retail trade	0.98	3.89	19	0.75	4.31	25	1.09	3.55	9	0.81	4.14	24
28	TS	Transport & storage	1.04	3.89	13	0.89	3.86	18	1.13	3.60	5	1.10	3.33	13
29	FPBS	Finance, property & business services	0.93	4.76	23	0.97	3.94	17	0.93	4.88	24	1.05	4.00	14
30	GAD	Government administration & defence	1.03	3.60	14	0.57	5.48	30	1.01	3.66	17	0.65	5.10	29
31	EHCS	Education, health & comm. services	0.82	4.40	24	0.57	5.48	32	0.78	4.47	30	0.59	5.43	31
32	OCS	Other commercial services	0.99	3.82	18	0.73	4.42	26	0.99	3.74	19	0.78	4.33	25
Average CoVs				4.06			3.72			3.87			3.75	

Legend

🟦 Strong backward linkages 🟪 Strong forward linkages

Source: Derived from the Leontief and Ghosh monetary models as described in Section 3.4 (continued from previous page)

5.1.1 Electricity sectors

As previously mentioned in Chapter 3, the electricity industry is disaggregated into six sectors: Coal Fired (CF), Gas Turbine (GT), Internal Combustion (IC, 1996 only), Combined Cycle (CC, 2001 only), Cogeneration (CG), Hydropower (HYDRO) and Other Renewables (OR). In interpreting the linkage analysis results, it is important to consider the generation share of the different electricity sectors, as listed in Table 5-2. For example, the CF sector generated approximately 93 and 91 per cent of electricity in 1996 and 2001, respectively, and therefore the linkage results for this sector would have wider implications, compared to the other electricity sectors. The high reliance on coal reflects the abundant reserve of black coal in NSW, and the historical legacy of investment into cheap coal fired electricity for baseload supply.

Table 5-2 Electricity generation mix in NSW (%)

Electricity sector	1996	2001
Coal fired (CF)	93.39	91.37
Gas turbine (GT)	< 0.01	< 0.01
Internal combustion (IC)	<0.01	N/A
Combined cycle (CC)	N/A	1.47
Cogeneration (CG)	0.52	1.41
Hydropower (HYDRO)	5.99	5.50
Other renewables (OR)	0.10	0.24

The results from the linkage analysis confirm that electricity is an important infrastructure industry in the economy. All electricity sectors exhibited strong forward linkages in both years, indicating that electricity is used extensively by other sectors. Amongst the electricity sectors, CG measured the highest forward linkages in both 1996 (1.64) and 2001 (1.28). A significant proportion of the electricity generated in this sector is embedded in the BMP sector, which is reflected in the high CoV values for CG in both years. That is, electricity from this sector is less evenly spread across the other sectors in the economy.

In 1996, GT (1.04) and IC (1.71) measured strong backward linkages and were therefore key sectors in NSW. Both sectors, however, generated less than 0.01 per cent of the electricity in the state, and therefore this result should be interpreted with caution. In 2001, GT (1.07), CF (1.11) and CC (1.37) measured strong backward linkages and were considered key sectors. Unlike other electricity sectors, CC sourced most of its water needs from the water sector, Bulk & Retail Water (BRW), rather than from the Environment directly. This would serve to strengthen its connection with the production sectors in the economy and account for its stronger backward linkages compared with many of the other electricity sectors.

In general, however, the backward linkages were weaker compared with the corresponding forward linkages. Most of the inputs used by the electricity sectors would be fuel from other energy sectors – such as Coal Mining – and therefore the electricity sectors would draw relatively less on the outputs of other (non-energy) production sectors. The backward linkages strengthened between the two time periods, which suggests a greater and more dispersed reliance on the outputs of other production sectors. In other words, the percentage contribution of primary inputs such as Labour to the output of the electricity sectors decreased relative to the contribution of production sectors. A possible explanation is the reduction in labour that accompanied industry reforms in the 1990s, as part of efforts to improve labour productivity in the electricity industry.

5.1.2 Water sectors

The water industry in the input-output models comprises three sectors: Irrigation & Drainage Water (IDW), Bulk & Retail Water (BRW) and Sewerage (SEW). The results for IDW were higher compared to BRW and SEW. For example, its backward linkages for 1996 and 2001 were 0.93 and 1.28, respectively, and therefore it exhibited a strong backward linkage in 2001. The backward linkages were comparatively weaker for BRW (0.76 in 1996 and 0.98 in 2001) and SEW (0.74 in 1996 and 0.94 in 2001).

A possible explanation is that IDW may be more reliant on the production sectors within the inter-industry table. In comparison, BRW and SEW rely more on primary inputs – such as Labour, Other Value Added and Raw Water (in the case of BRW) – and therefore their backward linkages with other production sectors are lower. However, for all three sectors, the backward linkages increased in strength between the two time periods. It appears that the water sectors drew more heavily on the outputs of other production sectors in the latter time period. As with the electricity sectors, a possible explanation is that the sectors relied less on primary inputs, such as Labour. This would have been brought about by industry reforms that reduced staff numbers as part of efforts to improve labour productivity.

In terms of forward linkages, IDW measured the same strong forward linkage of 1.34 in both years. IDW therefore emerged as one of the six key sectors in 2001. The strong results are an indication of the relative importance of irrigation for Agriculture, which is an important primary industry for NSW. Agriculture in turn supplies some manufacturing sectors, such as FBT and TCFL. In 1996 and 2001, the forward linkages were comparatively stronger for BRW (0.82 and 0.85, respectively) than SEW (0.57 and 0.58, respectively). This indicates that the outputs from BRW were more widely consumed in the economy, compared with SEW. This also reflects the limited use of treated effluent – an output of the SEW sector – by other economic sectors during both time periods.

5.1.3 Other production sectors

The remaining production sectors are represented by the following major sectoral groups: Agriculture, Mining, Manufacturing, Construction, Gas and Services. The linkages discussed in this section form part of the analysis of the implications of the nature of the nexus on the wider economy, and complement the intensities and elasticities presented in Chapter 6. Figure 5–2 illustrates the general changes to the composition of the Australian economy, and provides further context to the discussion on linkages in NSW in this section.

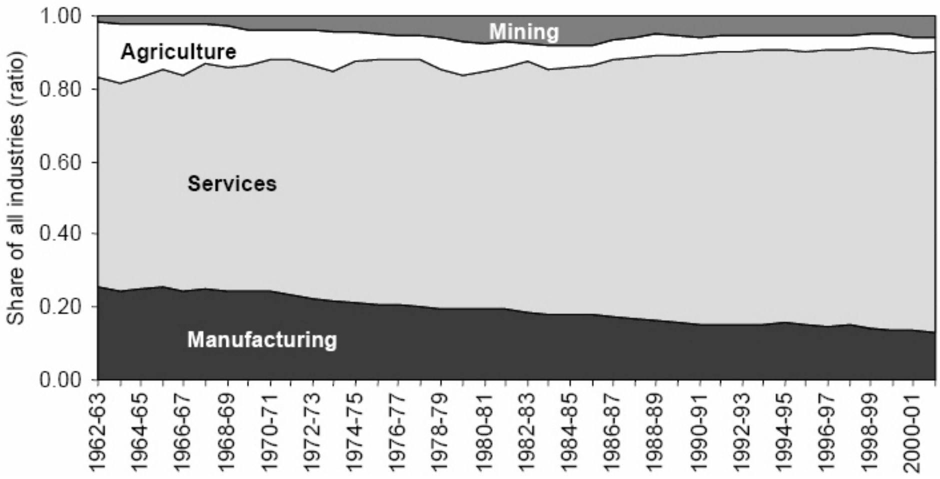

Figure 5–2 Changes in the composition of the Australian economy (1962-63 to 2001-02 current prices) Source: Productivity Commission (2003)

Agriculture

Agriculture is an aggregate sector that incorporates all agricultural, forestry and fishing activities. In 1996 and 2001, the sector measured strong backward linkages of 1.01 and 1.02 respectively, which suggests that the sector has an above-average influence on stimulating production activity in the economy. In contrast, the forward linkages were below one for 1996 (0.89) and 2001 (0.90). Whilst Agriculture is an important primary industry for the Australian economy, the outputs from this sector are only directly used as inputs by a select number of manufacturing sectors, such as Food, Beverage & Tobacco (FBT), Textile Clothing Leather & Footwear (TCLF) and Wood Paper & Printing Products (WPP). This would account for the relatively weak forward linkages compared to the overall average.

Mining

There are two mining sectors in the input-output models, which represent Coal Mining (COAL) and Other Mining & Services to Mining (OMS). The models do not contain oil or gas extraction sectors, because NSW does not have proven commercial reserves of either. Instead, these resources are imported into the state and are therefore accounted for in the primary inputs section of the input-output models, which directly allocates imports.

Of the two mining sectors, it is observed that COAL had weaker backward (0.78 in 1996 and 0.82 in 2001) and weaker forward (0.87 in 1996 and 0.84 in 2001) linkages compared to OMS. A possible explanation is that the outputs from this sector are largely exported overseas. Domestic uses focus on a few economic activities, such as electricity generation (CF) and iron and steel manufacturing, represented by the Basic Metals & Products (BMP) sector. COAL outputs are therefore not widely dispersed. Further, this sector does not process inputs from other sectors, but rather draws from Raw Coal, which accounts for the relatively weak backward linkages for both years. Raw Coal is a primary energy source and therefore located in the primary inputs section of the input-output models.

In contrast, OMS exhibited strong backward linkages in both 1996 and 2001 (1.09 and 1.08, respectively), and strong forward linkages in 1996 (1.06). It therefore emerged as one of the seven key sectors in 1996. A decrease in its forward linkages from 1996 to 2001 (0.95) may be attributed to growth in exports, particularly to Asian economies such as China, that require raw materials to fuel its development. This would reduce the percentage share of the sector's output that is being used as inputs by other sectors in the NSW economy.

Manufacturing

The manufacturing sectors comprise the 12 sectors from Food, Beverage & Tobacco (FBT) to Miscellaneous Manufacturing (MM) in Table 5-1. These sectors accounted for approximately 13 per cent of GDP in Australia in 2001-02, of which NSW contributed approximately one third (ABS 2006c; Productivity Commission 2003). Manufacturing has grown substantially since the mid 1950s to today. This sectoral group's contribution to economic output, however, is in decline, because of the relatively faster growth rates of other sectoral groups, such as services (refer to Figure 5–2).

The Productivity Commission (2003) suggests several reasons for this declining trend. Firstly, there has been a slower growth in manufacturing prices compared with other goods and services. Secondly, there has been an increasing trend of outsourcing non-core activities, such as information, communication and technology (ICT), engineering and accountancy services. This has reallocated activities from the manufacturing to the services sectors. Thirdly, labour productivity has reportedly increased for manufacturing sectors, which has resulted in fewer employees – and therefore less payments to households – to produce the same output. Lastly, Australia's increase in prosperity since the 1960s has led to a shift in consumer preferences towards services.

The general declining trend must nevertheless be viewed in light of more specific trends that divide the manufacturing sectors into three sets. The first set of sectors – Food Beverage &Tobacco (FBT), Wood Paper & Printing Products (WPP), and Basic Metals & Products (BMP) – are strongly connected with natural resources and account for a growing share of economic output from the manufacturing sectors. This share has increased from 36.5 per cent in 1968-69 to nearly 44 per cent in 2000-01 (Productivity Commission 2003). The backward and forward linkages for these sectors would therefore have significant implications for the economy. The FBT and BMP sectors exhibited strong backward linkages in both years (1.18/1.12 and 1.28/1.18, respectively), suggesting that both sectors have an above-average effect of stimulating economic activity. In contrast, the WPP sector exhibited strong forward linkages in both years (1.05 and 1.17), and therefore its outputs are considered to be widely dispersed in the economy.

A second set of manufacturing sectors relate to those that require a higher degree of skill or research and development. These sectors – which include Petroleum Refining (PR), Petroleum & Coal Products (PCP), Chemicals (CHEM) and part of Other Machinery & Equipment (OME) –

have also increased their contribution to economic output in Australia, from 3.5 per cent to 6.8 per cent between 1968-69 to 2000-01 (Productivity Commission 2003). The first three sectors of this set – PR, PCP and CHEM – are generally aggregated in statistical accounts, however, these sectors are disaggregated in this research so that energy flows from the PR sector may be represented by physical energy units (PJs). The backward linkages for the PR sector were weak in both 1996 (0.77) and 2001 (0.76), as this sector relies most heavily on Crude Oil imports – a primary input – rather than the outputs of other production sectors. In contrast, its forward linkages were strong in both 1996 (1.31) and 2001 (1.44), and increased between the two periods. This reflects the high reliance in the economy on petroleum fuel. The PCP sector exhibited strong forward linkages in both 1996 (1.71) and 2001 (1.62) and a strong backward linkage in 1996 (1.09). The backward and forward linkages for CHEM were above one in both years (1.25/1.03 and 1.17/1.04, respectively). In 2001, the coefficient of variation (CoV) of the backward linkage for the CHEM sector was above average in 2001 and therefore it was only considered a key sector in 1996. The OME sector exhibited a strong backward linkage (1.10) in 1996. The other linkages for the OME sector were below one and appeared to decline between the two time periods. This decline may be attributed to the trend that is associated with the third set of manufacturign sectors, of which the OME sector forms part.

A third set of manufacturing sectors refers to those that produce less complex goods, such as OME (part), TCFL, Non-metallic Mineral Products (NMMP), Fabricated Metal Products (FMP), Transport & Equipment (TE) and Miscellaneous Manufacturing (MM). These sectors have faced strong import competition from countries with lower wage levels and therefore their contribution to economic output has generally declined. This trend explains the decrease in forward linkages for OME from 0.87 in 1996 to 0.84 in 2001, and the weak backward and forward linkages for TCFL in both years. In contrast, NMMP and FMP were key sectors in both years. Both sectors have strong linkages to the mining sectors (backward linkages), as well as other manufacturing sectors that further transform its outputs (forward linkages). The backward linkages (1.20/1.08 for NMMP and 1.26/1.17 for FMP) and forward linkages (1.13/1.04 for NMMP and 1.20/1.15 for FMP), however, weakened between the two periods. TE and MM exhibited strong backward linkages in both periods (1.08/1.03 and 1.20/1.00, respectively). Similar to the other sectors in this set, the linkages have weakened for the above-mentioned reasons. Further, the forward linkages for TE and MM were below one in both periods.

Retail Gas Supply

The forward linkages for the Retail Gas Supply (GAS) sector were relatively stronger than the backward linkages. For example, in 1996 and 2001, the GAS sector exhibited strong forward linkages of 1.41 and 1.43, respectively, which are an indication of the importance of the energy sectors for economic output. In contrast, the backward linkages for these two time periods were 0.68 and 0.98, respectively. As with PR, this sector relies most heavily on primary energy imports, which accounts for the weak backward linkages with other production sectors.

Construction

Construction is represented by one sector (CONST) in the input-output models. Over the last three decades, this sector experienced slower economic growth and declined in relative importance compared to other sectors, such as the services sectors (McLachlan, Clark & Monday 2002). In terms of linkages, CONST exhibited strong backward linkages in 1996 (1.00) and 2001 (1.10), which reflected the material-intensive nature of this sector, and its reliance on manufacturing output. At the same time, it's forward linkages weakened from 0.78 in 1996 to 0.62 in 2001, which reflected the decrease in its contribution to the economy.

Transport

Transport is represented by the Transport and Storage (TS) sector. This sector has been one of the fastest growing in the economy over the last three decades (McLachlan, Clark & Monday 2002). It measured strong backward linkages in both 1996 (1.04) and 2001 (1.13), which increased in strength between the two time periods. This sector also measured a strong forward linkage in 2001 (1.10), and therefore emerged as one of the seven key sectors during this period.

Services

The services sectoral group comprise five sectors in the input-output models: Wholesale & Retail Trade (WRT), Financial, Property & Business Services (FPBS), Government Administration & Defence (GAD), Education, Health & Community Services (EHCS) and Other Commercial Services (OCS). The contribution of the services sectors has increased over the last three decades. As described previously, some of the reasons for this increase include the preference for services as incomes increase, and an increase in out-sourcing by the manufacturing sectors. Other factors include the need for more specialist knowledge due to increasingly complex business arrangements brought about by globalisation, additional monitoring associated with government regulation, and the introduction of new service products such as ICT that also require specialist knowledge (McLachlan, Clark & Monday 2002). The trend of increasing contribution by the services sectors to economic output should be viewed in light of more specific trends that divide the services sectors into three sets.

The first set comprises high growth sectors, such as FPBS and EHCS (Health & Community Services sub-sector). The FPBS sector (Communications Services sub-sector) grew the fastest amongst the services, at a rate of approximately 8.4 per cent per annum from 1974-75 to 2000-01 (McLachlan, Clark & Monday 2002). Whilst the backward linkages for this sector were below one for both years (0.93), the forward linkages increased from 0.97 in 1996 to 1.05 in 2001. This reflects the strong growth in this sector, and the increase in reliance of its output by other sectors. Despite the high growth rate of part of the EHCS sector, the backward and forward linkages were below one for both years (0.82/0.57 for 1996 and 0.78/0.59 for 2001). A possible explanation is that this sector predominantly provides services to households, which are considered a final sector category (under Household Consumption) in the input-output models, rather than to other production sectors.

The second set of sectors comprise those that grew in line with the national average, such as EHCS (Education sub-sector) and OCS (Culture & Recreation sub-sector). The backward linkages for OCS were approaching one in both years (0.99). The forward linkages were also below one in 1996 (0.73) and 2001 (0.78), although the forward linkages strengthened between the two time periods. As with EHCS, many of the services provided by OCS are consumed by Households rather than other production sectors.

The third set of sectors comprise those that grew slowly over the last three decades, which include Wholesale & Retail Trade (WRT), Government Administration & Defence (GAD) and OCS (Personal & Other Services sub-sector). Despite this trend, the backward (0.98/1.09) and forward (0.75/0.81) linkages for WRT increased between the two periods, and it was considered to have a strong backward linkage in 2001. This sector is closely linked with manufacturing sectors, which explains the high backward linkages. As with many other service sectors, the weak forward linkages could be attributed to the fact that a significant proportion of its output – especially retail trade services – is used directly by final sectors such as Households. For similar reasons, GAD exhibited weak forward linkages in both 1996 (0.57) and 2001 (0.65). However, its backward linkages were strong in both 1996 (1.03) and 2001 (1.01).

In general, the backward and forward linkages for the services sectors increased from 1996 to 2001, which complements the opposite trend observed in the results for the manufacturing sectors. The results reinforce the reported trend away from manufacturing towards a service economy. Further, the backward linkages were comparatively higher than the forward linkages for the service sectors. A possible explanation is that Households consume most of the outputs from the service sectors, and therefore the consumption of service sector outputs by other production sectors (that is used to calculate forward linkages) are comparatively less.

5.1.4 Some discussion

Linkages reflect the role of the different sectors in an economy. Over time, these roles are likely to change as the demand for various outputs shift and the structure of the economy changes. An understanding of the existing linkages and trends is useful for gaining a deeper appreciation of the water and energy interactions between the sectors and the implications for the economy at large. For this reason, this research quantified the backward and forward linkages for all production sectors in the NSW economy for 1996 and 2001. The salient findings from this analysis are summarised below.

- Water and electricity are fundamental inputs to the economy and it is therefore not surprising that a significant number of water and electricity sectors exhibited strong forward linkages, or were considered key sectors in both years. Further, it appears that changes in labour productivity as a result of reform have increased the proportion to which these sectors rely on the outputs of other sectors, resulting in a further strengthening of these links.

- The manufacturing sectors generally measured strong backward and/or strong forward linkages and comprised a significant proportion of key sectors in 1996. However, the linkages generally weakened by 2001. These results reflect the general decline of the role of the manufacturing sectors in Australia, because of the relatively faster growth rates of other sectors, such as the services sectors, in the NSW economy. This decline is also attributed to the reallocation of activities previously undertaken by the manufacturing sectors, which are now outsourced to the services sectors, and the increased demand for services that has accompanied the growth in income and prosperity in Australia. This relative decline is not consistent across all the manufacturing sectors, therefore the specific linkage analysis results should be viewed in light of the following specific trends: sectors that are strongly connected to natural resources have grown strongly, and sectors that require a higher degree of skill (and are therefore less exposed to imports from countries where unskilled labour is cheap) have increased their contribution to economic output.

- The contribution of the services sectors has increased over the past few decades, for the reasons stated above. In addition, globalisation, the ascent of ICT services and additional monitoring associated with government regulation have all increased the demand for services. The linkage results for the services sectors reflect these trends and demonstrate that services are playing an increasing role in the NSW economy, even in the relatively short time period between 1996 and 2001. As with the manufacturing sectors, the growth in services is not consistent across all the sectors, and therefore a closer examination of the trends is required when analysing the linkage results.
- Of the remaining sectoral groups – GAS, CONST and TRANS – the TRANS sector exhibited the strongest growth trends and linkages, highlighting the criticality of transportation infrastructure in connecting regional NSW to major demand centres, such as Sydney, as well as the ports that service as the gateway to international markets, particularly in Asia.

The results of the linkage analysis are referred to later in this chapter and in Chapter 6. The remaining sections in this chapter focus on the interactions between water and energy, within the water and energy sectors.

5.2 Water intensities for the energy sectors

Recent events discussed in Chapters 2 and 4 suggest that energy security is highly dependent on water security. In particular, lack of water in 2007 severely reduced generation output in NSW and in other NEM states. In recognition of the growing importance of this upstream link, the purpose of this section is to analyse the direct and total (which includes indirect use) water intensities for the energy sectors in the NSW economy, using the Leontief hybrid models. As described in Section 3.4.3, the intensities represent the amount of water required to satisfy a unit increase in the final demand for energy.

The energy sectors refer to the Electricity sectors and the following non-electric sectors: Coal Mining (COAL), Petroleum Refining (PR), and Retail Gas Supply (GAS). The water intensities for Petroleum & Coal Products (PCP), which produces non-energy petroleum and coal products, are presented in this section, because the outputs from this sector are represented in equivalent energy units in the data obtained and therefore also in the input-output models.

This section is structured according to the following. Section 5.2.1 presents the empirical findings for the energy sectors for both years. Section 5.2.2 compares the results for the Electricity sectors with four external reports, in order to provide additional validation for the results and the input-output models developed for this research. Section 5.2.3 discusses some of the implications of the results for NSW and for the modelling of future energy scenarios.

5.2.1 Empirical findings

Tables 5-3 and 5-4 summarise the results of the models for 1996 and 2001. The tables show the direct and total water intensities for the energy sectors, as well as the percentage breakdown of the total intensities to the direct and indirect components. As discussed previously in Section 3.4, water is supplied either as outputs from the three water sectors, or by the energy sectors extracting water directly from the Environment. The three water sectors include the Irrigation & Drainage Water (IDW) sector, the Bulk & Retail Water (BRW) sector, and the Sewerage (SEW) sector. The environmental extractions are classified as Raw Water (which is consumed) and Instream Use (which is discharged).

The results for the electricity sectors include water demand by the transmission and distribution functions of the industry, which is largely potable water used by employees. This demand has been apportioned to the electricity sectors according to whether the electricity from the sectors is supplied via the transmission and distribution grid or the distribution grid only.

From Tables 5-3 and 5-4, it can be seen that the total water intensities offer a better indication of the water demand by the energy sectors, because they include indirect demand. In some instances – such as the IDW intensities –indirect demand accounts for 100 per cent of the total value. This indirect component is embedded in the material output from other sectors, which is consumed as part of operation and maintenance activities. An estimation based on direct demand would therefore not reflect the true water demand of the energy sectors. Further, the total Raw Water intensities offer a more accurate estimate of the water demand compared with the total IDW and BRW intensities, as these two water sector intensities are embedded in the total Raw Water intensities (refer to Section 3.4.3 for a more detailed explanation).

Table 5-3 Direct and total water intensities for the energy sectors in 1996 (ML/PJ)

		Water production sectors						Water primary inputs			
		IDW		BRW		SEW		Raw Water		Instream Use	
		Direct	Total	Direct	Total	Direct	Total	Direct	Total	Direct	Total
Electricity sectors	CF	-	2.86	93.83	106.89	3.63	8.40	0.69	160.85	-	73.62
			(100%)	(88%)	(12%)	(43%)	(57%)	(0.4%)	(99.6%)		(100%)
	GT	-	3.67	4.20	20.70	-	0.32	-	29.15	-	212.89
			(100%)	(20%)	(80%)		(100%)		(100%)		(100%)
	IC	-	3.39	4.20	19.11	-	0.29	-	26.90	-	189.88
			(100%)	(22%)	(78%)		(100%)		(100%		(100%)
	CG	-	1.15	0.26	2.38	-	0.06	-	4.84	-	10.94
			(100%)	(11%)	(89%)		(100%)		(100%)		(100%)
	HYDRO	-	0.43	2.92	3.71	-	0.02	-	4.63	179,967.23	180,187.03
			(100%)	(79%)	(21%)		(100%)		(100%)	(99.9%)	(0.1%)
	OR	-	1.40	-	2.58	-	0.07	-	5.58	-	13.31
			(100%)		(100%)		(100%)		(100%)		(100%)
Non-electric energy sectors	COAL	-	0.56	0.70	1.20	1.47	1.55	16.37	18.84	-	20.96
			(100%)	(59%)	(41%)	(95%)	(5%)	(87%)	(13%)		(100%)
	PR	-	0.62	2.12	3.56	-	0.08	-	5.05	-	51.67
			(100%)	(59%)	(41%)		(100%)		(100%)		(100%)
	PCP	-	0.53	-	0.82	-	0.05	-	1.97	-	13.26
			(100%)		(100%)		(100%)		(100%)		(100%)
	GAS	-	0.39	3.00	3.75	-	0.02	-	4.56	-	6.39
			(100%)	(80%)	(20%)		(100%)		(100%)		(100%)

Source: Derived from the Leontief hybrid models as described in Section 3.4

Table 5-4 Direct and total water intensities for the energy sectors in 2001 (ML/PJ)

		Water production sectors						Water primary inputs			
		IDW		BRW		SEW		Raw Water		Instream Use	
		Direct	Total	Direct	Total	Direct	Total	Direct	Total	Direct	Total
Electricity sectors	CF	-	5.26	36.02	44.68	5.28	8.21	251.31	351.99	-	256.37
			(100%)	(81%)	(19%)	(64%)	(36%)	(71%)	(29%)		(100%)
	GT	-	7.87	3.39	43.24	-	0.27	-	66.60	-	434.43
			(100%)	(8%)	(92%)		(100%)		(100%)		(100%)
	CC	-	6.13	275.56	302.56	-	0.16	-	318.80	-	141.62
			(100%)	(91%)	(9%)		(100%)		(100%)		(100%)
	CG	-	3.00	2.12	5.26	-	0.08	-	13.04	-	44.90
			(100%)	(40%)	(60%)		(100%)		(100%)		(100%)
	HYDRO	-	3.44	4.57	8.18	-	0.09	-	17.10	615,852.87	616,803.23
			(100%)	(56%)	(44%)		(100%)		(100%)	(99.8%)	(0.2%)
	OR	-	4.36	3.35	7.92	-	0.11	78.81	98.16	-	65.24
			(100%)	(42%)	(58%)		(100%)	(80%)	(20%)		(100%)
Non-electric energy sectors	COAL	-	0.43	0.40	0.84	0.88	0.91	9.64	12.12	7.04	69.98
			(100%)	(48%)	(52%)	(96%)	(4%)	(80%)	(20%)	(10%)	(90%)
	PR	-	1.74	13.36	16.33	-	0.07	0.19	22.19	-	171.84
			(100%)	(82%)	(18%)		(100%)	(1%)	(99%)		(100%)
	PCP	-	1.59	5.98	7.64	-	0.03	0.08	12.05	-	50.13
			(100%)	(78%)	(22%)		(100%)	(1%)	(99%)		(100%)
	GAS	-	0.82	1.77	2.91	-	0.02	-	5.14	-	28.08
			(100%)	(61%)	(39%)		(100%)		(100%)		(100%)

Source: Derived from the Leontief hybrid models as described in Section 3.4

Based on the 1996 results, it was observed that:

- The Hydropower (HYDRO) sector measured the highest total Instream Use intensity of 180,187.03 ML/PJ. This water is typically discharged and may be reused by other water users downstream, such as irrigators. As mentioned previously in Chapter 2, temporal water needs may differ, however, between hydropower generators and other users, which may be further compounded by the occurrence of drought. In contrast, the total Raw Water intensity for the HYDRO sector was amongst the lowest in the electricity industry, because this sector does not require water for cooling, unlike the Coal Fired (CF) sector.

- The CF sector measured the highest total intensities compared to all other energy sectors for BRW (106.89 ML/PJ), SEW (8.40 ML/PJ), and Raw Water (160.85 ML/PJ). The water intensities may be attributed to the consumption of freshwater at inland power stations, which were constructed in the 1970s and 1980s in order to plan for an expected minerals boom, which did not take place. At the time, there was little consideration given to the implications of consuming freshwater, because drought did not pose a threat to electricity generators. In contrast, in 2007 inland power stations transferred their generation capacity to coastal power stations, as a result of water shortages (refer to Sections 2.1.1 and 4.4.4). Technological advancements in generation and long-distance transmission enabled the development of these inland power stations close to coal mines, and away from demand centres along the coast (refer to Section 4.3.3).

- There is a significant gap between the water intensities for the CF sector and the second highest consumptive water user, the Gas Turbine (GT) sector. In contrast, the total Instream Use intensities (non-consumptive use) for the GT sector (212.89 ML/PJ) was significantly larger than the CF sector, which suggests that the GT sector was more reliant on the outputs of energy-intensive sectors (most instream use of water in NSW is attributed to hydropower generation). For example, the GT sector used fuel oil supplied by the Petroleum Refining (PR) sector, which is an energy-intensive sector.

- The water intensities for the Internal Combustion (IC) sector were marginally lower compared with GT. These intensities were 19.11 ML/PJ for BRW, 0.29 ML/PJ for SEW, 26.90 ML/PJ for Raw Water and 189.88 ML/PJ for Instream Use. Similar to the GT sector, the IC sector exhibited strong backward linkages during this period, and the majority of its water use was indirect. Generation from this sector ceased soon after 1996, and therefore this sector did not form part of the generation mix in the 2001 model.

- The Cogeneration (CG) and Other Renewables (OR) sectors exhibited the lowest water intensities in 1996. Cogeneration plants are typically installed in locations such as coal mines that are net water producers, which accounts for the low values. Renewable energy technologies, such as wind, do not directly require water to generate electricity. The water intensities are therefore largely from indirect use.

- Of the four non-electric energy sectors, the PR and GAS sectors measured total Raw Water intensities of 5.05 ML/PJ and 4.56 ML/PJ, respectively. New South Wales does not have commercial oil and gas extraction industries, which are upstream to the PR and GAS sectors. Potable water consumption and water embedded in material inputs from other production sectors therefore comprises a significant proportion of the water intensities. The value of these intensities are comparable to the water intensities for the CC, HYDRO and OR sectors. Based on these results, substitution of electricity with gas and petroleum would reduce water use in the economy, particularly if this substitution offsets electricity generated by the water-intensive CF sector.

In 2001, the results indicate that:

- Similar to 1996, HYDRO measured the highest total Instream Use intensity of 616,803 ML/PJ. Compared with the previous time period, this value increased substantially in 2001. Given that the HYDRO did not undergo significant technological change during the two periods, the discrepancy between the two results could reflect improvements in data collection and estimation techniques used by the Australian Bureau of Statistics (ABS) (2004). Since 2001, drought has reduced the generation capacity of hydropower stations in the state, resulting in some trade-offs. For example, this technology is considered a renewable source, because it emits zero carbon emissions directly. The reduction in hydropower capacity increased the generation output of greenhouse-gas intensive sectors, such as the Gas Turbine (GT) sector (refer to Section 2.1.1). The reduction also decreased the flexibility of the NEM to respond to electricity demand fluctuations, as hydropower is considered a peaking plant, because of its short start up time.

- The Combined Cycle Gas Turbine (CC) sector exhibited the highest total BRW water intensities (302.56 ML/PJ) in 2001. The power station represented by this sector is located in Sydney, placing it in direct competition with other potable water users in the city. In the past, many small-scale power stations were located in Sydney that used seawater from the harbour to generate steam. A shift to large-scale centralised power generation shifted investment to inland locations and in coastal areas north of Sydney, close to coal mines (refer to Section 4.3.3). Policies that encourage the return of power station developments in Sydney should ensure that such developments are cognisant of the limits on freshwater resources in the city. An alternative is for these power stations to use recycled water.

- The total BRW intensity (44.68 ML/PJ) for the CF sector decreased in 2001, whilst the total Raw Water intensity increased (351.99 ML/PJ). This sector also consumed larger quantities of treated effluent (5.28 ML/PJ) from the SEW sector. Given that there have been no significant changes to coal fired plants during this period, improvements in data collection may account for the differences. Based on the total Raw Water intensities, CF continued to be the most water-intensive sector in 2001.

- The water intensities for the OR sector significantly increased between 1996 and 2001: the total BRW and Raw Water intensities were 7.92 ML/PJ and 98.16 ML/ PJ, respectively. By 2001, electricity generators had begun to invest in renewable energy, in preparation for the national Mandatory Renewable Energy Target, which required the electricity industry to generate 9,500 GWh of electricity from renewable energy sources by 2010 (refer to Section 4.4.3). Considered a renewable energy source, biomass co-firing of woodwaste in coal fired power stations was one strategy adopted by generators in NSW. This has resulted in a trade-off of increasing water consumption, because biomass co-firing uses the existing infrastructure of water-intensive coal fired power stations.

- Similar to the other sectors, the water intensities for the GT sector increased substantially in 2001. Most of this increase may be attributed to indirect consumption, that is, water embedded in the outputs of other production sectors. The direct BRW intensity (3.39 ML/PJ) comprised only 8 per cent of its total BRW intensity, and indirect consumption comprised 100 per cent of its total Raw Water intensity (66.60 ML/PJ). A possible explanation of the differences between the two years is improvements in the quality of data collected by the ABS. The water intensities for the CG sector also increased in 2001, however, it was still one of the smallest water users amongst the electricity sectors. Its total Raw Water value was 13.04 ML/PJ.

- As in 1996, the water intensities for the non-electric energy sectors of COAL, PR, PCP and GAS were generally lower than the Electricity sectors. Changes were observable for the different sectors: water intensities decreased for the COAL sectors and generally increase for the PR, PCP and GAS sectors. Improvements to the quality of data collected by the ABS may explain some of these changes. The results also indicate that the Instream Use intensities increased for all four sectors, which could also reflect an increase in the Electricity intensities of these sectors.

5.2.2 Comparison with other reports

This section compares the 1996 and 2001 results with four external reports that quantify freshwater consumption in the electricity industry. This comparison would assist in assessing the validity of the results and in turn the validity of the input-output models developed for this research. Table 5-5 presents the results in terms of ML/GWh (which is equivalent to L/kWh), for the Electricity sectors that are common to the external reports and this research.

Table 5-5 Comparison of water intensities for select electricity sectors (ML/GWh)

Sector/ Technology	This research		Nunn et. al. (2002)	Wibberley (2001)	Woods (2006)	AWEA (2008)
	1996	2001				
NSW transmission grid*			1.11			
NSW distribution grid*			1.17			
CF	0.34(d), 0.58(t)	1.05(d), 1.27(t)				
CF (freshwater)	0.56(d)	1.72(d)		1.76	1.82	1.90
CC	N/A	0.99(d), 1.15(t)		0.97	0.68	0.95
OR (aggregate)	0.02(t)	0.30(d), 0.35(t)				
OR (biomass co-firing)				1.76		
OR (wind)				0.01		0.004
OR (photovoltaics)				0.18		0.11

Sources: Derived from the Leontief hybrid models, Nunn et. al. (2002) Wibberley (2001) Woods (2006) and AWEA (2008)

Notes: *excludes Snowy. Intensities refer to freshwater consumption, represented by BRW and Raw Water intensities. Direct (d) is a summation of the direct BRW and Raw Water Intensities and Total (t) refers to the total Raw Water intensities, which incorporate the total BRW intensities.

The report authored by Nunn et. al. (2002) for the Cooperative Research Centre for Coal in Sustainable Development (CCSD) was previously reviewed in Chapter 2. The report presents the results of a life cycle assessment (LCA) of the NSW electricity grid for 2001 that estimated – among other environmental parameters – the freshwater used to extract, process and transport primary fuels, and generate, transmit and distribute electricity. The report presents two water intensities: 1.11 ML/GWh for the NSW transmission grid and 1.17 ML/GWh for the NSW distribution grid (which also includes transmission). These results are similar to the total Raw Water intensity of 1.27 ML/GWh for the CF sector in 2001. The CF sector generated over 91 per cent of electricity in the state in 2001 and therefore would offer a close approximation of the water intensity of the NSW distribution grid.

The difference between the values 1.17 L/kWh and 1.27 L/kWh may be caused by truncation errors that commonly occur in LCA studies that use process analysis to quantify indirect water use. Input-output analysis resolves this error by eliminating the need to identify LCA boundaries that cause the truncation errors, as the Leontief inverse matrix captures all indirect uses. Further, Nunn et. al. (2002) adopted 1997 water data from the ABS to develop intensities for 2001, which created additional descrepancies in the results. The 1996 results from this research are significantly lower compared to Nunn et. al. (2002). One possible explanation, as stated previously, is the difference in the quality of the water data collected for the two time periods (ABS 2004).

The results for coal fired power generation from the remaining three reports refer to specific electricity generation technologies, rather than the electricity grid. The report prepared by Wibberley (2001) for the Australian Coal Association Research Program presents the results of an LCA study on different electricity generation technologies in Australia. Unlike the first study by Nunn et. al. (2002), this study also considered water used during construction. The results from this study are therefore higher than if only water use during operation and maintenance were considered. The two remaining reports by Woods (2006) and the American Wind Energy Association (AWEA) (2008) only consider direct water use.

In order to facilitate the comparison between this research and the water intensities contained in remaining three external reports for the CF sector, Table 5-5 contains an additional intensity labelled CF (freshwater). This intensity is calculated by dividing the total freshwater consumed to generate electricity (either supplied by the BRW sector or extracted directly from the Environment as Raw Water), with the amount of electricity generated by freshwater.

The water intensity for CF (freshwater) was marginally lower in 2001 (1.72 ML/GWh) compared to Wibberley (2001) (1.76 ML/GWh). The difference in the results may be attributed to the water used during construction. Further, the modified water intensities for CF (freshwater) only consider direct water used to generate electricity, and not total (which includes indirect) water used. Additional modification to the input-output table would have been required to generate total intensities (such as disaggregating the CF sector into electricity generated using freshwater and electricity using seawater; seawater consumption data was not available for 1996 and 2001). The water intensity for the CF (freshwater) sector in 1996 was significantly lower than the intensities presented in the three reports, which again might indicate that the ABS data was incomplete for that year.

The direct water intensity for the CC sector (0.99 ML/GWh) in 2001 was similar to the intensity reported by AWEA (2008) (0.95 ML/GWh). Both were significantly higher than the water intensity reported by Woods (2006) (0.68 ML/GWh). The total water intensity for the CC sector (1.15 ML/GWh) was also higher than the total intensity reported by Wibberley (2001) (0.97 ML/GWh). The intensities calculated by this research are comparatively higher, because the intensities incorporate indirect use of freshwater. The results from this research therefore offer a better indication of the water required by the different electricity sectors.

The OR sector in this research is an aggregate of different renewable generation technologies installed in NSW in 1996 and 2001. The intensities from the three external reports are contained in Table 5-5, in order to provide an indication of the freshwater used by specific renewable technologies. It is observable that the intensities differ considerably, but – with the exception of biomass co-firing in coal fired power stations – the intensities are lower compared to the CF and CC sectors. This provides a strong case for encouraging investment into renewable energy technologies, in order to reduce freshwater consumption, in addition to carbon emissions.

In summary, the water intensities calculated from the 2001 model are comparable to the intensities presented in the four external reports mentioned above. The differences between the intensities are attributed to weaknesses in the methods adopted by the other reports (such as truncation errors in the case of Nunn et. al. (2002) and Wibberley (2001)), or because the external reports only consider direct water use (in the case of Woods (2006) and AWEA (2008)). The 2001 model developed for this research therefore offers distinct advantages over these existing reports and would offer a suitable base from which to develop models to explore future water and energy scenarios for NSW.

5.2.3 Some discussion

The Coal Fired (CF) sector supplies the majority of electricity in NSW. It is also one of the highest consumptive users of freshwater. Given its strong forward linkages with other sectors in the economy, it is likely to contribute significantly to the water embedded in the outputs of other sectors. Further, the results presented in Tables 5-3 and 5-4 for the CF sector would underestimate its water use, because no data was available regarding the amount of seawater used for cooling, and the freshwater use was averaged out over the total amount of electricity generated by this sector. The results, however, are representative of the water used by the NSW electricity grid, because of the high proportion of electricity generated by this sector. The CF (freshwater) intensities presented in Table 5-5 offer a better indication of the actual water used by this sector, as only electricity generated using freshwater is considered.

The high water intensities for the CF sector are historical legacies of investment decisions. For most of the 20th century, inland power stations were constructed with little regard to the water requirements of river systems. Drought, which has been prevalent throughout the history of NSW, was not a sufficient driver to curtail the development of these inland power stations. Drought has since affected the ability of these power stations to generate electricity, and has stimulated investment into advanced wastewater treatment technologies, in order to recycle water in the power stations.

The other high water user in 2001, the CC sector, requires significant volumes of water from the BRW sector. It therefore directly competes with end users for drinking water. A possible alternative is to replace the water from the BRW sector with treated effluent from the SEW sector. The financial and energy cost of treating the sewage may be comparatively higher than normal water treatment processes required to supply the water that the plant currently uses. It may, however, offer a more sustainable option if, in the longer term, drinking water supplies need to be supplemented by seawater desalination.

The indirect intensities for the Gas Turbine (GT) sector are significant for both 1996 and 2001. Given the method used to disaggregate the input-output data between the electricity sectors (largely based on generation output), the majority of the indirect water use would come from the energy inputs that are unique to the GT sector, such as fuel oil from the Petroleum Refining (PR) sector. Gas turbine power plants – using natural gas as the fuel source – are being installed to meet intermediate and peak demand in NSW. The water implications of using gas turbines requires further analysis. Firstly, as with coal fired plants, freshwater use can be reduced if the plants are located in coastal areas. Secondly, the existing plants in the models use fuel oil. A switch to natural gas instead would reduce the indirect water consumption, as the results indicate that for both 1996 and 2001, the total water intensities for the PR sector are higher than the GAS sector. Thirdly, the choice of technology would also need to be considered. The input-output models developed for this research include a GT sector (which represent open cycle gas turbine plants) and a CC sector (which represent combined cycle gas turbine plants). The results indicate that the water intensities for the GT sector are lower than for the CC sector. Combined cycle technology, however, is more energy efficient, emitting fewer greenhouse gases. An assessment of the water requirements for future gas turbine plants would therefore need to consider these three factors, in balance with priorities to reduce carbon emissions.

In this research, the Other Renewables (OR) sector represents an 'average' renewable energy technology comprising wind, photovoltaics, and technologies that combust bagasse, biogas and biomass. The water intensities presented in Tables 5-3 and 5-4 may therefore overestimate the water used by some of the individual renewable technologies. The increase in water use in 2001 is largely attributed to biomass co-firing in coal-fired power plants, and reflects a shift in the electricity industry to renewable energy as a result of government policies, such as the Mandatory Renewable Energy Target. In this instance, a policy aimed at reducing carbon emissions has resulted in a trade-off in terms of increasing the water-intensity of sectors that are considered less harmful to the Environment. The renewable technologies were aggregated in the 1996 and 2001 models, because of the limited historical data on renewable generation. It is recommended that the renewable technologies be disaggregated when analysing future water and energy scenarios, so that the impact of individual technologies may be determined.

In summary, the electricity sectors exhibited strong forward linkages in both 1996 and 2001, confirming the importance of electricity for the NSW economy. The water required to generate electricity represented a substantial indirect use of water for all economic sectors. Due to the significant differences in the water results for the various electricity sectors, future investment decisions in the electricity industry should take into consideration the water requirements of the different generation technologies, as well as substitution possibilities between electricity and gas. The severity and duration of recent droughts, and the uncertainty over the availability of water resources as a result of climate change reinforce this recommendation (refer to Chapter 2 for further discussion). Further, the results from the 2001 model appear to be consistent with similar studies or data contained in other reports. The model results, particularly for the CF and CC sectors were noticeably higher compared to the external reports, because of indirect water use. This suggests that any meaningful analysis into water use in the electricity industry should consider indirect use.

5.3 Energy intensities for the water sectors

As discussed in Chapters 2 and 4, climate change is motivating water utilities the world over to adopt 'adaptive management' strategies in order to cope with the inherent uncertainties and challenges that climate change will present. Such uncertainties and challenges include changes to rainfall patterns and potentially drier conditions. In Australia, the recent drought has provided further impetus to develop adaptive management strategies and to pursue non-rainfall dependent sources of water, some of which come at a high energy cost.

The purpose of this analysis is to examine the energy demand of the NSW water industry as a whole, in order to determine which of the water sectors are the most energy-intensive, and to assess whether this consumption is derived mainly from direct or indirect use. The water industry comprises three sectors: Irrigation & Drainage Water (IDW), Bulk & Retail Water (BRW) and Sewerage (SEW). Section 5.3.1 presents the empirical findings for the water sectors for both years. Section 5.3.2 compares the results with other published data, and Section 5.3.3 discusses some of the implications of the results for the NSW water industry.

5.3.1 Empirical findings

Tables 5-6 and 5-7 list the energy intensities for the water sectors. The tables list the amount of energy supplied by the energy production sectors in the economy, namely the Electricity sector (as an aggregate of six the electricity sectors), the Petroleum Refining (PR) sector and the Retail Gas Supply (GAS) sector. These results are useful for determining direct and indirect energy consumption by the water sectors. The tables also list the Primary Energy intensities for the water sectors, in the form of Raw Coal, Crude Oil and Gas. These sources are depicted in the input-output models as the following primary inputs: Raw Coal and Raw Coal imports; Crude Oil imports and Petroleum Refining imports converted to their crude oil equivalent; and Gas imports. The relationship between the energy production sectors and primary inputs is similar to that in the water industry. That is, the energy sector intensities of Electricity, PR and GAS are embedded in the primary energy intensities of Raw Coal, Crude Oil and Gas, respectively (refer to Section 3.4.3 for further discussion).

Primary energy intensities offer some distinct advantages. The intensities account for conversion losses and therefore offer a better indication of the total energy required to produce energy for final use, and in turn carbon emissions. In addition, the energy sectors themselves consume energy from other sectors (for example, the GAS sector consumes electricity and therefore this electricity consumption would be embedded in the GAS intensities for all other sectors). Converting all the energy sector outputs to their primary energy equivalent therefore avoids double counting.

Table 5-6 Direct and total energy intensities for the water sectors in 1996 (MJ/ML)

	Energy production sectors						Energy primary inputs			
	Electricity		Petroleum Refining		Gas Supply		Raw Coal	Crude Oil	Gas	Primary energy
	Direct	Total	Direct	Total	Direct	Total	Total	Total	Total	Total
IDW	22.63	28.35	3.26	13.15	-	4.53	73.13	14.66	4.52	92.31
	(80%)	(20%)	(19.9%)	(80.1%)		(100%)				
BRW	1,418.60	1,634.60	204.67	491.72	-	124.87	4,019.33	532.16	124.50	4,675.99
	(87%)	(13%)	(29.4%)	(70.6%)		(100%)				
SEW	628.55	855.23	90.69	523.19	-	201.63	2,299.17	590.76	201.02	3,090.95
	(73%)	(27%)	(14.8%)	(85.2%)		(100%)				

Source: Derived from the Leontief hybrid model as described in Section 3.4

Table 5-7 Direct and total energy intensities for the water sectors in 2001 (MJ/ML)

	Production sector						Production factors			
	Electricity		Petroleum Refining		Gas Supply		Raw Coal	Crude Oil	Gas	Primary energy
	Direct	Total	Direct	Total	Direct	Total	Total	Total	Total	Total
IDW	28.75	37.29	3.86	25.23	0.63	8.82	91.40	29.55	8.79	129.74
	(77%)	(23%)	(13%)	(87%)	(7%)	(93%)				
BRW	1,392.91	1,696.79	186.87	901.57	30.37	317.26	4,091.38	1,049.50	316.14	5,457.02
	(82%)	(18%)	(17%)	(83%)	(9%)	(91%)				
SEW	929.26	1,241.59	124.67	935.26	113.36	423.07	3,069.70	1,098.00	421.58	4,589.29
	(75%)	(25%)	(12%)	(88%)	(21%)	(79%)				

Source: Derived from the Leontief hybrid model as described in Section 3.4

The results indicate that:

- Direct consumption accounts for a large proportion of the Electricity intensities for the water sectors in both years, ranging from 73 per cent for SEW to 87 per cent for BRW in 1996. Further, the Electricity intensities were substantially higher than the PR and GAS intensities. Significant reductions in energy consumption may be gained, therefore, by focusing on the direct electricity consumption in the water sectors. The results further reinforce the historical importance of the electricity industry for the development of the water industry. The water industry's pursuit of energy-intensive treatment technologies, in order to combat drought (such as desalination and advanced wastewater treatment processes) will serve to strengthen the importance of this link in the future (refer to Section 4.4.1). In the context of climate change, it is critical that the water industry uses electricity from renewable sources, in order to reduce carbon emissions, and indirectly reduce the impact of climate change on water resources.

- The total Electricity intensities for BRW were the highest in both 1996 (1,634.6 MJ/ML) and 2001 (1,696.79 MJ/ML). It is likely that transporting water – particularly using electricity to pump water – accounts for a significant proportion of this figure. The direct Electricity intensities decreased from 1,418.60 MJ/ML in 1996 to 1,392.91 MJ/ML in 2001. A possible explanation for this decrease is the implementation of activities to reduce leaks in the water pipelines between the two time periods (refer to Section 2.1.2).

- The direct Electricity intensities for SEW increased substantially from 628.55 MJ/ML in 1996 to 929.26 MJ/ML in 2001. A possible explanation is the commencement of recycled water schemes between the two time periods, such as the Water Reclamation and Management Scheme in Sydney which commenced in July 2000 and the Rouse Hill Recycled Water Scheme in Sydney's north-west which commenced in 2001 (Sydney Olympic Park 2008; Sydney Water 2008a).

- Refined petroleum is the second most dominant fuel source after electricity, although the refined petroleum intensities are significantly less than electricity. Motor vehicle use accounts for most of the direct consumption of refined petroleum in the water sectors. For the SEW sector – which consumes the largest amount of refined petroleum – transporting biosolids from inland sewage treatment plants to areas for disposal or reuse would account for most of the petrol use. Converting vehicles from petrol to natural gas would reduce the greenhouse gases emitted by the water sectors.

- Indirect consumption – that is energy embedded in the supply chains of the water sectors – accounts for the majority of the Petroleum Refining intensities. Indirect consumption approximately doubled between 1996 and 2001, which is disproportionate to changes in the direct consumption figures. This trend is evident in all three water sectors, but carries fewer implications for the IDW sector, given the comparatively small amount of energy this sector consumes. A possible explanation for this increase is the commissioning of water infrastructure between the two periods, such as the Prospect Water Filtration Plant which was completed in 1996 to provide drinking water to over 80 per cent of Sydney, and the two recycled water schemes previously mentioned (Degremont 2008). This highlights the impact of water infrastructure development on energy demand. Energy savings from existing infrastructure may be achieved by analysing the supply chains of the water sectors to determine which material inputs are contributing most to indirect consumption, and where possible substituting these materials with those that are less energy-intensive. Such analysis would require suitable tools to assist with assessing the material inputs from an energy-oriented LCA approach for the Australian context.

- The energy data obtained for this research indicated that no gas was directly consumed by the water sectors in 1996, although this had changed by 2001. Similar to the PR intensities, indirect consumption accounted for most of the GAS intensities for the water sectors. Again, the commissioning of water infrastructure between the two periods may account for this increase.

- Based on the primary energy results, the total energy intensities increased between 1996 and 2001 for the reasons cited above. That is, more energy was required to transport and treat the same amount of water or sewage, or to deliver irrigated water in 2001, compared with 1996. Given the link between energy use and climate change, the water industry can ill-afford to let its energy consumption go unchecked. Yet the business of adapting to a changing climate – a necessity for the water industry – is itself an energy-intensive process. This further strengthens the impetus to derive as much energy saving in existing practices and procurement activities as possible.

5.3.2 Comparison with other reports

There have been no studies to date that estimate the total energy intensities for the water industry in NSW. A report prepared by Foran, Lenzen and Dey (2005) for the (then) Commonwealth Department of Environment and Heritage presents the results of a triple bottom line account of the Australian economy based on input-output analysis, which includes an analysis of the water industry. The account assessed the impact of 135 sectors on a range of economic, social and environmental indicators, including direct and total primary energy use.

Foran, Lenzen and Dey (2005) estimate the total Primary Energy intensity for the water industry at 4.02 MJ per dollar of final demand[14]. In order to compare this result with the results from this research, two additional calculations were required. In the first calculation, 4.02 MJ/$ was multiplied with the final demand data from the 2001 Leontief monetary model for this research, resulting in a total primary energy consumption figure of 7,913 MJ. In the second calculation, which uses data from this research only, the total Primary Energy intensities in Table 5-7 were multiplied with the corresponding amount of water in ML supplied to the final demand categories from the 2001 Leontief hybrid model, resulting in a total primary energy consumption figure of 7,759 MJ. That is, both calculations – using data from and this research and Foran, Lenzen and Dey (2005)– derived similar results, with a difference of approximately two per cent.

Whilst the results from this research are in line with Foran, Lenzen and Dey (2005), the models developed for this research offer distinct advantages for the purpose of examining the links between water and energy. The disaggregation of the water industry into three sectors enables a more accurate estimation of the energy intensities for the different sectors. This is of particular importance, given the substantial differences in the energy intensities for IDW compared to BRW and SEW. Further, the state-based approach better represents the electricity generation mix for NSW.

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[14] Financial data for the triple bottom line account appears to be based on 1994-95 data (refer to page 53 of Volume 1). Adjustments for inflation have not been made in this comparison.

5.3.3 Some discussion

The analysis of the NSW water industry undertaken in this research – to the best knowledge of the author – appears to be the first of its kind. Its state-based approach is also appropriate, considering that although water policies are driven by a national framework, they are implemented by state governments (refer to Chapter 4). Some additional points of discussion now follow:

- Strategies to reduce energy consumption should be tailored to the types of energy consumed. For example, direct consumption comprises the bulk of the Electricity intensities for the water sectors, particularly for the Bulk & Retail Water (BRW) sector. A large proportion of this comprises water for pumping and therefore leak reduction initiatives and the maintenance of pumping station equipment to optimise performance would further reduce electricity consumption. Increasing the supply of electricity from renewable energy sources would assist in reducing the carbon emissions in the industry, given that there are strong historical links between water and electricity. Demand management strategies in the water industry would also reduce electricity consumption (this is explored later in the water and energy scenarios).

- A significant proportion of the PR intensities is from indirect consumption. Given that in 2001, refined petroleum accounted for approximately 20 per cent and 25 per cent of primary energy consumed by the BRW and Sewerage (SEW) sectors, respectively, there is scope to further examine the supply chains of both sectors, in order to determine the possibility of substituting existing materials and services with those that rely less on refined petroleum.

- The Retail Gas Supply (GAS) intensities increased between 1996 and 2001, although its contribution to the overall energy consumption figure was relatively minor. Whilst it is not clear in the results, this increase may have actually offset increases in the electricity intensities. A significant proportion of this gas would have been consumed for heating in offices, where substitution possibilities with electricity would exist (Petre 2005). Given that gas consumption emits fewer greenhouse gases than electricity – and that GAS consumes less water than any energy sector in NSW (see Table 5-4) – substitution of electricity with gas should be encouraged, particularly in office buildings.

- In comparison with the BRW and SEW sectors, the energy intensities for the Irrigation & Drainage Water (IDW) sector were minimal. A significant proportion of irrigation water in

NSW is delivered by gravity to farm gates. As discussed in Chapter 4, a water market has been established in the rural water industry which will enable water licences to be traded between users. In order to function properly, the market will require technology that can effectively meter the water delivered to users. Improvements to onsite irrigation practices, with a view to reduce water consumption, may require more sophisticated technology. Both activities are likely to increase energy consumption, particularly electricity, in the water industry. Some of this consumption could be offset by installing micro and mini hydro turbines in weirs along irrigation channels, which has begun to occur in NSW.

- The links between the water sectors and the wider economy – as discussed in Section 5.1.2 – are strongest for IDW, which was one of the key sectors in the NSW economy in 2001. From an energy perspective, this augurs well for sectors that are highly reliant on agricultural outputs, because of the comparatively low energy intensities for IDW, as discussed above.
- It is clear in the discussion in Chapter 2 that future options to supply and treat water and wastewater differ significantly in their energy consumption. Any analysis into the future supply of water and electricity should include – as separate input-output water sectors – the latest best available technologies that are likely to become industry standards in the coming years.

5.4 Summary and conclusion

This chapter forms part one of the empirical investigation into the links between water and electricity, which has been reinforced by the qualitative findings from the historical analysis in Chapter 4. The structural trends and linkages described in this chapter offer insights into the role of the various sectors in the NSW economy, and how these roles have changed. In general, there has been a perceivable shift towards the services sectors, due to a combination of both global and domestic forces outlined in this chapter. The insights are useful for understanding the wider implications of the water and energy intensities of these sectors, which are quantified in Chapter 6. In the case of the water and electricity sectors, the results confirm the importance of these sectors as fundamental infrastructure providers, with many exhibiting strong forward linkages. As described, the increase in the strength of the linkages for these sectors reflects changes to their labour productivity between 1996 and 2001, brought about largely by the implementation of the reform program in these years.

This chapter also quantified the water intensities for the energy sectors. The intensities are disaggregated into water supplied by the water sectors – IDW, BRW and SEW – and water used directly from the Environment, which is represented by Raw Water and Instream Use. This level of disaggregation is not undertaken in the four external reports reviewed in this chapter. However, such a disaggregation offers additional insights that these external reports cannot. The water intensities for the electricity sectors clearly show that some sectors, such as GT, rely heavily on the water sectors, and therefore would be in direct competition with other drinking water users, particularly during water shortages. In contrast, other electricity sectors such as CF and HYDRO predominantly source water directly from the Environment, which generally places these sectors in competition with a different group of water users, such as irrigators, and the Environment itself. It is also evident that the generation technologies vary in their water intensity, with CG and OR generally having the lowest intensities. The non-electric energy sectors – GAS, PR, PCP and COAL – are less water-intensive compared with the electricity sectors. Substitution between electricity and gas would reduce water consumption in the economy, in addition to carbon emissions. Similarly, electricity generated using gas has the potential to reduce water consumption.

This chapter also presented energy intensities for the water sectors, disaggregated into energy supplied by the energy sectors Electricity, PR and GAS, as well as their primary energy equivalent. The study by Foran, Lenzen and Dey (2005) referred to in Section 5.3.2 calculates the primary energy intensity for the water industry as a whole, and fails to recognise the very different energy intensity profiles that exist in the three water sectors. For example, IDW consumes a minimal amount of energy compared with BRW and SEW. Whilst consumption of electricity comprises largely direct use, the consumption of petroleum and gas comprises largely indirect use. The analysis also clearly shows an increase in energy intensities, brought about by the commissioning of water infrastructure between the two time periods. This highlights the impact of water infrastructure investment decisions on energy and reinforces the importance of assessing infrastructure from an energy perspective, including accounting for indirect consumption.

The following chapter explores the interactions between water and energy within the other sectors in the NSW economy, and discusses the implications of these interactions in the context of the sectoral linkages identified in the early sections of this chapter.

Chapter 6

Water-energy nexus: an empirical investigation (II)

When we try to pick out anything by itself, we find it hitched to everything else in the Universe

John Muir

This chapter forms part 2 of the empirical investigation. As highlighted in the review of the water-energy nexus in Chapter 2, the interactions between water and electricity have implications for other sectors in the economy. In order to better understand these interactions, this chapter focuses on the remaining nineteen sectors in NSW that do not form part of the water or energy industries. The major groups to which these sectors belong include Agriculture, Mining, Manufacturing, Construction, Transport and Services.

Section 6.1 quantifies water and energy intensities for these sectors and identifies possible correlations between them using scatter plots. Section 6.2 analyses the wider impacts of these sectors in terms of their contribution to economic output, income generation and employment growth, using multiplier analysis. As discussed in Section 3.4.3, multipliers measure the impact arising from a change in final demand for a particular sector. The multipliers are examined in the context of the water and energy intensities, with a view to identifying potential trade-offs between using water and energy, and the sectors' wider socio-economic functions. These trade-offs are statistically validated using the Pearsons Product Moment Correlation Coefficient equation (as described in Section 6.2).

Section 6.3 examines the extent of substitution possibilities between water and electricity using cross price elasticities of demand. Recent studies (reviewed in Chapter 2) have demonstrated that water demand responds to electricity price changes, and conversely that electricity demand responds to water price changes. Additional insights may thus be gained by examining such relationships for the remaining nineteen sectors in NSW. In addition, Section 6.3 presents own price elasticities for water and electricity, in order to determine the responsiveness of demand, to incremental changes in their own price. Section 6.4 summarises the outcomes from this chapter and offers some concluding remarks.

6.1 Physical links between water and energy

The Leontief hybrid models described in Chapter 3 form the basis of the analysis presented in this section. Section 6.1.1 presents the water and energy intensities for each of the major sectoral groups. It follows a similar approach to that adopted in Sections 5.2 and 5.3. That is, water intensities have been calculated for water supplied by the water sectors, Irrigation & Drainage Water (IDW), Bulk & Retail Water (BRW) and Sewerage (SEW), and water that is extracted from the Environment (Raw Water and Instream Use). Similarly, energy intensities have been calculated for energy supplied by the energy sectors (Electricity, Petroleum Refining (PR) and GAS) and for their primary energy equivalent (Raw Coal, Crude Oil and Gas). Section 6.1.2 identifies trends and correlations between the intensities using scatter plots.

Section 3.4 described the basis for the calculation of the direct and total intensities. An important point to note is that total intensities comprise both direct and indirect use, and therefore account for water and energy embedded in the material flows between the different sectors. As described previously, the direct and total intensities represent the amount of water or energy required to produce one unit of final demand for a particular sector. The corresponding units are ML/ $000 for water and MJ/ $000 for energy.

6.1.1 Water and energy intensities for the remaining sectors

Tables 6-1 and 6-2 list the direct and total water and energy intensities for the remaining sectors, respectively (refer to Appendix 6 for a percentage breakdown of the total intensities into the direct and indirect components). The results indicate that total intensities are significantly higher than direct intensities.

Table 6-1 Direct and total water intensities (ML/$000 2001)

		1996										2001									
		Water production sectors						Water primary inputs				Water production sectors						Water primary inputs			
		IDW		BRW		SEW		Raw water		Instream use		IDW		BRW		SEW		Raw water		Instream use	
		D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T
1	Ag	311.59	351.70	-	0.48	0.94	1.08	302.02	693.13	-	5.22	293.79	323.78	0.13	0.57	0.26	0.29	371.61	732.91	0.05	14.55
3	OMS	-	0.41	2.05	2.98	2.00	2.27	2.11	6.26	-	22.32	-	0.52	2.53	3.21	1.15	1.25	8.12	13.86	0.16	96.22
4	FBT	-	64.84	1.99	2.83	-	0.21	0.06	130.64	-	7.18	-	44.10	1.57	2.22	-	0.05	0.33	102.59	-	19.88
5	TCFL	-	10.95	5.91	7.12	-	0.04	0.02	28.75	-	7.22	-	12.96	0.58	0.94	-	0.02	0.04	30.44	-	10.23
6	WPP	-	5.28	1.95	2.62	-	0.04	0.22	13.33	-	7.32	-	4.19	0.53	1.04	0.00	0.02	0.76	11.64	-	19.69
9	CHEM	-	2.74	1.71	2.97	-	0.06	0.03	8.52	-	11.08	-	1.83	0.80	1.32	-	0.01	0.01	5.67	-	15.11
10	NMMP	-	0.82	1.17	2.24	-	0.20	0.02	4.22	-	20.31	-	0.30	0.58	1.17	-	0.05	0.03	2.61	-	50.54
11	BMP	-	0.52	3.57	5.70	-	0.19	0.02	7.40	-	56.63	-	0.30	1.08	1.98	-	0.10	0.02	4.39	-	155.24
12	FMP	-	0.66	2.45	4.56	-	0.06	-	6.07	-	19.28	-	0.46	1.09	1.91	-	0.03	-	3.57	-	56.82
13	TE	-	0.45	0.56	1.57	-	0.03	-	2.57	-	12.59	-	0.27	0.15	0.55	-	0.01	0.00	1.42	-	22.05
14	OME	-	0.41	0.67	1.83	-	0.04	0.16	2.94	-	11.60	-	0.21	0.11	0.38	-	0.01	0.00	1.04	-	14.69
15	MM	-	2.12	2.11	3.71	-	0.09	-	8.08	-	9.63	-	1.71	0.09	0.55	-	0.02	0.00	4.72	-	15.21
26	CONST	-	0.52	0.39	1.08	0.00	0.03	0.00	2.18	-	3.87	-	0.67	0.43	0.96	-	0.02	0.01	2.77	-	14.54
27	WRT	-	0.58	0.48	0.96	-	0.02	0.00	2.14	-	4.73	-	1.29	0.52	1.03	-	0.01	0.00	4.22	-	18.19
28	TS	-	0.37	0.54	0.97	-	0.01	0.00	1.73	-	3.46	-	0.38	0.56	1.10	-	0.01	0.00	2.11	-	10.65
29	FPBS	-	0.38	0.40	0.76	-	0.01	0.01	1.55	-	2.48	-	0.45	0.39	0.74	-	0.01	0.01	1.91	-	6.80
30	GAD	-	1.22	0.55	1.13	-	0.02	0.05	3.64	-	5.64	-	0.86	0.48	0.92	-	0.01	0.19	3.33	-	18.82
31	EHCS	-	0.44	0.78	1.07	-	0.01	0.06	2.04	-	3.63	-	0.37	1.07	1.27	0.00	0.01	0.19	2.42	-	11.24
32	OCS	-	6.01	1.32	1.86	0.30	0.34	0.31	14.06	-	4.30	-	4.87	4.04	4.61	0.24	0.27	1.89	17.79	-	11.64

Source: Derived from the Leontief hybrid models as described in Section 3.4. Appendix 6 details the percentage breakdown of total intensities into direct and indirect components.

Notes: D = direct, T = total (direct + indirect)

Table 6-2 Direct and total energy intensities (MJ/$000 2001)

	1996										2001									
	Energy production sectors						Energy primary inputs				Energy production sectors						Energy primary inputs			
	Electricity		PR		GAS		Raw Coal	Crude Oil	Gas	Primary energy	Electricity		PR		GAS		Raw Coal	Crude Oil	Gas	Primary energy
	D	T	D	T	D	T	T	T	T	T	D	T	D	T	D	T	T	T	T	T
1 Ag	304	553	1,059	2,365	-	200	1,449	2,415	199	4,064	260	467	2,683	4,175	0	226	1,143	4,552	226	5,921
3 OMS	1,741	2,361	12	1,364	-	204	6,033	1,443	204	7,680	2,540	3,089	2,487	3,866	0	293	7,359	4,239	292	11,889
4 FBT	373	761	102	1,687	461	773	2,355	1,755	771	4,881	369	639	20	2,097	332	568	1,748	2,309	566	4,623
5 TCFL	492	763	97	798	332	534	2,100	845	533	3,478	179	329	9	960	199	331	853	1,064	330	2,248
6 WPP	487	775	51	991	-	182	2,227	1,051	182	3,459	385	633	7	1,268	0	180	1,678	1,428	180	3,285
9 CHEM	592	1,174	1,831	3,433	1,888	2,780	3,638	4,604	2,771	11,012	276	486	446	1,453	1,375	1,841	1,358	2,312	1,834	5,504
10 NMMP	1,395	2,149	255	2,823	4,055	4,962	8,177	2,921	4,947	16,045	1,122	1,625	227	3,145	2,575	3,259	5,368	3,459	3,248	12,074
11 BMP	4,101	6,140	193	1,590	2,506	3,657	35,944	4,443	3,646	44,033	3,538	5,071	91	1,524	1,341	2,100	23,193	3,903	2,093	29,189
12 FMP	413	2,073	78	1,109	275	1,333	9,973	1,802	1,329	13,104	591	1,843	13	1,171	271	891	6,711	1,760	888	9,359
13TE	607	1,342	15	714	142	599	4,839	965	597	6,401	187	715	3	510	43	324	2,561	751	323	3,635
14 OME	331	1,244	63	800	101	682	5,440	1,162	680	7,281	108	477	13	430	34	223	1,780	608	222	2,610
15 MM	19	1,035	15	1,101	88	750	5,033	1,488	747	7,269	14	494	0	861	65	345	1,914	1,105	344	3,362
26 CONST	5	413	454	1,348	9	446	1,707	1,434	444	3,586	7	470	267	1,310	9	455	1,601	1,634	454	3,689
27 WRT	311	500	64	930	201	296	1,320	950	295	2,565	391	585	24	1,507	241	363	1,420	1,652	361	3,433
28 TS	133	367	16,789	19,900	35	228	1,011	19,807	228	21,045	131	344	15,159	18,365	82	371	873	19,922	370	21,164
29 FPBS	119	263	1	495	1	90	781	520	90	1,391	103	219	2	601	1	63	559	668	63	1,290
30 GAD	351	597	54	1,067	121	257	1,636	1,104	256	2,996	406	605	105	1,059	134	260	1,507	1,368	259	3,134
31 EHCS	265	384	51	450	136	239	1,014	482	238	1,734	277	361	73	383	136	202	872	429	201	1,502
32 OCS	243	455	3	776	15	156	1,246	810	156	2,212	199	374	5	691	12	130	939	775	129	1,843

Source: Derived from the Leontief hybrid models as described in Section 3.4. Appendix 6 details the percentage breakdown of total intensities into direct and indirect components.

Notes: D = direct, T = total (direct + indirect)

That is, indirect use of water and energy comprise a significant proportion of their total intensities. Total intensities therefore provide a better indication of the water and energy requirements of the different sectors.

Agriculture

The Raw Water and IDW intensities for Agriculture were highest in NSW in both 1996 and 2001. The direct Raw Water intensities increased from 302.02 ML/$000 in 1996 to 371.61 ML/$000 in 2001, whilst the direct IDW intensities decreased from 311.59 ML/$000 in 1996 to 293.79 ML/$000 in 2001. This suggests that Agriculture required more water to produce the same amount of unit output in 2001 compared to 1996, and that there appears to be a shift towards greater reliance on extracting water directly from the Environment. The increase in the Raw Water intensities may be a result of changes to the estimation techniques from the first to the second Water Account, rather than any changes to the physical use of water. The first Water Account underestimated water consumed by livestock, because of the lack of suitable data (ABS 2004). In contrast, this research obtained more complete irrigation water data from ANCID and directly from irrigators, which were used to calculate the IDW intensitites. The IDW intensities are therefore based on better quality data and would better reflect the actual physical changes between the two periods. For example, a decrease in the direct IDW intensities noted above may reflect improvements to on-farm irrigation practices.

In terms of energy use, the demand for petroleum was the highest in both years. The direct PR intensities were 1,059 MJ/$000 in 1996 and 2,683 MJ/$000 in 2001; on-farm vehicle use accounted for most of this use. There appears to be an increase in the energy intensity of this sector between the two time periods. A possible explanation is an increase in the mechanisation of the sector, which would require additional petroleum fuel. In contrast, the direct Electricity intensities were substantially lower at 304 MJ/$000 in 1996 and 260 MJ/$000 in 2001.

Mining

There are two mining sectors in the input-output models – Other Mining & Services to Mining (OMS) and Coal Mining (COAL). The outputs of COAL are in physical energy units (PJs) in the Leontief hybrid models, and therefore the results for this sector were previously discussed in Section 5.2.1.

The OMS sector is one of the most energy-intensive sectors in NSW. It relies heavily on electricity, second only to the manufacturing sector, Basic Metals & Products (BMP). An expected boom in the output of this sector in the 1980s prompted substantial investment into electricity generation capacity, in order to meet the demand for electricity. This boom did not occur, but led to overcapacity, which became one of the initial drivers of reform in the 1980s (refer to Section 4.4.3). In terms of primary energy, it is most reliant on Raw Coal, as a result of electricity consumption. The Raw Coal intensities for this sector were 6,033 MJ/$000 in 1996, increasing to 7,359 MJ/$000 in 2001.

The water intensities for this sector reflect its high dependence on electricity. The total Instream Use intensities (due to the consumption of hydropower) were 22.32 ML/$000 in 1996 and 96.22 ML/$000 in 2001, second highest in the economy after the BMP sector. In general the water intensity of the sector appears to have increased in 2001, particularly for Instream Use and Raw Water.

A possible explanation for the increases in the intensities for OMS is that it is capital-intensive. A further increase in the mechanisation of this sector would therefore increase its energy intensity. This sector has also experienced a growth in output over the last two decades, particularly in the metallic minerals sub-sector that includes gold (that grew by eighteen per cent per annum) and copper (that grew by 10.4 per cent per annum) (ACIL Tasman 2006).

Manufacturing

The input-output models developed for this research comprise twelve manufacturing sectors. Two of these sectors – Petroleum Refining (PR) and Petroleum & Coal Products NEC (PCP) – were discussed in Section 5.2.1, because the outputs of both sectors are measured in physical energy units (PJs) in the Leontief hybrid models. The results for the remaining ten manufacturing sectors are discussed below.

As depicted in Tables 6-1 and 6-2, the manufacturing sectors that rely most on the outputs from Agriculture – namely Food, Beverage & Tobacco (FBT), Textile, Clothing, Leather & Footwear (TCFL) and Wood, Paper & Printing Products (WPP) – were amongst the highest water users in both years. This relationship is evident in the total IDW and Raw Water intensities for these sectors, which is largely composed of indirect use. As mentioned in Chapter 5, FBT and WPP accounted for a growing contribution to economic output in Australia; FBT exhibited strong backward linkages and WPP exhibited strong forward linkages in both years. The water intensity of FBT is significantly affected by the sectors that it relies on such as Agriculture, whilst WPP contributes significantly to the indirect water consumption of other sectors. Therefore policies that improve the water efficiency of WPP in particular would have wider benefits for the economy. These relationships between IDW, Agriculture, FBT and WPP reflect the historical importance of irrigation to national development programs implemented by the Federal Government (refer to Section 4.3). The TCLF has experienced competition from cheap imports, and also exhibited weak linkages in both years. Therefore the high water intensities would have less of an impact on the indirect water use by other sectors, compared with FBT and WPP.

The most energy-intensive manufacturing sectors (in terms of electricity) also exhibited the highest Instream Use intensities. These sectors included Basic Metals & Products (BMP), Non-metallic Mineral Products (NMMP), Fabricated Metal Products (FMP), Transport Equipment (TE) and Other Machinery & Equipment (OME). Whilst Instream Use of water is not consumptive, these sectors were more reliant on Instream Use compared with water supplied by the water sectors or extracted as Raw Water from the Environment.

The BMP sector had the highest Electricity intensity in both 1996 (4,101 MJ/$000) and 2001 (3,538 MJ/$000). This sector also consumes coke for iron and steel manufacturing and its total Raw Coal intensity was also the highest in 1996 (35,944 MJ/$000) and 2001 (23,193 MJ/$000). As mentioned in Chapter 5, the BMP sector’s contribution to economic output increased, as did the other sectors closely linked with natural resources. Coupled with the strong backward linkages and high forward linkages in both years, it is likely that this sector will continue to play a significant role in the NSW economy. Efforts to reduce energy consumption in the state should therefore consider energy efficiency measures for this sector.

The remaining manufacturing sectors exhibiting high electricity intensities – such as NMMP, FMP, TE and OME – have reduced their contribution to economic output. Nonetheless, some of these sectors – namely NMMP and FMP – were key sectors in both years and therefore continue to play an important role in the economy. The NSW economy at large would therefore still benefit from measures to improve the energy efficiencies of these sectors.

These energy-intensive manufacturing sectors have assisted in ‘locking in’ coal fired generation in the electricity industry. In the past, the NSW electricity industry invested heavily into coal fired technology, because of the abundant reserves of cheap black coal in the state. Due to the high capital costs and low operating costs, this technology operates best as a baseload supply.

Manufacturing sectors with production processes that operate 24 hours per day provided ongoing demand for electricity and further impetus for the development of coal fired power stations in the state. Today, government policies are more focused on promoting energy efficiency in energy-intensive sectors, in order to reduce carbon emissions (discussed later in Section 8.1). These policies would also reduce water consumption associated with water-intensive coal fired power stations.

The PR intensity for Chemicals (CHEM) was the highest amongst the manufacturing sectors in both 1996 (1,831 MJ/$000) and 2001 (446 MJ/$000). This sector has increased its contribution to economic output since the 1950s, although it appears that the energy intensity has decreased substantially. This has had beneficial repercussions for the economy, given the strong forward linkages exhibited by CHEM in both 1996 and 2001. Possible reasons for reductions in the intensity include improvements to production processes, or changes to the composition of CHEM sub-sectors. The high reliance on refined petroleum by CHEM is also reflected in its total Crude Oil, which was 4,604 MJ/$000 in 1996 and 2,312 MJ/$000 in 2001.

The Retail Gas Supply (GAS) intensities for NMMP were highest for both 1996 (4,055 MJ/$000) and 2001 (2,575 MJ/$000), followed by BMP (2,506 MJ/$000 in 1996 and 1,341 MJ/$000 in 2001). These results are also reflected in the primary energy intensities for the GAS sector. Measures to improve the energy efficiency of both NMMP and BMP should be encouraged, for the reasons given above.

Construction

The water and energy intensities for the Construction (CONST) sector were amongst the lowest in both years (refer to Tables 6-1 and 6-2 for actual figures). This sector experienced slower economic growth compared to other sectors, and there is less of an impetus to implement strategies in this sector to reduce its water and energy use. Rather, because this sector is material-intensive and exhibited strong backward linkages in both years, improvements to the water and energy efficiencies of the manufacturing sectors upon which it relies – such as Non-metallic mineral products (NMMP) and Fabricated Metal Products (FMP) for example –would reduce its indirect water and energy intensities, which comprises a significant proportion of the total intensities (refer to Appendix 6 for a percentage breakdown).

Transport

The Transport & Storage (TS) sector was one of the lowest water users in the economy, however its Petroleum Refining (PR) intensities were second highest to the manufacturing sector Basic Metals & Products (BMP) in both 1996 (16,789 MJ/$000) and 2001 (15,159 MJ/$000). This sectors is also one of the fastest growing in NSW and exhibited strong linkages with other sectors. The results reflect the importance of this sector for connecting industries in NSW to demand centres in the cities (such as Sydney) and to trading ports that serve international markets, particularly in Asia. In 2001, it was one of the key sectors in the economy, and therefore would have been a main contributor to indirect refined petroleum use – and in turn crude oil use – in the economy. The results also indicate that its direct Retail Gas Supply (GAS) intensities increased from 32 MJ/$000 to 82 MJ/$000 in 2001, which may reflect a substitution of petrol with natural gas as a transport fuel.

Services

Generally, the Services sectors measured low water and energy intensities in both years, particularly Financial, Property & Business Services (FPBS) (refer to Tables 6-1 and 6-2 for actual figures). This sector is also one of the fastest growing in the economy and its forward linkages increased between 1996 and 2001. It is likely that this sector will continue to play a significant role in the economy, with little impact on water and energy demand.

In contrast, Other Commercial Services (OCS) exhibited high total Raw Water intensities in 1996 (14.06 ML/$000) and 2001 (17.79 ML/$000). This sector includes accommodation facilities, cafes and restaurants, which use more water than other service sectors. These facilities rely heavily on the Food Beverage & Tobacco (FBT) sector, which in turn relies on water-intensive Agriculture. The increase in the total Raw Water intensities between the two time periods may be attributed to the differing growth paths of its sub-sectors. The Culture and Recreation sub-sector – which would include the more water-intensive activities mentioned above – grew in line with the national average. In contrast, the Personal and Other Services sub-sector grew more slowly. Therefore, the more water-intensive sub-sector of Culture and Recreation would have increased its output share in the sector. Measures to reduce water consumption in this sub-sector should therefore be encouraged. Further, given the relatively high backward linkages for this sector, improvements in the water efficiency of manufacturing sectors that it relies on would improve its total water intensities. The high reliance on water-intensive manufacturing sectors by OCS is reflected in the indirect proportion of the total Raw Water intensities, which were 98 per cent in 1996 and 89 per cent in 2001.

6.1.2 Correlation between water and energy intensities

The purpose of this section is to identify possible correlations between the total water and energy intensities presented in the previous sections. This is achieved with the aid of scatter plots. Scatter plots are useful for distinguishing relationships between two datasets, with a pair of data forming the x and y coordinates of the points in the plot. Two scatter plots have been developed for both 1996 and 2001. In the first scatter plot, the total Primary Energy and total Raw Water intensities presented in Tables 6-1 and 6-2 form the x and y coordinates. In the second scatter plot, the total Instream Use intensities replace the total Raw Water intensities as the x coordinates. These three primary inputs of Primary Energy, Raw Water and Instream Use better represent an aggregate of water and energy use compared with the production sector intensities – namely IDW, BRW, SEW, Electricity, PR and GAS – for the following reasons. Firstly, not all water that is used in the economy is supplied by the water sectors. For example, Agriculture extracts a large proportion of its water directly from the Environment. Secondly, Instream Use is not captured by the water sector intensities, although it comprises a significant use of water in NSW. Thirdly, the IDW and BRW intensities are embedded in the total Raw Water intensities, because the water sectors themselves extract water from the Environment, before processing and supplying this water to other sectors. Lastly, the energy sector intensities exclude energy that is lost during conversion processes, whereas these losses are captured by the total Primary Energy intensities.

The scatter plots are shown as Figures 6–1 to 6–4. The numbers in the figures correspond to the different sectors, as listed in the following legend:

Legend

1	Agriculture	15	Miscellaneous manufacturing
3	Other mining & services to mining	26	Construction
4	Food, beverages & tobacco	27	Wholesale & retail trade
5	Textile, clothing, footwear & leather	28	Transport & storage
6	Wood, paper & printing products	29	Finance, property & business services
9	Chemicals	30	Government administration & defence
10	Non-metallic mineral products	31	Education, health & community services
11	Basic metals & products	32	Other commercial services
12	Fabricated metal products	▲	Key economic sector
13	Transport equipment	┼	Median intensities (year of analysis)
14	Other machinery & equipment	┼	Median intensities (alternate year)

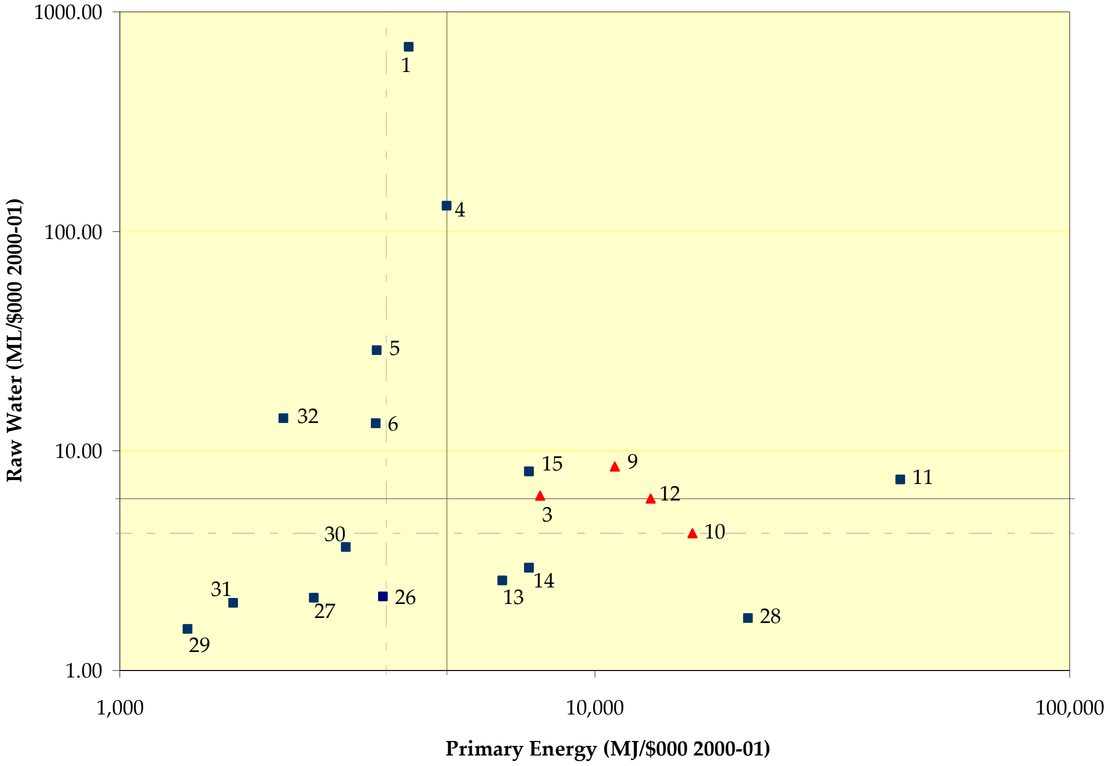

Figure 6–1 Correlation between total Raw Water and Primary Energy intensities for 1996

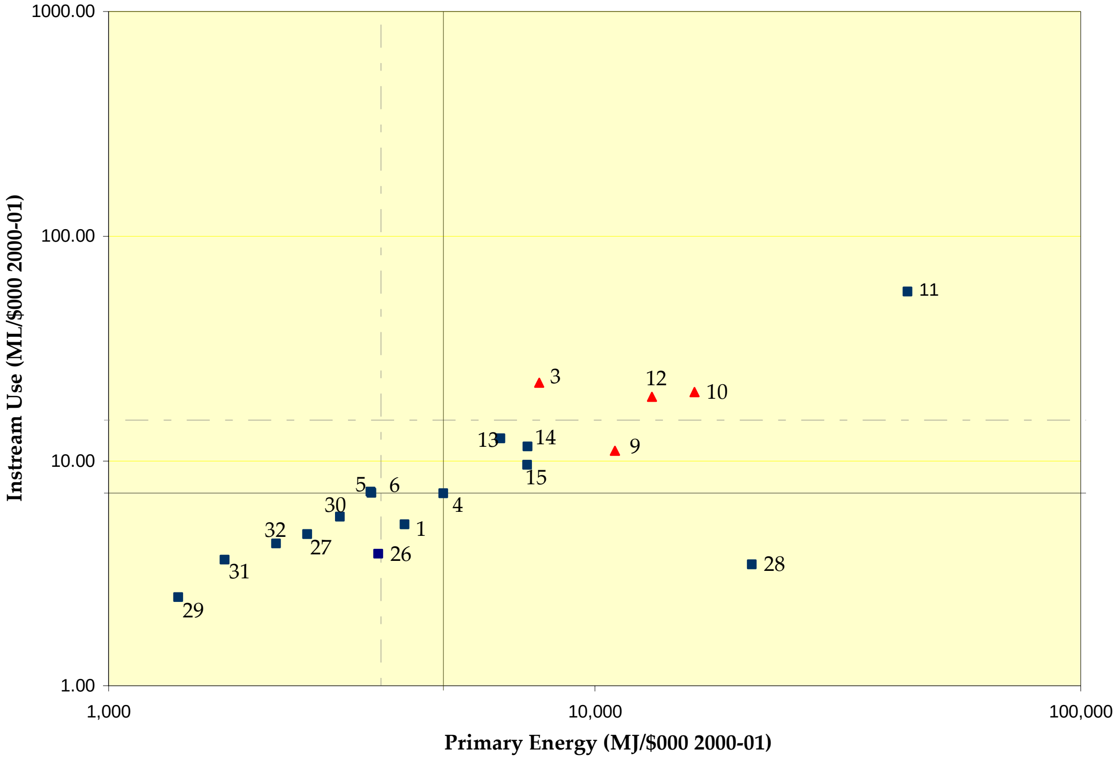

Figure 6–2 Correlation between total Instream Use and Primary Energy intensities for 1996

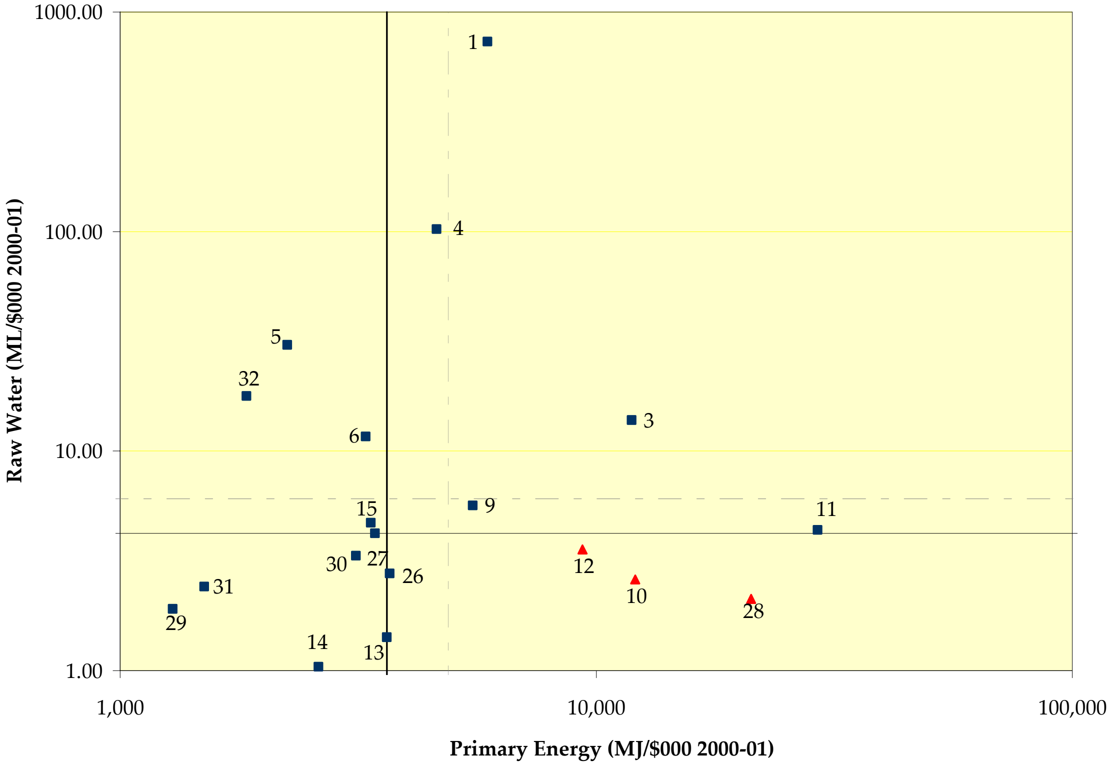

Figure 6–3 Correlation between total Raw Water and Primary Energy intensities for 2001

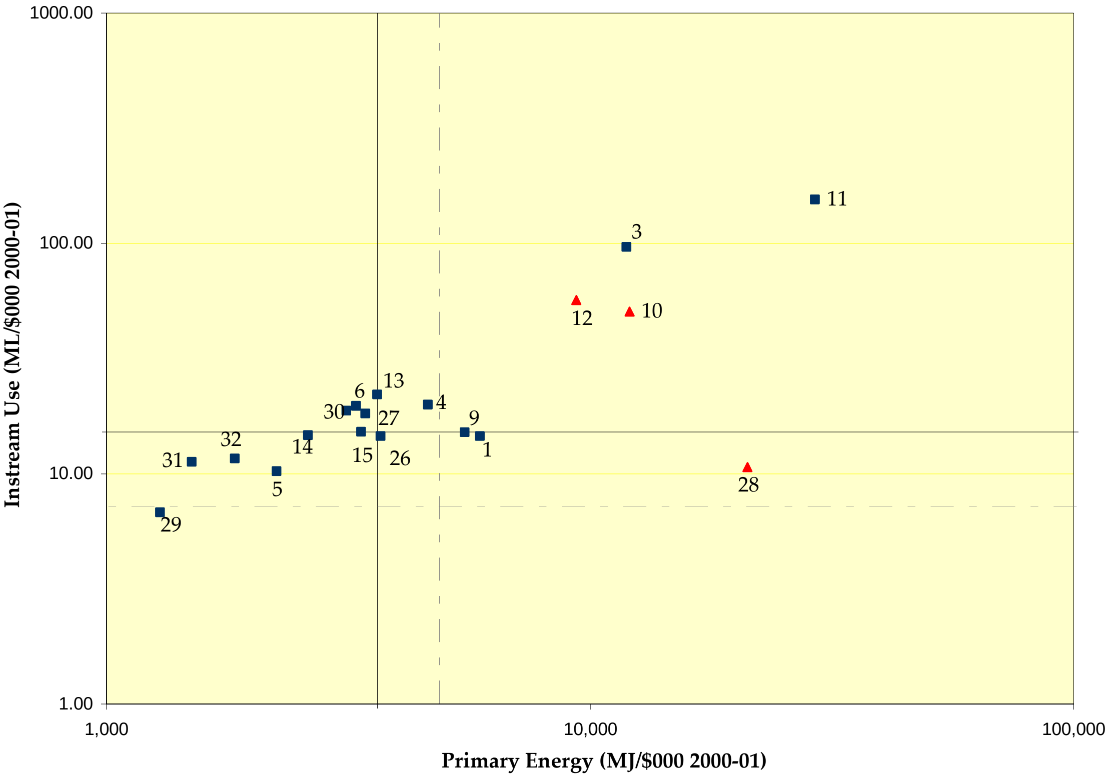

Figure 6–4 Correlation between total Instream Use and Primary Energy intensities for 2001

There appears to be little correlation between the total Raw Water and total Primary Energy intensities in Figures 6–1 and 6–3. Given the range of water and energy intensities detailed in Section 6.1.1, this general observation appears reasonable. For example, the manufacturing sectors Textile, Clothing, Leather & Footwear (TCFL) (5), Food, Beverage & Tobacco (FBT) (4) and Wood Paper & Printing Products (WPP) (6) are water-intensive because they rely heavily on the Agricultural sector, which is the highest consumer of water in NSW. The service sector Other Commercial Services (OCS) (32), which includes accommodation facilities and restaurants, is also water-intensive. The water intensity of these sectors would therefore align more with their links with Agriculture, or with the types of services they provide.

If one were to isolate the intensities of these sectors – that are generally located in the upper left hand quadrant in Figures 6–1 and 6–3 – a correlation does emerge between the total Raw Water and total Primary Energy intensities for the remaining sectors. That is, an increase in energy intensity corresponds with an increase in water intensity.

In the case of energy-intensive sectors such as Basic Metals & Products (BMP) (11), Non-metallic Mineral Products (NMMP) (10) and Fabricated Metal Products (FMP) (12), the total Raw Water intensities are more significantly correlated with the total Primary Energy intensities, given that most if not all of their Raw Water use is from indirect consumption. This indirect consumption may be attributed to water required to generate electricity. The intensities for Construction (CONST) (27), Finance Property & Business Services (FPBS) (29), Government Administration & Defence (GAD) (30) and Education Health & Community Services (EHCS) (31) appear to be similarly correlated in Figures 6–1 and 6–3. These sectors are the least water- and energy-intensive in the economy. Therefore, water used to generate electricity may have a greater contribution to their total Raw Water intensities, compared to the water- intensive sectors.

Based on Figures 6–2 to 6–4, there appears to be a strong positive correlation between total Primary Energy intensities and total Instream Use intensities in both years. This result reflects the high proportion of water used instream to generate hydropower electricity, and the high proportion of energy demand that is met by the electricity sectors. In 1996, for example, all direct Instream Use of water was attributed to hydropower generation. One notable exception is the TS sector (28), which consumes the largest amount of petroleum in the economy. Crude oil would therefore comprise the bulk of the primary energy fuel consumed by this sector.

6.2 Exploration of policy trade-offs

Water and electricity are fundamental infrastructure industries that have underpinned much of the economic and social development in NSW, yet it is evident from the discussions in Chapters 2 and 4 that this high reliance on both industries has not been without consequences: water and energy infrastructure has caused environmental degradation, carbon emissions have increased with increased energy consumption, and both water and energy security are at risk from future droughts and climate change. Much policy debate in both industries in recent years has therefore focused on how to adapt to and mitigate these impacts. What appears to be missing from the debate, however, is a deeper understanding of the trade-offs that may arise between sectors that are water- and energy-intensive, with their contribution to stimulating economic growth, income generation and employment. These trade-offs reflect the interplay of different policy objectives that would need to be reconciled in order to balance between moderating the growth in water and energy demand and the wider socio-economic objectives of governments.

The purpose of this section is to explore such trade-offs for NSW. This is undertaken by comparing the water and energy intensities presented in Section 6.1, with the sectors' output, income and employment multipliers. In brief, multipliers measure the impact on the total economy – in this case, in terms of economic output, income generation and employment growth – of an initial and exogenous change to the final demand of a sector. This research uses the Leontief monetary models to calculate multipliers for both 1996 and 2001, as described in Section 3.4.

The trade-offs may be described with an optimisation equation that aims to minimise water and energy use whilst maximising output, income and employment multipliers:

$$OP = \left\{ {}_{min}PE \cap {}_{min}RW \cap {}_{max}O \cap {}_{max}N \cap {}_{max}E \right\} \qquad \text{Eqn. 6-1}$$

where *PE* is the total Primary Energy intensity, *RW* is the total Raw Water intensity, *O* is the output multiplier, *N* is the income multiplier and *E* is the employment multiplier. Eqn. 6-1 excludes Instream Use, because of the strong correlation between total Primary Energy and total Instream Use intensities previously identified in Figures 6–2 and 6–4.

In addition, the trade-offs between the intensities and multipliers may be statistically validated using the Pearsons Product Moment Correlation coefficient equation, otherwise known as the sample correlation coefficient equation. The correlation coefficient is a measure of the degree to and direction of linear relationship between two variables and may be calculated for any set of data regardless of units (Gravetter & Wallnau 2004). Denoted by *r*, the correlation coefficient is defined as:

$$r = \frac{N(\sum xy) - (\sum x)(\sum y)}{\sqrt{\left[N(\sum x^2) - (\sum x)^2\right]\left[N(\sum y^2) - (\sum y)^2\right]}} \qquad \text{Eqn. 6-2}$$

where *N* is the number of observations (in this case the number of sectors), and *x* and *y* are pairs of data. The following sections discusses some of the trade-offs that have been identified.

6.2.1 Empirical findings

Table 6-3 lists the total intensities, multipliers and corresponding rank for each sector. In order to identify the sectors that satisfy the five criteria in Eqn. 6-1, the top nine ranking sectors for each criteria have been shaded. This includes all the sectors above the median value. Tables 6-4 and 6-5 list in matrix form the correlation coefficients for 1996 and 2001, respectively.

The results indicate that trade-offs between water and energy use, economic output, income generation and employment growth are inevitable. There were no sectors in either year that satisfied all five optimisation conditions. At most, there were sectors that satisfied four, in particular Construction (CONST), and the services sectors, Wholesale & Retail Trade (WRT), Government Administration & Defence (GAD), Education Health & Community Services (EHCS), and Transport & Storage (TS) (1996 only). In 1996, these sectors ranked low in terms of their contribution to economic output (*O*). By 2001, WRT and TS increased their *O* ranking to the top nine in the state, but ranked lower in terms of Raw Water (*RW*) and Primary Energy (*PE*), respectively. Whilst these sectors satisfied most of the conditions, based on the findings presented in Chapter 5, these sectors were at best growing in line with the national average (EHCS), experiencing slower growth (GAD and WRT) or were in decline (CONST).

Sectors that contributed significantly to economic output were also energy-intensive, particularly in 1996. This is reflected in the *O* and *PE* correlation coefficients, which were strongly and positively correlated to a significant level in both 1996 (0.62) and 2001 (0.62). This is particularly the case for the mining sector Other Mining & Services to Mining (OMS) and the manufacturing sectors Food Beverage & Tobacco (FBT), Chemicals (CHEM), Non-metallic Mineral Products (NMMP), Basic Metals & products (BMP), Fabricated Metal Products (FMP), Transport Equipment (TE), Other Machinery & Equipment (OME) and Miscellaneous Manufacturing (MM). These sectors are also capital-intensive and therefore – with the exception of FMP, TE and MM – their contribution to income generation and employment growth was ranked lower than other sectors in the economy.

Table 6-3 Total intensities, multipliers and corresponding ranks for 1996 and 2001

Sector		1996 (in $2001)					2001				
		Primary Energy MJ/$000	**Raw Water** ML/$000	**Output** $000/$000	**Income** $000/$000	**Employment** Jobs/$000	**Primary Energy** MJ/$000	**Raw Water** ML/$000	**Output** $000/$000	**Income** $000/$000	**Employment** Jobs/$000
1	Ag	4,064 (9)	693.13 (19)	1.60 (12)	0.42 (6)	0.015 (4)	5,921 (14)	732.91 (19)	1.67 (12)	0.43 (5)	0.013 (5)
3	OMS	7,680 (14)	6.26 (11)	1.72 (8)	0.32 (13)	0.008 (18)	11,889 (16)	13.86 (15)	1.76 (8)	0.24 (14)	0.005 (15)
4	FBT	4,881 (10)	130.64 (18)	1.88 (6)	0.31 (16)	0.009 (11)	4,623 (12)	102.59 (18)	1.83 (4)	0.25 (12)	0.007 (12)
5	TCFL	3,478 (7)	28.75 (17)	1.56 (17)	0.32 (14)	0.010 (9)	2,248 (4)	30.44 (17)	1.53 (16)	0.24 (13)	0.007 (13)
6	WPP	3,459 (6)	13.33 (15)	1.57 (14)	0.31 (17)	0.009 (14)	3,285 (7)	11.64 (14)	1.74 (9)	0.29 (10)	0.008 (10)
9	CHEM	11,012 (15)	8.52 (14)	1.98 (3)	0.30 (18)	0.008 (16)	5,504 (13)	5.66 (13)	1.68 (11)	0.18 (17)	0.005 (17)
10	NMMP	16,045 (17)	4.22 (9)	1.90 (5)	0.32 (15)	0.008 (17)	12,074 (17)	2.61 (6)	1.77 (7)	0.25 (11)	0.006 (14)
11	BMP	44,033 (19)	7.40 (12)	2.03 (1)	0.30 (19)	0.006 (19)	29,189 (19)	4.38 (11)	1.92 (1)	0.21 (16)	0.005 (18)
12	FMP	13,104 (16)	6.07 (10)	2.00 (2)	0.38 (8)	0.011 (8)	9,359 (15)	3.57 (9)	1.90 (2)	0.30 (8)	0.008 (9)
13	TE	6,401 (11)	2.57 (6)	1.71 (9)	0.38 (9)	0.010 (10)	3,635 (10)	1.42 (2)	1.69 (10)	0.18 (18)	0.005 (16)
14	OME	7,281 (13)	2.94 (7)	1.74 (7)	0.34 (12)	0.009 (12)	2,610 (5)	1.04 (1)	1.40 (18)	0.14 (19)	0.004 (19)
15	MM	7,269 (12)	8.08 (13)	1.90 (4)	0.40 (7)	0.012 (7)	3,362 (8)	4.72 (12)	1.63 (14)	0.22 (15)	0.009 (7)
26	Const	3,586 (8)	2.18 (5)	1.59 (13)	0.49 (4)	0.013 (5)	3,689 (11)	2.77 (7)	1.80 (5)	0.48 (3)	0.014 (3)
27	WRT	2,565 (4)	2.14 (4)	1.56 (16)	0.46 (5)	0.015 (3)	3,433 (9)	4.22 (10)	1.78 (6)	0.45 (4)	0.016 (2)
28	TS	21,045 (18)	1.73 (2)	1.64 (10)	0.35 (11)	0.009 (15)	21,164 (18)	2.12 (4)	1.85 (3)	0.33 (7)	0.008 (8)
29	FPBS	1,391 (1)	1.55 (1)	1.47 (18)	0.36 (10)	0.009 (13)	1,290 (1)	1.91 (3)	1.52 (17)	0.29 (9)	0.007 (11)
30	GAD	2,996 (5)	3.64 (8)	1.63 (11)	0.51 (2)	0.013 (6)	3,134 (6)	3.33 (8)	1.65 (13)	0.48 (2)	0.012 (6)
31	EHCS	1,734 (2)	2.04 (3)	1.30 (19)	0.65 (1)	0.020 (1)	1,502 (2)	2.42 (5)	1.28 (19)	0.60 (1)	0.018 (1)
32	OCS	2,212 (3)	14.06 (16)	1.56 (15)	0.51 (3)	0.018 (2)	1,843 (3)	17.79 (16)	1.62 (15)	0.40 (6)	0.014 (4)

Legend	
▨	Top ranking sectors
(number)	Rank

Source: Derived from the Leontief hybrid and monetary models as described in Section 3.4

Table 6-4 Correlation matrix for 1996

	PE	*RW*	*O*	*N*	*E*
PE	1.00				
RW	-0.13	1.00			
O	0.62	-0.08	1.00		
N	-0.42	0.03	-0.61	1.00	
E	-0.53	0.21	-0.61	0.92	1.00

🟧 Significant at a five per cent level[15]

Source: Derived from the Pearsons Product Moment Correlation coefficient

Table 6-5 Correlation matrix for 2001

	PE	*RW*	*O*	*N*	*E*
PE	1.00				
RW	-0.05	1.00			
O	0.62	0.01	1.00		
N	-0.26	0.20	-0.21	1.00	
E	-0.36	0.24	-0.25	0.95	1.00

🟧 Significant at a five per cent level[15]

Source: Derived from the Pearsons Product Moment Correlation coefficient

Three of these sectors – NMMP, FMP (2001 only), TE and OME – were amongst the least water-intensive. An increase in the production output of these sectors would contribute significantly to economic output in NSW, with less impact on water than energy supplies. However, this does not hold true for other sectors, such as FBT, CHEM and BMP. Whilst these sectors generate a high level of economic output, they were also water- and energy-intensive compared to other sectors in the economy. All three sectors exhibited strong backward and/or forward linkages and increased their contribution to economic output. It is therefore important that these sectors reduce their water and energy consumption. Such reductions would have wider benefits for the economy, due to their strong linkages with other sectors. In particular the indirect consumption of water and energy would decrease for sectors reliant on the output from FBT, CHEM and BMP.

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[15] Based on a two-tailed test, the probability is less than five per cent that a correlation could have occurred by chance for $N = 19$ when $r \geq 0.456$; for one per cent significance level, $r \geq 0.575$.

Whilst the manufacturing sectors were ranked high in terms of their output multipliers in 1996, by 2001 there was a perceivable shift in the ranks. In particular, TE, OME and MM decreased in their ranks, which corresponded with a decline in their contribution to economic output. Only the WPP sector significantly increased in its output multiplier rank. This sector also increased its contribution to economic output. CONST, WRT and TS ranked high in 2001, and also satisfied four of the five optimisation conditions, and ranked low in terms of Raw Water (WRT) or Primary Energy (CONST and TS).

The results also suggest that CONST and the services sectors offer a better balance between water use, energy use, and the other optimisation conditions of economic output, income generation and employment compared with Agriculture, Mining and Manufacturing. A possible explanation is that the latter sectors are generally more capital-intensive and therefore rely more on energy than labour to produce their output. This is also reflected in the *PE-E* correlations coefficients for both 1996 (statistically significant at -0.53) and 2001 (-0.36). As primary energy intensities increased, employment multipliers tended to decrease. This suggests that there are substitution possibilities between energy and labour. Further, income (*N*) and employment (*E*) are strongly and positively correlated in both 1996 (statistically significant at 0.92) and 2001 (statistically significant at 0.95). Therefore, for some sectors, an increase in the Primary Energy intensity may reduce income generated in the economy.

Despite the apparent advantages of the services sectors over the other sectoral groups in the economy, policies that encourage greater development of the services are not conducive to maintaining a balance between the economic activities in the economy. For this reason alone, there are inherent advantages to ensuring the productive future of all the major sectoral groups in the economy. The key therefore is to ensure that water and energy efficiency strategies are paramount in the development of future policies, particularly for those sectors within the groups with the highest intensities.

6.3 Water and electricity price elasticities

The results in the preceding sections demonstrate that there are physical links between water and energy use. Recent studies into the water-energy nexus have also demonstrated that there are links between the demand and price of water and electricity: water demand is responsive to electricity prices and conversely, electricity demand is responsive to water prices (refer to

Section 2.3). The purpose of this section is to explore these quantity-price relationships for the NSW economy, with a view to determining the extent of substitution or complementarity between water and electricity.

These relationships are explored by quantifying cross price elasticities of demand for a select number of sectors from the input-output models that are high water and energy users, including Agriculture, Food Beverage & Tobacco (FBT), Textile Clothing Footwear & Leather (TCFL), Wood Paper & Printing Products (WPP), Non-metallic Mineral Products (NMMP), Basic Metals & Products (BMP), and Fabricated Metal Products (FMP). Households and Services (an aggregate of those in the input-output models) are also included in the analysis.

Denoted by η_{ij}, cross price elasticities of demand measure the change in demand for one good as a result of an incremental change in the price of another. They are useful for determining whether two goods – in this case water and electricity – are complements ($\eta_{ij} < 0$), substitutes ($\eta_{ij} > 0$), or independent ($\eta_{ij} = 0$) of each other.

In addition to cross price elasticities, this section examines the own price elasticities of demand for water and electricity use. Own price elasticities (η_{ii}) measure the change in demand for a particular good or service as a result of an incremental change in its price. A good or service is considered to be relatively price inelastic if the absolute value of η_{ii} is between zero and one. Conversely, an absolute value of greater than one indicates that it is relatively price elastic.

For the purpose of this analysis, water demand is limited to water supplied by the water sectors IDW and BRW, because an economic transaction takes place and a water price may be determined. In the case of electricity, electricity demand does not differentiate between the various generation technologies, unlike the input-output models.

This research adopts the classical arc price elasticity method, because of the absence of long-term historical water use data that precludes the adoption of more complex methods, such as econometrics. Nonetheless, the analysis presented in this section offers some general insights into the quantity-price relationships that elasticities capture.

6.3.1 Empirical findings

Table 6-6 lists the average own and cross price elasticities for water and electricity for five time periods between 1993-94 to 2004-05. These time periods include 1993-94, 1994-95, 1995-96, 1996-

97, 2000-01 and 2004-05, and were selected based on the availability of end use water data from the Australian Bureau of Statistic's Water Accounts. The results show substantial fluctuations between each time period, particularly for results using water data. A possible explanation is that the Australian Bureau of Statistics (ABS) revised their data collection methods between the first Water Account which includes water data for the first four time periods, and subsequent editions that include data for the remaining two time periods. The data for the latter time periods would therefore be of a higher quality. In recognition of this, the average own price elasticity for water (η_{ww}) and cross price elasticity for water demand and electricity price (η_{we}) in the last column of Tables 6-6 and 6-8 represent a 'weighted average'. In both cases, a higher weight has been assigned to the last time period.

Table 6-6 Own price elasticities: water (η_{ww})

	93/94-94/95	94/95-95/96	95/96-96/97	96/97-00/01	00/01-04/05	Weighted Average
Weight:	**12.5%**	**12.5%**	**12.5%**	**12.5%**	**50%**	**100%**
AG	-1.801	-0.893	2.407	1.388	-8.138	-3.93
FBT	-0.522	-0.034	0.419	-0.382	1.978	0.92
TCLF	-0.152	-0.128	0.756	23.971	3.498	4.80
WPP	-0.430	-0.462	-2.111	9.661	1.897	1.78
NMMP	-0.980	-0.373	2.925	4.162	4.057	2.75
BMP	-0.353	-0.086	-0.038	8.039	0.392	1.14
FMP	-0.378	-0.274	0.352	8.537	0.392	1.23
Services	0.109	0.215	2.131	-6.144	-8.035	-4.48
Household	-0.121	0.146	1.338	-0.885	-2.101	-0.99

Source: Derived from Eqn 3-18 in Section 3.5

Table 6-7 Own price elasticities: electricity (η_{ee})

	93/94-94/95	94/95-95/96	95/96-96/97	96/97-00/01	00/01-04/05	Average
AG	-0.008	-0.006	0.020	0.009	0.181	0.04
FBT	-0.002	0.000	-0.002	0.624	-0.035	0.12
TCLF	0.008	0.013	0.015	-1.613	0.005	-0.31
WPP	0.001	0.004	0.011	0.000	0.112	0.03
NMMP	-0.001	-0.001	0.000	0.490	-0.037	0.09
BMP	0.001	0.000	-0.011	0.365	-0.047	0.06
FMP	-0.003	0.002	-0.015	0.528	-0.047	0.09
Services	-0.006	-0.019	-0.005	0.466	-0.029	0.08
Household	-0.005	-0.004	-0.060	0.041	0.088	0.01

Source: Derived from Eqn 3-18 in Section 3.5

Table 6-8 Cross price elasticities: water demand and electricity price (η_{we})

	93/94-94/95	94/95-95/96	95/96-96/97	96/97-00/01	00/01-04/05	Weighted Average
Weight:	**12.5%**	**12.5%**	**12.5%**	**12.5%**	**50%**	**100%**
AG	3.02	-3.71	-1.69	-18.26	15.29	5.07
FBT	0.87	-0.14	-0.29	5.03	-3.72	-1.17
TCLF	0.26	-0.53	-0.53	-315.46	-6.57	-42.82
WPP	0.72	-1.92	1.48	-127.14	-3.57	-17.64
NMMP	1.64	-1.55	-2.05	-54.77	-7.62	-10.90
BMP	0.59	-0.36	0.03	-105.80	-0.74	-13.56
FMP	0.63	-1.14	-0.25	-112.35	-0.74	-14.51
Services	-0.18	0.89	-1.50	80.85	15.10	17.56
Household	0.59	0.97	-14.17	5.28	-9.77	-5.80

Source: Derived from Eqn 3-19 in Section 3.5

Table 6-9 Cross price elasticities: electricity demand and water price (η_{ew})

	93/94-94/95	94/95-95/96	95/96-96/97	96/97-00/01	00/01-04/05	Average
AG	0.41	-0.09	-1.74	-0.04	-5.14	-1.32
FBT	0.13	0.00	0.19	-2.61	0.99	-0.26
TCLF	-0.42	0.23	-1.25	6.75	-0.14	1.03
WPP	-0.04	0.06	-0.96	0.00	-3.18	-0.83
NMMP	0.04	-0.02	0.00	-2.05	1.06	-0.19
BMP	-0.05	0.00	0.91	-1.53	1.34	0.14
FMP	0.18	0.04	1.25	-2.21	1.34	0.12
Services	0.28	-0.32	0.45	-1.95	0.81	-0.15
Household	0.14	-0.06	0.63	-0.79	2.21	0.43

Source: Derived from Eqn 3-19 in Section 3.5

Own price elasticities for water (η_{ww})

The own price elasticities for water, η_{ww}, appear to be relatively price elastic for most sectors. This is particularly the case for Agriculture (-3.93), Services (-4.48), and Textile Clothing Leather & Footwear (TCFL) (4.80). It would appear that water pricing policies that encourage full cost recovery would be an effective instrument for reducing water demand in these sectors. In the case of Agriculture, the rural water market provides a mechanism by which to allocate scarce water resources that are already over-allocated. However, one could argue that the market does not necessarily reduce water consumption, but rather shifts consumption patterns to users with high value crops. Therefore, other policy instruments may be required to reduce consumption, external to the natural decreases brought about by drought. Policies that encourage improvements in irrigation practices, such as installing pipes in previously open channels or drip irrigation systems, would reduce water consumption. Such policies have been implemented by the Federal Government, as a means to obtain water for environmental flows (refer to Chapter 4). Similar arguments could be put forward for Services and TCFL. That is, other policies, such as demand management programs may have a more significant impact on water consumption than price. However, full cost recovery of water and higher water prices would reinforce the link between consumption behaviour and price.

In contrast, the absolute η_{ww} values for Food Beverage & Tobacco (FBT) (0.92) and the Household sector (-0.99) are just below one, indicating that water demand is relatively price inelastic. In the case of the Household sector, water demand would remain constant to a certain level regardless of water prices, in order to meet basic human needs. One could argue that discretional water use, such as watering gardens and washing cars may be more responsive to changes in price.

The elasticities also appear to have increased towards the latter periods. The implementation of full cost recovery policies in the water and electricity industries as a result of reform in the latter periods would strengthen the links between demand and price. The results may reflect other factors at play during this period, such as the enforcement of water restrictions by Sydney Water from 1 October 2003 due to drought (Sydney Water 2008d), and improvements to the collection of water data by the ABS, as previously mentioned. Despite the potential influence of these factors, the results reflect trends reported elsewhere. For example, Dunlop, Foran & Poldy (2001) report that industry reforms in urban areas and increases in the price of water has reduced water consumption; that is, water in urban areas is price elastic.

Own price elasticities for electricity (η_{ee})

The η_{ee} values for all the sectors are below one, which suggests that electricity demand is inelastic to changes in price. This is particularly the case for the Household sector (0.01), where it may be difficult to immediately substitute electricity with other forms of energy. Households may not have access to reticulated gas supply, and solar hot water heating may not be a feasible option, particularly for those that live in a multi-dwelling property.

The inelastic behaviour of the sectors generally concord with results presented elsewhere, although there are substantial differences between the actual figures. For example, Graham et al. (2005) report the National Institute of Economic and Industry Research's (NIEIR) estimate of

-0.35 across the NEM, and the Commonwealth Scientific and Idustrial Research Organisation's (CSIRO) lower estimate of 0.1. The CSIRO uses this lower value in long term energy scenario forecasting for Australia to 2050, because it is argued that the cost of electricity will comprise a smaller proportion of incomes in the future, and therefore it will become more price inelastic. The (then) NSW Department of Energy (1998) (now Department of Water and Energy) also reported that electricity is generally price inelastic for manufacturing sectors in the state, ranging from -0.09 for FBT to -0.86 for BMP; only the Wood, Wood Products and Furniture sub-sector of the Wood Paper & Printing Products sector (WPP) is price elastic. These elasticities are based on data from 1974 to 1995, and therefore largely fall outside the period of reform that took place from the early to mid 1990s.

Given the close link between primary energy consumption and economic output, as demonstrated in the previous section, the inelastic nature of electricity demand to prices warrants consideration of alternative policy instruments to the price mechanism, in order to decouple electricity consumption and economic output. Such instruments include regulation or further implementation of voluntary energy efficiency programs. The impact of a carbon price on electricity consumption would require further analysis, which is beyond the scope of this research. It remains to be seen how the carbon price will influence behaviour, and what impact the allocation of permits to greenhouse-gas intensive electricity generators will have. Will there be a shift in the generation mix – tempered by assistance to coal fired generators – or will there be sufficient incentive to instigate behavioural change to reduce energy consumption? What are the flow on effects for water resources?

Cross price elasticities for water demand and electricity price (η_{we})

The η_{we} values fluctuated significantly, particularly between 1996-97 to 2000-01. The fluctuations should be interpreted with some caution, because of the influence of changes to water data collection methods employed by the ABS, as previously mentioned. Nonetheless, the weighted averages listed in Table 6-6 capture the general nature of the relationship between water demand and electricity price for the different sectors.

For the Manufacturing and Household sectors, the η_{we} values are below zero, indicating that the demand for water decreases when the electricity price increases, particularly for the Textile Clothing Footwear & Leather (TCFL) sector (-42.82). This suggests that water and electricity are complements and therefore electricity pricing policies influence water demand. This contrasts with the own price elasticity of demand for electricity, which indicates that electricity demand is relatively price inelastic. In these sectors, electricity pricing policies may therefore have more of an impact on water demand than electricity demand.

For the Agriculture and Services sectors, it appears that water and electricity are substitutes. That is, when the price of electricity increases, the demand for water increases. The result, particularly for the Agriculture sector, appears counter-intuitive, given that electricity is not a major energy source for this sector, and that water use by this sector is largely independent of energy supply (unlike energy-intensive manufacturing sectors, for example). A possible explanation is that the latest period of analysis – which was assigned the greatest weight – corresponded with an extended dry period throughout much of NSW, affecting irrigators across the state (refer to Chapter 4). This is reflected in the water data for Agriculture for this time period. In contrast, the cross price elasticities for the previous time periods not in drought were generally below zero, indicating that water and electricity were complements.

For the Services sectors, it could be argued that the price of electricity would increase the costs associated with treating and transporting water. Given that water is price elastic for Services, an increase in the price of water– as a result of an increase in the price of electricity – would decrease demand. Water utilities are already mindful of the link between the price of electricity and their operating costs, particularly in light of the record electricity prices reached in the wholesale market in May 2007, due to the lack of water[16].

Cross price elasticities for electricity demand and water price (η_{ew})

Based on the η_{ew} values in Table 6-6, it appears that water and electricity are substitutes for Textile Clothing Footwear & Leather (TCFL) (1.03), Basic Metals & Products (BMP) (0.14), Fabricated Metal Products (FMP) (0.12) and Households (0.43). Therefore, incremental changes to the price of water would result in incremental changes to the demand for electricity. However, both BMP and FMP are energy-intensive and one would therefore assume that the price of water would have little influence over the demand for electricity. If such relationship were true, then there are implications for electricity demand in these sectors in the future. In particular, the water prices are likely to increase in order to fund – under a policy of full cost recovery – infrastructure projects such as Sydney's desalination plant and other water recycling

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[16] Presentation by Dr Kerry Schott, Managing Director of Sydney Water at the University of Technology Sydney, 20 May 2008

schemes, as well as infrastructure maintenance, which is likely to become a critical expenditure item in the coming years due to ageing infrastructure.

The η_{ew} value for Agriculture (-1.32), Food Beverage & Tobacco (FBT) (-0.26), Wood Paper & Printing Products (WPP) (-0.83), Non-metallic Mineral Products (NMMP) (-0.19), and Services (-0.15) suggest that water and electricity are complements, which means that an increase in the price of water would decrease the demand for electricity. However, in the case of Agriculture, the analysis does not differentiate between surface water and groundwater. A more detailed analysis for a region using both groundwater and surface water may yield different results. An increase in surface water prices may increase the demand for electricity if groundwater becomes a cheaper source of water.

The above results indicate that water demand is generally more responsive to changes in the price of water and electricity, compared to electricity demand. Policies aimed at reducing water demand should therefore not only consider water prices, but also take into account electricity prices. This finding would require further validation when additional years of end use water data becomes available. Whilst the literature suggests that more complex methods of calculating elasticities would not offer additional insights that could be gained from the classical arc price elasticity approach adopted by this research, this research does acknowledge that such complex methods would enable one to consider the influence of weather and other external factors on the quantity-price relationships between water and electricity.

6.4 Summary and conclusion

Using various analytical methods, this chapter empirically investigated the links between water and energy in the remaining sectors of the NSW economy. Table 6-10 lists the main findings from this investigation, for each of the production sectors.

Table 6-10 Summary of the sectoral findings

Sector	Main findings
Agriculture	Significant contribution to employment and income generation. Most water-intensive and significant trade-offs with electricity generators. Water efficiency strategies are likely to lead to increases in energy intensity. Increase in water price in rural water market may increase electricity demand, as groundwater extractions rise. This is reflected in the cross price elasticities.
OMS	Strong forward linkages and significant contribution to economic output. High direct Raw Water intensities, which may give rise to regional water management issues. High Electricity intensities and therefore high carbon emissions. Water and energy efficiency strategies should be encouraged, which will benefit other sectors.
FBT	Significant contribution to economic output and strong backward linkages High total water intensities, due to links with Agriculture. This sector would indirectly benefit from efficiency strategies in Agriculture.
TCFL	High water intensities, due to links with Agriculture. Energy intensities amongst the lowest. Efficiency strategies should focus on reducing direct reliance on the BRW sector. This sector would also indirectly benefit from efficiency strategies in Agriculture. Water and electricity demand appear responsive to price changes.
WPP	Strong forward linkages and significant contribution to economic output. Very water-intensive, because of links with Agriculture and therefore would benefit from efficiency strategies in Agriculture. Energy intensities were amongst the lowest. Water demand is responsive to changes in water and electricity price.
CHEM	Strong forward linkages in both years and strong backward linkages in 1996. Contributed significantly to economic output in 1996. Energy-intensive, particularly for petroleum. Energy efficiency strategies should be encouraged and would benefit other sectors. Water intensive, largely from indirect use.
NMMP	Key sector in both years, and significant contribution to economic output. Amongst the highest Electricity and GAS intensities. Energy efficiency strategies should be encouraged and would benefit other sectors.
BMP	Strong backward linkages and significant contribution to economic output. Highest Electricity intensities of all sectors. Energy efficiency strategies should therefore be encouraged, particularly as electricity demand is inelastic to price changes.
FMP	Key sector in both years. Significant contribution to economic output, income generation and employment growth. Amongst the highest Electricity intensities. Energy efficiency strategies should be encouraged, particularly as electricity is price inelastic, and would benefit other sectors.
TE	Strong backward linkages in both years. Significant contribution to economic output and income generation impact in 1996, which declined in 2001. Energy intensities largely from indirect consumption. Therefore this sector would benefit from energy efficiency strategies in sectors whose output it relies on.
OME	Decline in linkages and impact on economic output from 1996 to 2001. Water and energy intensities were not amongst the highest, and also decreased between the two years.
MM	Decline in linkages and impact on economic output from 1996 to 2001. Electricity intensities also declined. No significant water-energy trade-offs.

(continued on next page)

Table 6-10 Summary of the sectoral findings (continued)

CONST	Strong backward linkages. This sector would benefit from implementation of water and energy efficiency strategies in sectors whose output, such as NMMP and FMP, it relies on.
WRT	Slow growth sector, although significant contribution to income generation and employment in both years, and to economic output in 2001. Water and energy intensities generally amongst the lowest.
TS	One of the fastest growing sectors in NSW. Exhibited strong linkages with other sectors. Significant contribution to economic output, income and employment generation. Amongst the lowest water intensities, but one of the highest refined petroleum intensities. Contributes significantly to petroleum consumption of other sectors. Due to the importance of this sector in the economy, strategies to reduce its energy intensity – such as fuel switching – should be pursued.
FPBS	One of the fastest growing sectors, with moderate impact on income generation and employment. Low water and energy intensities.
GAD	Slow growth sector, although significant contribution to income generation and employment. Low water and energy intensities.
EHCS	Growth in line with the national average and moderate contribution to income generation and employment. Low water and energy intensities.
OCS	Slow growth sector, although high impact on income generation and employment. Some associated activities water-intensive, e.g. cafes and restaurants. High reliance on water-intensive sectors, such as FBT and in turn Agriculture. Would benefit from direct water efficiency strategies to reduce reliance on BRW sector, and indirectly from strategies in other water-intensive sectors.
SERVICES (general)	In general, water demand is price elastic whereas electricity demand is price inelastic. Given that the energy intensities are generally low, the urgency to reduce energy demand is not as critical.
HOUSEHOLDS	Water demand is relatively price inelastic. One could argue that demand is relatively price inelastic to a certain level to meet human needs, but beyond that it would be discretional. Demand for water, however, decreases as price of electricity increases. A possible cause is the concurrent implementation of water demand management programs and electricity price reviews. Electricity demand is also price inelastic, yet demand appears to increase with water prices. Given the likely increase to water prices in the future due to full cost recovery policies, the impact on electricity demand should be further analysed.

The salient findings from the empirical investigation may be summarised as follows:

- The selection of appropriate policy instruments to reduce water and energy use is dependent on several factors. For some sectors, the indirect component of the intensities are most significant and therefore higher gains are achievable by focusing on water and energy-intensive sectors with which there are strong backward linkages. In other sectors, particularly the manufacturing sectors, more direct instruments such as regulation or voluntary demand management programs should be further implemented in order to decouple energy, and to a lesser extent, water intensities with economic output. This is of particular importance to energy-intensive sectors, given the current debate over climate change and emphasis on reducing carbon emissions.

- Where energy-intensive sectors depend predominantly on electricity, reductions in energy consumption would also lower the indirect water intensities for these sectors. This physical relationship is evident in the scatter plots for Raw Water and Primary Energy, when water-intensive sectors such as Agriculture are excluded from the plots. In addition, as expected, the scatter plots for Instream Use and Primary Energy also demonstrate a high level of correlation, which the sample correlation coefficients confirm.

- It is also apparent that there is a general trend towards an increasing role for the services sectors in the economy, and concommittantly a decreasing role for manufacturing sectors. This would augur well in terms of water and energy use, given the low water and energy intensities that the services sectors generally exhibit (with the exception being accomodation and café facilities under OCS), and the greater role these sectors are fulfilling in terms of income generation and employment growth. However, the ability to stimulate economic output is highest amongst the manufacturing sectors. Strategies to decouple energy from economic output for these manufacturing sectors are therefore important for the longer term sustainability of the economy.

- The elasticities calculated in this research highlight some general relationships between the quantity and price of water and electricity. It appears that water demand is more responsive to changes in the price of water and electricity, and therefore the price mechanism would be an appropriate policy instrument to reduce water demand. In contrast, electricity appears to be less responsive to the changes in the price of both electricity and water. This research acknowledges that improvements to the collection of water data, and additional years of data would enable the adoption of more complex methods, such as econometrics.

The empirical investigation presented in this chapter and Chapters 5 have been reinforced by the historical analysis in Chapter 4, demonstrating that qualitative analyses do provide additional insights and contexts that cannot be explicable by quantitative findings alone. This chapter has explored the existing relationship between water and energy, and in particular electricity, for the remaining sectors in the economy. It is clear that the links between water and energy are complex and that different policy instruments have varying degrees of influence over water and energy demand in the various sectors. The next chapter examines the implications of the nature of the nexus in the future. In particular, it analyses the potential water and energy trade-offs that may ensue with the adoption of various water and energy technologies and demand management strategies under alternative scenarios.

Chapter 7

Analysis of alternative water and energy scenarios

The future belongs to those who give the next generation reason for hope

Pierre Teilhard de Chardin

The water and electricity industries have changed significantly over the past two decades, due to industry reform, drought and overallocation of river systems. Coupled with the need to adapt to and mitigate climate change, it is likely that further changes are afoot in both industries. To date, the strategies developed by the industries to deal with such changes – for example the Metropolitan Water Plan in the urban water industry and the National Electricity Market – have largely been implemented with little regard to the links between water and electricity. It is therefore imperative that policy makers have a deeper understanding of the implications of the nexus on the future of the water and electricity industries, in order to assist in the development of more integrated strategies. The purpose of this chapter is to examine – under alternative scenarios – a range of strategies to meet the future demand for water and electricity for NSW.

The UK Foresight Program's scenario matrix forms the basis of the scenarios developed for this research, because it enables the inclusion of social and cultural dimensions that are prevalent in the lower left and lower right hand quadrants of the AQAL framework. The matrix comprises four quadrants that are formed by the intersection of two scenario drivers, which are 'governance systems' and 'social values'. The scenarios are further differentiated by the following set of four variables that influence the supply of and demand for water and electricity: Environmental, Economic, Technological and Security of Supply. Section 3.6.1 describes the scenario drivers and variables in more detail.

The scenarios model the NSW economy in 2031, and provide a future snapshot of the water and electricity industries. This year has been selected because it is sufficiently far into the future to consider emerging technologies that are likely to be commercially available in the longer term. These technologies may provide advantages over existing technologies, in the form of improved efficiencies, reduced use of water and energy, and reduced carbon emissions. Significant changes in policies may be factored into the adopted timeframe, yet it is still within the horizon of the present to have impact on current policy development.

This research uses input-output analysis to model the scenarios. As described in detail in Section 3.6.2, the 2001 Leontief hybrid model developed by this research is updated using the RAS method and other technical data to reflect the structure of the NSW economy and the strategies adopted in the water and electricity industries under the four scenarios. The resulting models enable the quantification of the following indicators, so that potential trade-offs between the strategies may be identified: the water intensities for the electricity sectors, the energy intensities for the water sectors, and the resulting carbon emissions in the water sectors.

In order to select plausible strategies under each scenario, Section 7.1 reviews the key water supply and electricity generation technologies that are likely to be available by 2031. This review complements the analysis in Section 4.4, which identifies the existing policies in both industries that may also influence the selection of demand and supply strategies in the future. Based on this review, Section 1.1 discusses the rationale behind developing the scenarios and describes in detail the strategies selected for each scenario. Section 7.3 presents the empirical findings of the scenario modelling, focusing on the potential trade-offs in each of the scenarios. Lastly, Section 7.4 summarises and provides some concluding remarks.

7.1 Overview of water and electricity technologies

The long-term focus of the scenarios developed by this research enables the consideration of a range of technologies that are existing or under development in the water and electricity industries. This is of particular importance, given that an emerging technology today is likely to become a standard technology in the future. The purpose of this section is to provide a general overview of water and electricity technologies, and identify those that have been selected for the scenario analysis. Those familiar with such technologies may wish to proceed directly to Section 1.1.

7.1.1 Water supply technologies

This research assumes that demand management is implemented in each of the scenarios to varying degrees, and that any shortfall is met by additional supply capacity. The scenarios do not consider the construction of a new water storage dam, due to the indefinite deferment of the Welcome Reef Dam project in 2001 in Sydney's south, which had, since the 1960s, been considered the next large-scale dam in the state (NSW Government 2007). Whilst this option cannot be ruled out with complete certainty, it is likely that this dam will not be constructed within the timeframe of the scenarios, due to the State government's commitment to other supply options, and general public perception of the environmental impacts of water storage dams. The large-scale supply options considered in the scenarios are therefore seawater desalination and advanced wastewater treatment processes. Both options form part of the Metropolitan Water Plan's supply strategy (2006).

Seawater desalination

Desalination is a highly energy-intensive process that treats seawater to drinking water quality (refer to Table 2-2 for a list of energy intensities for common water treatment technologies, including desalination). The two main processes associated with seawater desalination are thermal distillation and reverse osmosis. Thermal distillation consumes up to three times more energy than reverse osmosis, because it requires both heat and electricity to operate (Sydney Water 2007e). The energy-intensity of reverse osmosis is lower than thermal distillation, because it enables the integration of energy recovery technologies, such as the pelton wheel.

The latest plant designs consume approximately 3.6 kWh of electricity for every ML of desalination water that is produced.

Sydney Water is currently developing a reverse osmosis desalination plant in Kurnell, in Sydney's south-east. The plant will have a starting capacity of 250ML pa when it is completed in late 2009, and will have the potential to upgrade to 500 ML pa in the future. It is envisaged that the operation of the plant will be dependent on the water levels in Sydney Water's dams, and therefore it is possible for the plant not to be in use during certain periods. In order to reduce its carbon emissions, the plant will offset its electricity consumption by purchasing renewable energy (Sydney Water 2007d).

Seawater desalination features strongly in two of the four scenarios developed in this research. This technology, however, is not consistent with the assumptions underpinning the remaining two scenarios, and is therefore not considered in these scenarios.

Advanced wastewater treatment processes

Advanced wastewater treatment processes enable sewage to be reused for both potable and non potable purposes. Reverse osmosis again is the main technology behind many of the processes. It is common for advanced wastewater treatment plants to incorporate additional technologies prior to reverse osmosis, in order to improve the operational performance of the plants. Two common technologies include conventional activated sludge (CAS) followed by filtration, and membrane bioreactors (MBRs). Both technologies were described in detail in Section 2.1.3.

New South Wales is actively pursuing the development of water recycling plants, as part of the Metropolitan Water Plan. These new developments have been factored into the supply capacities for the scenarios. Additional capacity from advanced wastewater treatment plants has also been incorporated into the scenarios to varying degrees, in order to meet expected demand in 2031.

Decentralised systems

Decentralised systems, such as rainwater harvesting and stormwater harvesting are alternatives to seawater desalination and advanced wastewater treatment processes that would reduce the demand for water from the mains supply. These decentralised options have been omitted in the current scenario models due to current constraints in data required for input-output modelling, but may be included in future work should the scenarios be expanded and upgraded. The energy consumed by these decentralised options may significantly offset the benefit derived from reducing water demand from the mains supply.

7.1.2 Electricity generation technologies

This section examines current and emerging electricity generation technologies, and identifies the technologies that are selected for the scenarios. The discussion below groups the technologies according to the following fuel sources: coal, gas, nuclear, biomass, geothermal, and other renewables.

Coal

Coal fired power plants generally have high capital costs and low operating costs, and are therefore most suited for baseload generation. The electricity industry in NSW is dominated by coal fired power plants, which generated over 90 per cent of the electricity in the state in 2001 (Electricity Supply Association of Australia (ESAA) 2003). The existing plants use subcritical pulverised fuel (CF) technology from the 1970s and 1980s. The current industry benchmark is supercritical pulverised fuel (SC) technology, which has been made possible by advancements in metallurgy. SC combusts coal at higher temperatures (> ~540°C) and pressures (>23.1 MPa) compared to CF, which results in improved thermal efficiencies. Some recent examples of SC plants include Callide C and Tarong North in Queensland. In addition, SC plants are also suitable for the retrofit of post carbon capture (PCC) technology (Wibberley et al. 2006).

In order to further improve the thermal efficiency and environmental performance of coal fired power stations, researchers are developing more advanced technologies such as ultrasupercritical pulverised fuel (USC) and integrated gasification combined cycle (IGCC). USC combusts coal at even higher temperatures (> 566°C) and pressures (35-40 MPa) compared to SC, which further improves the thermal efficiencies of pulverised fuel plants. USC is still a developing technology and some plants have been constructed overseas as part of ongoing research. It is likely to surpass SC as the industry benchmark for pulverised fuel plants in the future (Wibberley et al. 2006).

IGCC is the main alternative to pulverised fuel combustion. Gasification of coal is a mature technology that was used in the Australian colonies during the 1800s to produce town gas for street lighting. Its present day applications include hydrogen and chemical production. In the 1990s, researchers began to develop the technology for electricity generation, because of its potential to reduce pollutant emissions (such as NOx, SOx, particulates and Hg) and improve the thermal efficiency of coal fired power plants. Today, IGCC forms the basis for many clean coal technology programs worldwide (Wibberley et al. 2006). However, improvements to advanced pulverised fuel technologies such as USC are reducing the advantages of IGCC. The thermal efficiencies of both technologies are likely to be similar by 2020; current wet scrubbing and other end of pipe technologies to reduce pollutant emissions in pulverised fuel plants are now comparable to the best results obtainable from IGCC; and PCC technology in pulverised fuel plants is comparable in cost and complexity to IGCC (Hunwick 2008). For these reasons, IGCC has not been considered in the scenarios developed for this research.

One of the drawbacks of coal fired generation – despite the improvements to thermal efficiencies and pollutant emissions made possible by recent technological developments – is the associated carbon emissions. With the expected introduction of a national emissions trading scheme in Australia in 2010, there will be a greater impetus for the coal industry to develop carbon capture technologies. PCC and oxygen fired pulverised fuel (OXY-CF) are two carbon capture technologies that are currently under development. PCC may involve one of several methods to capture carbon from the flue gas, including physical and chemical sorbents, gas-solid adsorption, membrane separation and cryogenic technologies. In contrast, OXY-CF entails the injection of pure oxygen and recirculated flue gas into the plant's combustion chambers, in order to increase the concentration of CO_2 in the flue gas and thereby facilitate its capture. This process requires the on-site production and storage of large volumes of pure oxygen.

PCC and OXY-CF have not been modelled in the scenarios because of the limited availability of engineering data, but it is noted that both technologies would increase the auxiliary power requirements of a plant by 20 to 25 per cent and decrease the thermal efficiency. More water would be required to generate the same amount of electricity compared to a plant without carbon capture (Hunwick 2008; Wibberley et al. 2006). Once captured, the CO_2 would have to be transported to a suitable underground storage site, which would consume additional energy (refer to Rogner, Sharma & Jalal 2008 for an analysis of carbon capture and storage costs).

Gas

NSW currently imports natural gas from interstate. It is connected to gas supplies from Victoria and South Australia, via the Eastern Gas Pipeline and the Moomba to Sydney pipeline, respectively. Both pipelines have sufficient capacity to support the development of additional gas fired power plants in NSW (ACIL Tasman 2007). Furthermore, NSW has potentially enormous reserves of coal seam gas (CSG). CSG is a by-product of the coalifaction process, during which organic matter is turned into coal (Sydney Gas Limited 2008).

The two main gas fired technologies currently used for electricity generation include open cycle gas turbine (OCGT) and combined cycle gas turbine (CCGT). OCGT plants are generally used as peaking plants or for emergencies, because of their rapid start up times and high fuel costs. The plants are relatively compact and do not require water for cooling. In contrast, CCGT plants exhibit higher thermal efficiencies and are generally used as intermediate or baseload plants. CCGT, as the name suggests, combines two generation cycles. The first cycle uses gas to generate electricity. Waste heat from this cycle raises steam, which is used in the second cycle to generate electricity in steam turbines. The second cycle therefore requires make up water and water for cooling (Electricity Commission of New South Wales 1991).

New OCGT and CCGT plants are under construction or in advanced planning stages in NSW and the capacities from these plants have therefore been incorporated in the scenarios. Additional gas fired capacity is considered in scenarios where the assumptions further support this choice of generation technology.

Nuclear

The first nuclear power reactor was developed in the 1950s. Today, nuclear power plants supply 15 per cent of electricity worldwide. The current technology is largely based on light water reactors (LWRs) and heavy water reactors (HWRs), which are considered 'third generation' reactors. LWRs include pressurised water reactors (PWRs) and boiling water reactors (BWRs), of which PWRs account for 60 per cent of the world's installed nuclear capacity. Research into fourth generation reactors is under way, in order to improve the economic, safety and thermal performance of the reactors, and to reduce the risk of proliferation. The first of these reactors are likely to become commercially available after 2015 (Commonwealth of Australia 2006).

The development of nuclear power plants is currently prohibited in NSW (NSW Government 1986). Proponents of the technology argue that it offers distinct advantages, particularly with the current global emphasis on climate change: there are substantial uranium reserves in Australia; a nuclear power plant emits fewer carbon emissions than a coal fired power plant; and nuclear power would diversify Australia's generation mix and in doing so provide additional baseload security. As discussed in Chapter 2, opponents argue that plant safety and proliferation risks are still causes for concern.

In 2006, the Liberal Federal Government commissioned a review to examine the feasibility of nuclear power generation in Australia, within a broader inquiry into uranium mining, nuclear fuel processing and disposal. The review suggested that in order for nuclear power to be competitive with coal fired power plants, carbon emissions will need to be explicitly recognised and government funding will be required to support private investment (Commonwealth of Australia 2006). Due to the long term nature of the scenarios developed for this research, nuclear power is considered in one of the scenarios, where the assumptions support the development of this technology.

Biomass

Biomass generally refers to organic matter, which in the context of this research, may be used as fuel to generate electricity. Some examples of biomass fuel sources in NSW include agricultural and forestry waste, bagasse from sugar cane refinery and methane from sewage. There are several methods to convert biomass to electricity, depending on whether the fuel is in solid, liquid or gas phase. An established method is direct combustion, such as co-firing wood waste in coal fired power plants. An alternative method is pyrolysis, which produces an oil suitable for use in diesel engines. More recently, researchers have developed biomass gasification processes, which dry and heat chipped biomass in order to produce a fuel gas. The gas may then be combusted in a gas turbine, such as a biomass integrated gasification combined cycle (BIGCC) plant, to generate electricity. The technology is similar to CCGT in that it comprises two generation cycles: the waste heat from the gas turbine in the first cycle raises steam for use in steam turbines in the second cycle (Boyle 2004; Stucley & Rural Industries Research and Development Corporation (RIRDC) 2004). In this research, BICGG provides baseload capacity for one of the scenarios, because its assumptions support the development of this technology.

Geothermal

Geothermal energy makes use of the heat generated in the earth's crust and therefore is the only renewable source that does not originate from the sun. This heat – normally in the form of steam or hot water – is pumped via deep bores to a power plant at the earth's surface. The geothermal industry is currently not well established in Australia because there are inadequate sources of steam and hot water to directly generate electricity. However, recent technological developments in this industry – in particular hot dry rock (HDR) technology – appear promising for the Australian context.

HDR technology makes use of the heat stored in impermeable dry rocks. It involves mechanically expanding the natural fractures in the dry rocks, in order to create an artificial heat exchange zone. Water is then injected into this zone and absorbs the heat from the surrounding rocks. It is subsequently pumped to the surface and – via a heat exchanger – is used to vaporise a secondary working fluid, such as pentane, butane or an ammonia-water mixture (Boyle 2004).

HDR technology is currently being pilot tested in locations across Australia, and several exploration licences have been issued in NSW (Department of Primary Industries and Resources of South Australia (PIRSA) 2008). Geodynamics Limited (2007) report that Australia has over 430 years of geothermal energy potential, and that by 2030, 4,000 MW of geothermal energy could be entering the national grid. In this research, geothermal provides baseload capacity for one of the scenarios.

Renewables

Renewable energy may be defined as 'energy obtained from the continuous or repetitive currents of energy recurring in the natural Environment' (Twidell & Weir 2002). In addition to biomass and geothermal energy that were previously discussed, other forms of renewable energy include solar, wave and tidal power, hydro, and wind.

Australia has an abundance of solar energy. The two technologies associated with solar energy are solar thermal and photovoltaics (PV). Solar thermal technology is widely used for domestic hot water heating. Whilst it does not produce electricity, it has the potential to considerably offset the demand for electricity. PVs are solid state devices made from silicon-based semiconductors which convert sunlight into electricity (Boyle 2004). The technology offers considerable potential for Australia, however high capital costs and low thermal efficiencies have prevented widespread uptake of the technology. Federal government subsidies have assisted in removing some of these barriers in the residential market. In addition, the invention of the sliver solar cell by Australian researchers in 2001 holds the potential to significantly improve the prospects of PV technology. It is reported that sliver solar cells use up to 90 per cent less silicon to manufacture, and achieve higher thermal efficiencies of up to twenty per cent, compared to fifteen per cent for conventional cells (Blakers, Weber & Everett 2006).

Wave and tidal power technologies harness the movement of water in the ocean to generate electricity. This form of renewable energy is still relatively immature compared to other forms and is therefore not considered in this research.

Hydropower comprised approximately six per cent of the electricity generated in NSW in 2001 (Electricity Supply Association of Australia (ESAA) 2003). Hydropower plants, such as the Snowy Scheme, often serve as peaking plants, because of the short start up times, and the ability to 'store' energy until required. Several factors currently prevent the development of further large-scale hydropower plants, including public concern over environmental impacts, the reliance on water resources and exposure to risk during drought, and the paucity of suitable sites. Nevertheless, there is still potential to develop smaller-scale hydropower plants using microhydro turbines. The Australian water industry has already installed microhydro turbines along weirs and other places in the network, to serve as pressure reduction valves.

Wind power is a mature technology that has the potential to power 20 per cent of Australia's electricity demand (Diesendorf 2007). In NSW, approximately 1650 MW of wind power capacity is currently under investigation, and it is estimated that the technology could supply 5.4 per cent of the state's electricity by 2020 (Australian Business Council for Sustainable Energy (BCSE) 2007). In operation, wind turbines do not directly emit carbon emissions nor use water. Proponents of the technology suggest that networks of wind farms across the NEM would collectively provide sufficient reliability and resolve intermittency problems caused by the lack of wind in a specific locality. Wind power has the potential to contribute significant capacity in the electricity industry compared to solar, wave and tidal power, and hydropower. In this research, wind power is the representative renewable energy technology in scenarios whose assumptions support the development of additional renewable capacity.

7.2 Development of water-energy scenarios

The water-energy scenarios developed in this research align with the UK Foresight Program's Environment Futures scenarios matrix, because it enables the inclusion of social and cultural dimensions that are prevalent in the lower left and lower right hand quadrants of the AQAL framework. The matrix, which is illustrated in Figure 3-6, is formed by the intersection of two axes that represent the two scenario drivers of social values and governance systems. The resulting quadrants represent the four scenarios, which are labelled: World Markets, Provincial Enterprise, Global Sustainability and Local Stewardship. In this research, the main variables differentiating the scenarios correspond to some of the salient issues facing the industries both in the present and in the future, which are classified as Environmental, Economic, Technological, and Security of Supply. A description of these variables is found in Section 3.6.1.

The scenarios are modelled using input output analysis, as detailed in Section 3.6.2. In brief, the 2001 Leontief hybrid input-output model forms the basis of the four input-output scenario models for 2031. These models have been developed using the RAS method – in conjunction with additional engineering data and expert judgement – in order to depict the structure of the NSW economy in 2031, and in particular the technological structure of the water and electricity industries under each of the four scenarios. Section 7.2.1 describes the assumptions adopted by this research to estimate the demand for and supply of water and electricity in 2031 under the four scenarios. Section 7.2.2 describes the scenarios in more detail, in terms of the variables and the adopted strategies.

7.2.1 Water and energy assumptions

In order to develop the water-energy scenario models, it is necessary to estimate water and energy demand in 2031. The following paragraphs outline the steps involved in this process. It is important to note that the purpose is not to derive an accurate demand forecast, but rather estimate the demand under each scenario, in order to examine the relative trade-offs that might occur under alternative futures. The following paragraphs also identify the suite of supply options adopted in each of the scenarios.

Water demand

Figure 7–1 outlines the process adopted to estimate the total demand for water.

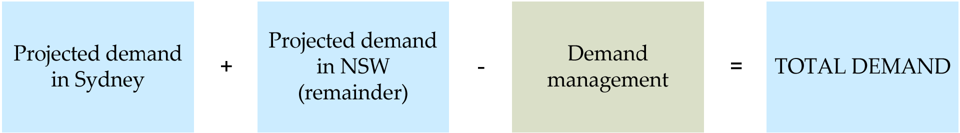

Figure 7–1 Estimation of water demand for 2031

As illustrated in Figure 7–1, the water demand for 2031 was estimated separately for Sydney and the remainder of the state. The rationale behind this approach is that the current Metropolitan Water Plan (NSW Government 2006) bases its water demand forecasts for Sydney on 426 litres per capita per day (lcd), which is significantly higher than actual figures in recent years. Based on data from the ABS and the 2001 model developed for this research, NSW consumed approximately 371 lcd in 2001, excluding water consumption in the water and electricity sectors. This equates to 303 lcd for the remainder of NSW, if one excludes the actual lcd for Sydney in 2001. Therefore, 426 lcd would overestimate water demand if it is applied to the entire population in the state. This two-part approach, which is depicted in Eqn. 7-1, would therefore yield a more realistic forecast[17]:

$$X_W(31) = lcd_s \cdot Pop_s + lcd_r \cdot Pop_r \qquad \text{Eqn. 7-1}$$

where lcd_s = 426 for Sydney, Pop_s = the 2031 population forecast for Sydney[18], lcd_r = 303 for the remainder of NSW, Pop_r = the 2031 population forecast for the remainder of NSW [18]. It is likely that this estimate would still be conservative, given that Sydney Water is committed to reducing consumption in Sydney to 329 lcd by 2011 (NSW Government 2006).

The estimate was further revised based on the demand management assumptions for the individual scenarios, as detailed in Section 7.2.2. As indicated above, the estimate excludes

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[17] Water demand may also be estimated by multiplying the direct water coefficients from the 2001 Leontief hybrid model with the estimated sectoral output for 2031. The researcher obtained very similar water demand estimations using this alternative approach.

[18] Source: NSW Department of Planning (2005)

water used by the energy sectors, because electricity demand differs for each scenario. Instead, the water demand by the energy sectors was calculated separately, based on the technological assumptions for each scenario, and later incorporated in the input-output models.

Water supply

The total supply of water in 2031 is estimated according to the process outlined in Figure 7–2.

Figure 7–2 Estimation of water supply for 2031

In terms of irrigation water, this research assumes that additional capacity is met by the existing IDW sector. For the urban water industry, this research assumes that the existing capacity of the water and sewage treatment plants remain constant. It is also assumed that leaks and supply losses in existing infrastructure reduce the supply capacity by ten per cent. In addition, this research assumes that committed projects in the Metropolitan Water Plan (2006) – such as recycled water projects and accessing deep water at the bottom of dams – become operational by 2031.

The new capacity required over and above these projects to meet the forecasted demand under each scenario is supplied by desalination and/or advanced wastewater treatment plants. Whilst a seawater desalination plant is currently under construction in Sydney at the time of writing, the operation of the plant is dependent on dam levels and therefore there may be extended periods when the plant is not in use. For this reason, this research does not consider seawater desalination as part of the supply mix for all of the scenarios.

Table 7-1 contains the specifications adopted by this research for both water supply options and Table 7-2 provides a percentage breakdown of the strategies to meet the additional demand for water in 2031 under the four scenarios. Figure 7–3 summarises the demand and supply strategies for each of the four scenarios.

Table 7-1 Water supply technical specifications

Water supply technology	O&M costs	Electricity use (kWh/kL)	Water usage rate
Desalination	Varies – see sources	Fixed + 3.9	50 per cent recovery rate
Water recycling - new	Varies – see sources	1.5	75 per cent recovery rate

Sources: Various including Leslie (2007) , Sydney Water (2007c), Voutchkov (2007)

Table 7-2 Breakdown of strategies to meet additional water demand in 2031 (% new capacity)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Demand Management	15		30	70
Desalination	35	70		
Water recycling - new	50	30	70	30

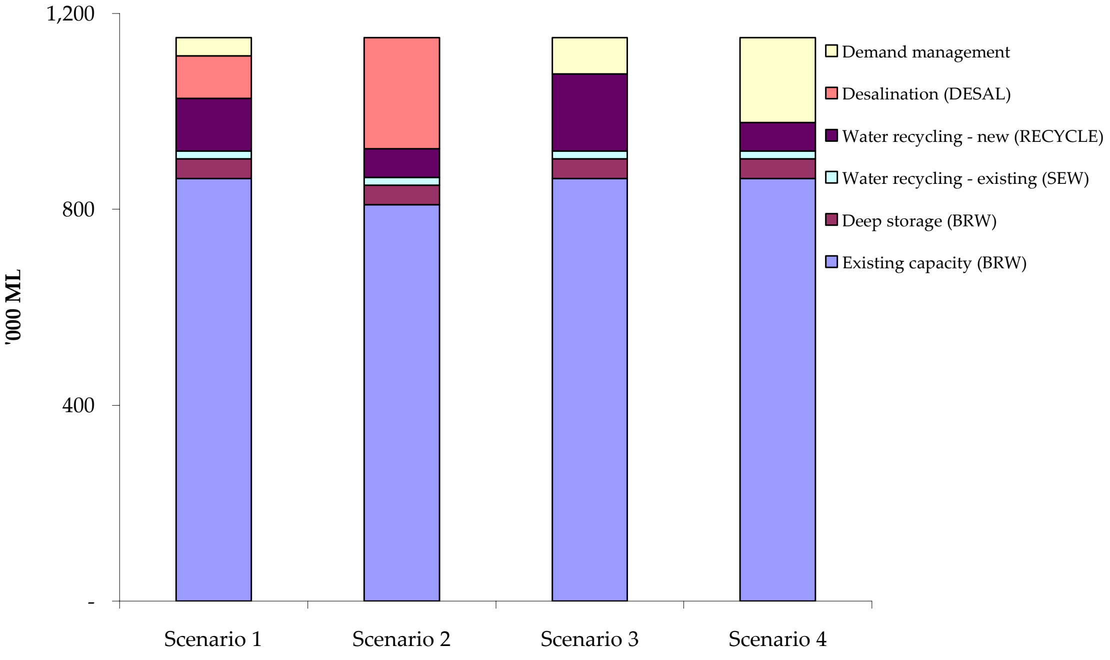

Figure 7–3 Water demand and supply mix in 2031 under the four scenarios

Energy demand

The energy demand for 2031 is calculated using the process outlined in Figure 7–4.

Figure 7–4 Estimation of energy demand for 2031

This research forecasted the demand for all the energy sectors in the 2001 models, including: Electricity, Coal Mining (COAL) Petroleum Refining (PR), Petroleum & Coal Products NEC (PCP), and Retail Gas Supply (GAS).

In the case of electricity demand, the direct electricity coefficients from the 2001 Leontief hybrid model, $A_E(01)$), were multiplied by the estimated output for each sector for 2031,($X_i(31)$ to derive total electricity demand for 2031, as depicted in the following equation:

$$X_E(31) = A_E(01) \cdot X_i(31) \qquad \text{Eqn. 7-2}$$

In scenarios where specific demand management strategies were not considered, the direct electricity coefficients $A_E(31)$ – which represent electricity intensities with units of PJ/$000 (2001) – were revised down by 0.5 per cent per annum, in order to account for technological improvements (Cuevas-Cubria & Riwoe 2006). Table 7-3 lists the electricity demand for each of the scenarios, which have been derived based on the above calculations and the scenario assumptions outlined in Section 7.2.2. The electricity demand in 2031 for Scenario 1 (359 PJ) and Scenario 2 (364 PJ) concord well with the latest forecasts developed by the Australian Bureau of Agricultural and Resource Economics (ABARE) for NSW for 2029-30 (362 PJ). The lower demand forcasts for Scenarios 3 and 4 reflect the adoption of rigorous demand management strategies.

Table 7-3 Comparison of electricity demand forecasts

	Electricity demand (PJ)
ABARE (2029-30)*	362
Scenario 1	359
Scenario 2	364
Scenario 3	294
Scenario 4	173

*Source: (Cuevas-Cubria & Riwoe 2006)

The energy demand for the remaining energy sectors – Coal Mining, Petroleum Refining, Petroleum & Coal Products NEC, and Retail Gas Supply – was also estimated using Eqn. 7-2. As with electricity, it was assumed that the direct coefficients from the 2001 model were revised for efficiency improvements equating to 0.5 per cent per annum to 2031.

Note, the water sectors were omitted from the energy demand forecasts, because water demand is not consistent across the scenarios. Instead, the energy demand for the water sectors was calculated and incorporated into the models separately.

Energy supply

Figure 7–5 outlines the process adopted to estimate energy supply in 2031.

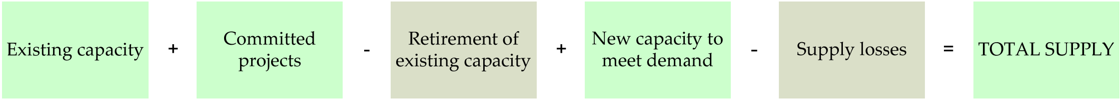

Figure 7–5 Estimation of energy supply for 2031

This research assumes that additional demand for non-electric energy is met by the existing energy sectors. In terms of electricity, the first step in estimating the additional supply required to meet demand is to factor in projects in the advanced stages of planning or under construction. Table 7-4 lists several such projects that were known at the time of developing the scenarios. It is also important to consider existing capacity that is expected to retire by 2031, which is listed in Table 7-5.

Table 7-4 Committed projects

Type	Technology	Capacity
Baseload upgrade	Sub-critical pulverised fuel	380 MW*
Intermediate	Combined cycle gas turbine	400 MW
Peak	Open cycle gas turbine	1660 MW

Notes: *Excludes 350 MW from Munmorah, because it is assumed that this plant will retire before 2031
Source: (EnergyAustralia 2007)

Table 7-5 Existing capacity that is expected to retire by 2031

Name	Technology	Capacity	Location
Munmorah	Sub-critical pulverised fuel	600 MW	Coastal
Liddell	Sub-critical pulverised fuel	2000 MW	Coastal
Vales Point B	Sub-critical pulverised fuel	1320 MW	Inland
Wallerawang C	Sub-critical pulverised fuel	1000 MW	Coastal
Smithfield	Combined cycle gas turbine	162 MW	Inland
Broken Hill	Open cycle gas turbine	50 MW	Inland
Hunter Valley	Open cycle gas turbine	50 MW	Inland

Source: Estimated from ESAA (2003)

In all scenarios, new generation capacity was required to meet electricity demand in 2031. This new capacity was divided into peak and baseload generation, based on data contained in Owen Inquiry documents and other reports (EnergyAustralia 2007; Macquarie Generation 2007; New South Wales Government 2004; Transgrid 2007). The shortfall of capacity was met by the generation technologies reviewed in Section 7.1.2. These technologies were selected depending on assumptions inherent in the four scenarios, as listed in Table 7-6. Table 7-7 lists the specifications for these technologies. Figure 7–6 shows the electricity generation mix under each of the four scenarios, and includes both existing and new capacity. The input-output data for the new sectors have been developed from sources previously listed in Table 3-9.

Table 7-6 New capacity required to meet electricity demand in 2031 (MW)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
CF (Upgrade)	380	380	380	380
USC	5,960			
SC		4,120		
Nuclear		2,090		
Geothermal			1,000	
BIGCC				1,120
CCGT	870	870	3,360	400
OCGT	1,060	1,660	910	910
Wind			1,220	620
Total	**8,270**	**9,120**	**6,870**	**3,430**

Source: Energy Australia (2007), Macquarie Generation (2007), NSW Government (2004), and Transgrid (2007)

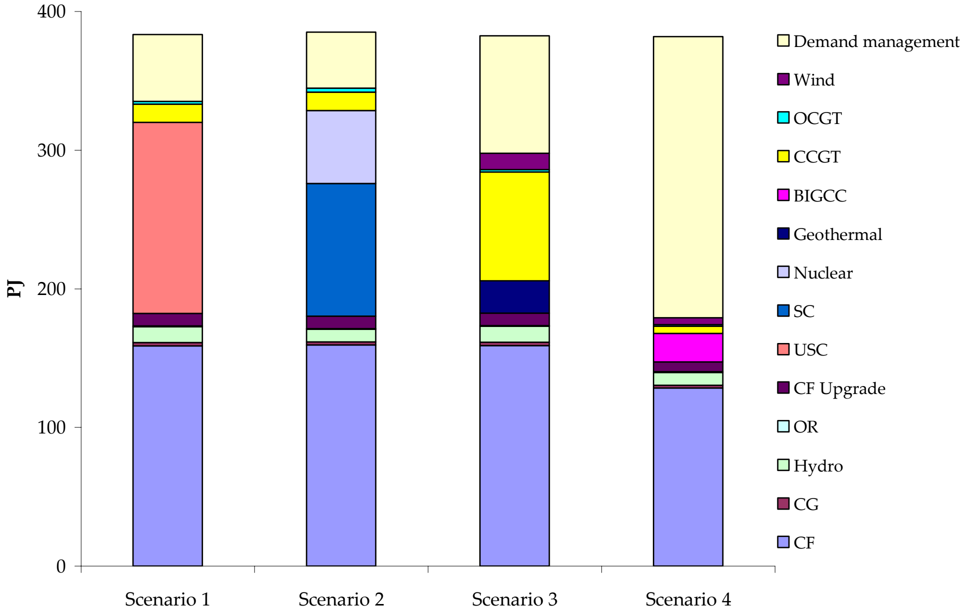

Figure 7–6 Electricity generation mix in 2031 under the four scenarios

Table 7-7 Electricity generation technical specifications

Generation technology	Auxiliary (%)	Thermal efficiency in 2031 (%)		Capacity factor (%)	O&M costs				Water use (kL/MWh)
		Generated	Sent out		Generation		Transmission ($/MWh)	Distribution ($/MWh)	
					Fixed ($/MW/year)	Variable (sent out) ($/MWh)			
CF	6.00	38	36	80	40,000	1.13	1.69	59.24	2001 model
CF Upgrade	6.00	42	42	80	40,000	1.13	1.69	59.24	2001 model
CG	5.00	N/A	N/A	46	12,800	2.28	N/A	59.24	N/A
HYDRO	2.00-2.26	N/A	N/A	12-18	2001 model		1.69	59.24	2001 model
OR	0.00	N/A	N/A	23	$10/MWh		N/A	59.24	2001 model
USC	7.50	53	49	80	40,000	1.20	1.69	59.24	1.00
SC	7.50	47	43	80	40,000	1.20	1.69/	59.24	1.00
Nuclear	0.13		33	80	87,308	2.80	1.69	59.24	1.514
Geothermal	6.75	N/A	N/A	80	168,000	N/A	1.69	59.24	10 l/s (~0.04)
BIGCC	9.00	N/A	N/A	80	12/MWh	15	100		0.50
CCGT (I)	2.40	63	61	50	12,800	4.84	1.69	59.24	0.88
CCGT (B)	2.40	63	61	80	12,800	4.84	1.69	59.24	0.88
OCGT	2.00	37	36	5.7	7,500	7.5	1.69	59.24	N/A
Wind	0.00	N/A	N/A	31.2	N/A	10	1.69	59.24	N/A

Notes: Cost information above is in real prices for various years, which have been converted to AUD$2001 in the models; (I) = intermediate; and (B) = baseload

Sources: Various including 2001 model, ACIL Tasman(2007), estimates calculated from ESAA (2003), Eraring Energy (2007), MMA (2006), APPEA (2007), ISA (2006), Commonwealth of Australia (2006), OECD (2005), Woods (2006), Hondo, Moriizumi & Uchiyama (2000), Kutscher (2000), Boyle (2004), Wibberley et al. (2006), and BBP (2007).

7.2.2 A description of the four scenarios

This section describes the four scenarios developed in this research, in terms of the main variables, and the technologies adopted in the water and electricity industries in order to meet demand for water and electricity in 2031. These variables may be summarised as: Environmental, Economic, Technological and Security of Supply. As previously discussed in Section 3.6.1, **Environmental** refers to the following factors: the priority accorded to environmental protection, the extent of water and energy conservation; and the influence of drought and climate change. **Economic** describes the extent to which cost determines decisions in the industries, which is influenced by the extent of private investment and the impact of an emissions trading scheme. **Technological** describes the propensity for innovation and for adopting new technologies, and the influence of emissions trading on the selection of and level of dependency on various technologies. **Security of Supply** refers to the importance of developing and using domestic energy resources in contrast with relying on energy imports from interstate and abroad. It also refers to the level of importance of non-rainfall dependent water supplies.

Table 7-8 summarises the main variables for each of the scenarios. A description of the four scenarios is contained below. The scenarios align with the scenario matrix developed by the UK Foresight Program on Environmental Futures, which has been used to analyse long-term scenarios related to water, energy and climate change (see for example Environment Agency 2001; Performance and Innovation Unit (PIU) 2001a, 2001b). There is therefore a degree of correspondence between the scenarios variables developed for this research and those contained in the studies.

Table 7-8 Summary of scenario variables

Variable	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Environmental	Low priority	Regional issues such as drought	Global issues such as climate change	Maximising local resources with minimum impact
Economic	Competitive global markets and low cost technologies	Emphasis on domestic production	Strong international cooperation	Low priority
Technological	High innovation	Low innovation	High innovation	Low innovation
Security of supply	Low priority	High priority	Moderate priority	Low priority

Scenario 1 World Markets

Scenario 1 is termed 'World Markets'. This scenario is characterised by consumerist values and therefore economics underpins many investment decisions. **Low cost technologies** and low cost **efficiency measures** are favoured to meet future demand in the water and electricity industries. In addition, an open and competitive global market enables technology transfer and fosters a high degree of innovation. The Environment is accorded a low priority and is not factored into decisions in either industry.

In 2031, planned capacity upgrades to existing CF plants and USC provides 380 MW and 8,270 MW of baseload capacity, respectively. USC enables the use of a cheap energy source in abundance in NSW – black coal – and represents the best available technology in the industry because of the high conversion efficiencies compared to other coal generation technologies, such as SC. This technology has been developed extensively overseas and is available in Australia because of the openness to international trade and high levels of technology transfer. New USC plants are developed in inland locations close to coal mines. The plants source freshwater for their cooling towers. CCGT and OCGT plants that are under development supply 400 MW and 1,060 MW of intermediate and peak generation capacity, respectively. An additional 470 MW of CCGT plant is also developed for intermediate capacity. With the exception of the projects under development that are located in coastal areas, all intermediate and peak plants rely on freshwater for cooling.

In terms of electricity demand, it is assumed that technological improvements in all sectors reduce the energy intensity of the sectors by 0.5 per cent per annum (Cuevas-Cubria & Riwoe 2006). This scenario also assumes that additional efficiency improvements and voluntary use reductions – driven by the desire to reduce costs – lower peak demand by an additional 600 MW by 2031. This figure is in line with demand reduction potentials outlined in the NSW Government's Green Paper (2004) and reports prepared for the previous Sustainable Energy Development Authority (2001). These improvements occur in the manufacturing, construction, transportation and services sectors, equivalent to 70 per cent of the 600MW. Efficiency improvements in Households comprise the remaining 30 per cent.

For the water sector, water recycling and seawater desalination comprise 50 per cent and 35 per cent of new supply capacity, respectively. Due to the focus on cost minimisation, water recycling plants located adjacent to users or on-site are favoured over those with high transportation costs. For seawater desalination, it is assumed that all electricity is sourced from the existing Renewables sector (OR sector). In addition, demand management strategies offset the requirement for additional supply capacity by 15 per cent. This is undertaken with a view to reduce costs rather than to conserve water.

Scenario 2 Provincial Enterprises

The Provincial Enterprise scenario is underpinned by individualist values. The main priority in the industries is **security of supply**, which favours technological diversity and resource independence. However, the regional focus of the scenario limits the transfer of emerging technologies. Environmental issues of a regional nature, such as drought, influence decisions in the industries. Global environmental issues, such as climate change, are not priorities.

In this scenario, SC and Nuclear power plants supply an additional 4,120 MW and 2,090 MW of baseload capacity, respectively. SC is the current benchmark technology for coal and is likely to be widespread worldwide by 2031. Other more advanced coal fired technologies are available overseas, however, SC presents a proven and reliable technology that is well established in Australia by 2031. Nuclear power provides additional security of supply, because uranium is in abundance in Australia, and would diversify the generation mix. In both cases, new plants are located in coastal areas, because of the threat of drought to electricity generation security. The capacity factor of the Snowy Mountains Scheme is also reduced from fifteen percent in 2001 to ten per cent, due to water shortages. The CCGT and OCGT plants under development provide 400 and 1,660 MW of intermediate and peak capacity, whilst an additional CCGT plant provide a further 400 MW of intermediate capacity. This plant is also located along the coast, to reduce the reliance on stressed inland river systems and limit exposure to drought. Technological improvements reduce the electricity intensities of all scenarios by 0.5 per cent per annum and curtail the growth of electricity demand (Cuevas-Cubria & Riwoe 2006).

The main priority in the water industry is to ensure that the water supply is independent from rainfall, because of the concern over the impact of drought. It is assumed that technologies provide the solution to augment supply in the industry, and there is therefore little interest in behavioural change to bring about water conservation. Desalination provides 70 per cent of additional capacity. It is assumed that all electricity for the desalination plant is sourced from the existing Renewable energy sector (OR), which is the current NSW Government Policy (NSW

Government 2006). Water recycling provides the remaining 30 per cent, and it is assumed that recycling plants are installed in inland locations to reduce the pressure on inland river systems.

Scenario 3 Global Sustainability

The Global Sustainability scenario is characterised by strong international cooperation in dealing with **global environmental issues**, particularly climate change. Technological innovation is high, due to the open international exchange of ideas. This innovation is focused on reducing reliance on coal and oil and maximising use of water resources, within a broader framework of embracing institutional and behavioural change.

In the electricity industry, new CCGT and geothermal plants provide a further 2960 MW and 1000 MW of baseload capacity by 2031. An emissions trading scheme and global agreements to slow down the rate of climate change gives gas fired technology a significant advantage over coal, because of its comparatively lower CO_2 emission factor[19]. NSW does not have proven natural gas reserves, but there is sufficient capacity in gas pipelines from interstate to meet demand. In addition, coal seam gas (CSG), of which NSW has potentially significant reserves, offers an alternative source of gas. Geothermal also offers a lower carbon emission option compared to coal for baseload generation, which makes this a feasible generation option. As with the other scenarios, the upgrade of existing CF plants provide an additional 380 MW of baseload capacity. CCGT and OCGT under development supply 400 MW and 910 MW of intermediate and peak capacity, and new wind plants supply an additional 1,220 MW of intermediate capacity.

In terms of electricity demand, energy efficiency measures reduce demand by 20 to 34 per cent, in line with the low Energy Efficiency Improvement (EEI) potential estimates contained in the National Framework for Efficiency report (Sustainable Energy Authority Victoria (SEAV) 2003), which are listed in Appendix 7. For those sectors that do not have an EEI potential, it is assumed that their efficiency improves by 0.5 per cent per annum to account for general technological improvements.

The main focus in the water industry is to maximise the use of water resources, in terms of using water that is fit for purpose, whilst minimising energy consumption. Recycled water from advanced wastewater treatment plants therefore constitutes 70 per cent of the new

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[19] The carbon emissions factor for black coal in NSW power plants is 86.03 – 94.72 Gg CO2/ PJ and 50.40 Gg CO2/ PJ for gas, compared to 89.8 Gg CO2/ PJ and 51.7 Gg CO2/ PJ for new entrant black coal and gas fired power plants, respectively (ACIL Tasman 2007).

capacity. In addition, there is general acceptance for the need to modify production processes and end use of water, which offsets an additional 30 per cent of new capacity.

Scenario 4 Local Stewardship

The main focus of this scenario is **maximum utilisation of local natural resources**, with **minimum environmental impact**. There is a tendency towards self-reliance, due to strong local and regional governance. Resource conservation is accorded priority over technological supply options. The regional focus generally limits technological innovation.

As with the first three scenarios, it is assumed that the upgrade of existing coal fired power plants provides 380 MW of baseload capacity. A new BIGCC plant supplies an additional 1,120 MW of baseload capacity. The biomass used by this plant is agricultural waste from wheat crops which is sourced from within the state. CCGT and OCGT projects under development supply an additional 400 MW and 910 MW of intermediate and peaking capacity, respectively. This is supplemented by the development of 620 MW of wind plants for intermediate demand. Wind plants do not consume water directly and therefore do not increase pressure on water resources.

Due to the emphasis on resource conservation, demand management is rigorously implemented in the electricity industry. Efficiency improvements are based on the high EEI potential estimates, which range from 40 to 74 per cent depending on the sector (refer to Appendix 7). The new capacity required under this scenario is significantly lower compared to the other three (refer to Table 7-8). As with Scenario 3, for those sectors that do not have an EEI potential, it is assumed that their energy efficiency improves by 0.5 per cent per annum to account for general technological improvements.

Demand management strategies in the water industry similarly limit water consumption considerably, resulting in an offset of 70 per cent of demand. Recycled water from advanced wastewater treatment plants – that will be well established in the state by 2031 – supply new capacity, which is equivalent to 30 per cent of demand.

7.3 Empirical findings

This section presents the findings of the scenario modelling, with a view to identifying potential trade-offs between the demand and supply of water and electricity in 2031. Section 7.3.1 focuses on water use by the electricity sectors. The scenarios are compared in terms of the calculated water intensities for each of the generation technologies, as well as the overall water consumption. Section 7.3.2 presents the energy consumption and intensities for the water sectors and compares the scenarios in terms of the primary energy consumption and carbon emissions. It is important to note that the results are not meant to be accurate forecasts of the future, but rather should be viewed in terms of the relative performance of the scenarios and the potential for future trade-offs in the water and electricity industries.

7.3.1 Water for the electricity sectors

The results presented below differentiate between water from the water sectors, and water that is extracted from the Environment. For both sets of results, the water used by the transmission and distribution functions of the electricity industry have been apportioned to the electricity generation sectors, based on whether the electricity generated by these sectors are delivered via the transmission and distribution network, or distribution network alone.

Table 7-9 lists the estimated water use in the electricity industry as a whole, under the four scenarios. It enables the scenarios to be compared, in terms of the influence of the generation mix, water source and demand management strategies on water use. Table 7-10 lists the weighted average total water intensities for each scenario. The ‘weighted average’ takes into account the total water intensities of each of the electricity sectors, in proportion to their contribution to the generation mix.

An explanation and derivation of the total intensities are contained in Section 3.4.3. In summary, total intensities refer to the amount of water required to satisfy the final demand for 1 MJ of electricity in the NSW electricity grid, and incorporate both direct and indirect use. Indirect use refers to water that is embedded in the inputs that the electricity sectors consume during operation and maintenance. A breakdown of the water consumption and intensities for each of the electricity sectors is contained in Appendix 8.

Table 7-9 Water required to deliver final demand for electricity (ML)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
IDW	301	421	303	29,592
BRW	2,125	2,207	2,337	1,480
SEW	758	535	837	362
RECYCLE	265	107	357	62
DESAL	25	98	-	-
RW	26,221	13,245	17,455	86,392
ISU	2,066,541	1,561,226	1,929,913	1,474,171
SW	3,576	19,210	3,522	2,516

Source: Derived from the Leontief hybrid model for 2031

Table 7-10 Weighted average total water intensities for the electricity industry (ML/PJ)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
IDW	3.00	4.20	3.68	623.87
BRW	21.20	22.02	28.40	31.20
SEW	7.57	5.34	10.17	7.64
RECYCLE	2.64	1.06	4.33	1.31
DESAL	0.04	0.05	-	-
RW	261.60	132.14	212.05	1,821.36
ISU	20,617.18	15,575.82	23,446.17	31,079.19
SW	35.67	191.65	42.79	53.05

Source: Derived from the Leontief hybrid model for 2031

The results in Table 7-9 highlight trade-offs that occur in each of the scenarios, as a result of where water is sourced, the type of cooling systems used, the generation mix, and the influence of demand management strategies. It is evident that the net effect of these influences results in significantly different consumption patterns across and within the scenarios, as the following discussion demonstrates.

Water supplied by the water sectors

Scenario 4 required the most water from the **Irrigation & Drainage Water** sector (29,592 ML), because of the high reliance on irrigation water to produce biomass crops for the BIGCC sector. In comparison, the consumption of irrigation water by Scenarios 1, 2 and 3 vary between 301 ML and 421 ML, which is significantly lower compared to water supplied by the Bulk & Retail Water and Sewage sectors, and extracted from the Environment. The reliance on irrigation water in Scenario 4 is also reflected in the raw water consumption figure, which is the highest across the scenarios at 86,392 ML. In this scenario, the BIGCC sector supplies approximately 11.5 per cent of electricity, largely using waste from wheat crops as the biomass source. One could argue that instead of consuming additional water, electricity generation from biomass is extracting additional value from the irrigation water; therefore the high water consumption by the BIGCC sector should not be seen as an impediment to its uptake. Rather, the biomass source is critical to determining the water impact of the BIGCC sector. Further, biomass sources should ideally have other productive uses, in order to optimise the use of water.

In general, the consumption and intensity values for the **Bulk & Retail Water** sector were highest compared to the values for the other water sectors. Scenario 3 consumes the most water from the Bulk & Retail Water sector (2,337 ML). A significant proportion of this is consumed by the CF sector to generate electricity (1,811 ML). The Geothermal sector, which supplies just below eight per cent of electricity in this scenario, consumes approximately 408 ML of water from the Bulk & Retail Water sector and therefore also contributes significantly to the overall water consumption for this scenario. This consumption comprises water embedded in the material inputs from water-intensive manufacturing sectors, such as Basic Metals & Products. Further, the Bulk & Retail Water intensity for the Geothermal sector is 63.21 ML/PJ, which is higher than the CF sector (39.03 ML/PJ).

Scenario 4 required the least amount of water from the Bulk & Retail Water sector (1,480 ML), and most of this consumption is attributed to the CF sector (1,404 ML). The overall figure suggests that rigorous electricity demand management strategies not only save on carbon emissions and delay the requirement for new generation capacity, but that they have a significant effect on lowering water consumption from existing power plants. The Bulk & Retail Water consumption for Scenario 4 (1,480 ML) is approximately 34 per cent lower than for Scenario 3 (2,337 ML), where demand management is less rigorous. The Bulk & Retail Water intensities, however, present a different picture, in that the weighted average intensity for Scenario 4 (31.20 ML/PJ) is the highest across all the scenarios. A possible explanation is that the CF sector – which contributes significantly to the weighted average intensity – comprises the largest proportion of the generation mix for this scenario.

Scenario 4 again requires the least amount of recycled water from the **Sewage** sector (362 ML), because the demand for electricity is significantly less compared with the other scenarios. The bulk of this consumption is derived from recycled water used for cooling purposes by the existing CF sector (322 ML). In comparison, Scenario 3 consumed the greatest amount of recycled water from the Sewage sector (837 ML). A significant proportion of this figure is derived from consumption by the CF sector (675 ML), and the Geothermal sector (135 ML). In the case of Geothermal, the recycled water consumption is embedded in material inputs from the manufacturing sectors.

The **Recycle** sector essentially refers to recycled water from advanced wastewater treatment plants installed after 2001. Again, Scenario 4 (62 ML) consumed the least amount of water from the Recycle sector, because of its low electricity demand compared to the remaining three scenarios. Scenario 3 (357 ML) again consumed the most recycled water, a significant proportion of which is derived from indirect consumption by the CF (255 ML) and Geothermal (82 ML) sectors. The water-intensity of material inputs can therefore contribute significantly to the water-intensity of the electricity sectors. This influence appears to significantly reduce the water savings attainable from demand management strategies implemented in this scenario.

The **Desalination** sector supplies approximately 7.5 per cent and 20 per cent of water in Scenarios 1 and 2, respectively. Scenario 2 (98 ML) therefore consumes more desalinated water, compared with Scenario 1 (25 ML). However, in both cases, consumption of desalinated water by the electricity sectors is marginal compared to water supplied by the other water sectors, and water extracted from the Environment.

Water from the Environment (water primary inputs)

The water production factors include Raw Water, Instream Use and Seawater. These water sources provide critical cooling water, or in the case of Instream Use, water for hydropower generation. Consumption levels are therefore generally higher compared to water supplied by the water sectors. In the case of **Raw Water**, Scenario 4 (86,392 ML) had the highest consumption, because of the reliance on the Agriculture sector – and in turn the Irrigation & Drainage Water sector – for biomass crop production. In contrast, Scenario 2 (13,245 ML) consumed the least amount of Raw Water, because new generation capacity is assumed to be located along the coast and therefore reliant on seawater. This new capacity comprises largely SC and Nuclear power plants. Therefore, despite having the largest electricity demand across all the scenarios, Scenario 2 places the least pressure on freshwater sources in the state.

Scenario 1 (26,221 ML) consumed the second highest amount of Raw Water, because it is assumed that new capacity, largely provided by USC coal power plants, is developed in inland locations, requiring freshwater for cooling. In addition, demand management is not as rigorous compared with Scenarios 3 and 4, and therefore little water savings are made through energy efficiency measures.

The Raw Water consumption for Scenario 3 is 17,455 ML. This figure largely comprises consumption by the CF sector (10,873 ML) and by Combined Cycle Gas Turbine plants (5,076 ML), the latter which supply over 25 per cent of electricity. The water intensities of both electricity sectors are 234.31 ML/PJ and 234.01 ML/PJ, respectively. From a water perspective, there are no significant differences between electricity generated by either the CF or CCGT sectors. Geothermal contributes another 1,412 ML to Raw Water consumption and has a total Raw Water intensity of 219.69 ML/PJ. It therefore has the lowest intensity of the baseload electricity sectors in this scenario.

The Raw Water intensities for the Cogeneration sector and sectors representing intermediate and peak plants are generally lower than baseload plants. Some of these sectors, such as Wind, may also be developed for baseload supply, and would offer a baseload option with little impact on water resources.

Instream Use refers to water for hydropower generation and therefore is a non-consumptive use. Scenario 1 had the highest Instream Use value of 2,066,541 ML, largely from direct use by the Hydropower sector. The Instream Use values for the CF sector (7,449 ML), and USC sector (4,730 ML) were also significantly higher compared with the other generation technologies in Scenario 1, which suggests that these sectors relied more on material inputs from energy-intensive manufacturing sectors. In contrast, Instream Use for intermediate and peaking technologies such as CCGT (185 ML), Cogeneration (15 ML), OCGT (38 ML) and Other Renewables (1 ML) was relatively low.

Scenario 4 had the lowest Instream Use value of 1,474,171 ML, again largely because of the low electricity demand compared with other sectors. Scenario 2 was second lowest at 1,561,226 ML, which reflects the shift in the generation mix away from Hydropower, because of the concerns over the impact of drought on generation. As with Scenario 1, the Hydropower sector accounted for most of this use in both scenarios, followed by the CF sector and other baseload generation sectors. Lastly, Scenario 3 had the second highest value at 1,929,913 ML. After the Hydropower sector, the Geothermal sector contributed most to this use, which reflects the similar trend identified earlier, that is, the Geothermal sector is highly reliant on energy-intensive sectors for material inputs.

The **Seawater** production factor provides cooling water for coastal power stations. In this research, only consumptive use is considered, rather than the rate of use of water through a once-through cooling system, which would be significantly higher (refer to Table 2-1 for a comparison). Scenario 2 (19,210 ML) consumed the highest amount of seawater, derived largely from the SC sector (8,504 ML), the Nuclear sector (6,590 ML) and the CF sector (3,116 ML). The coastal location of the additional power plants eases the strain on water resources that this scenario would otherwise create, considering that it also has the greatest demand for electricity. Further, nuclear power plants use significantly more water with cooling towers (see Table 2-1).

Seawater consumption for Scenarios 1 and 3 was similar, at 3,576 ML and 3,522 ML, respectively. Both figures were largely derived from seawater consumed by the CF sector (3,084 ML and 2,824 ML, respectively) and the CCGT sector (463 ML and 648 ML, respectively). Lastly, Scenario 4 had the lowest seawater consumption of 2,516 ML, of which 2,187 ML came from the CF sector.

Summary

The salient points from the analysis may be summarised as follows:

- Demand management strategies to reduce electricity consumption can significantly reduce water consumption. However, the benefits from such strategies may be offset by the installation of generation technologies that require significant material input from water- and energy- intensive sectors, as demonstrated by the Geothermal sector in Scenario 3;

- Geothermal does not directly rely on fossil fuels, however, the water and energy embedded in a geothermal power plant are quite substantial and in the scenario contributed signficantly to water use related to electricity consumption, such as Instream use and recycled water from the Sewage sector;

- Biomass would appear to reduce the reliance on fossil fuels and therefore reduce carbon emissions, but there is a significant water penalty, reflected in the high Irrigation & Drainage Water and Raw Water intensities for the BIGCC sector in Scenario 4. In order for the BIGCC sector to play a significant role in the electricity sector in the future, biomass sources should be selected that enable additional value to be extracted from the water that such sources require. For the purpose of simplicity, this research has not separated possible biomass sources from bagasse or biogas from sewage treatment plants, but it is likely that such sources would consume less water. In this research, waste from wheat crops has been used as the signature biomass source, and one can argue that additional value is being extracted from the irrigation water;

- The CF sector, which represents subcritical coal fired power plants that were installed prior to 2001 continue to have a significant influence on water consumption in 2031. One of the main strategies to reduce the pressure from such sources is rigorous demand management programs in the electricity industry;

- Other baseload generation sectors, such as USC in Scenario 1, SC and Nuclear in Scenario 2, and CCGT in Scenario 3, do not necessarily offer less water-intensive options compared to the existing CF sector. This strengthens the recommendation for the promotion of demand management strategies and development of power stations in coastal locations;

- The intensities for intermediate and peaking plants are generally lower compared to the baseload sectors. These plants include Other Renewables that were installed prior to 2001, OCGT plants, Cogeneration and Wind; and

- There is a strong case to pursue investment strategies that would improve the reliance on Wind – such as developing networks of wind farms across different regions – so that it is equivalent to a baseload source. As discussed previously, it is reported that there are sufficient wind resources across the state for such a strategy to be possible.

7.3.2 Energy for the water sectors

This section presents the energy intensities for the water sectors under the four scenarios. An explanation and derivation of the intensities are contained in Section 3.4.3. As with Chapter 5, the intensities encompass all energy fuels, including electricity (the primary focus of this research), refined petroleum and gas. This expanded focus enables the calculation of primary energy consumption, and in turn carbon emissions. A breakdown of the energy consumption and intensities for each of the water sectors is contained in Appendix 8.

Energy supplied by the energy sectors

Table 7-11 lists the amount of energy required to satisfy the final demand for water, in terms of energy supplied by the Electricity, Petroleum Refining and Retail Gas Supply sectors, and the primary energy equivalent. Table 7-12 depicts the total weighted average energy intensities of the urban water industry (that is excluding the IDW sector) for each of the scenarios. The total energy intensities, as described earlier in Section 3.4.3, essentially refer to the amount of energy required to deliver 1 ML of water to final users in NSW, and includes both direct and indirect requirements. A breakdown of the energy consumption and intensities for each of the water sectors is contained in Appendix 8.

Table 7-11 Energy required to satisfy water demand in 2031 (PJ)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Electricity	2.94	3.96	2.17	2.08
Petroleum Refining	1.35	1.34	1.36	1.40
Gas Supply	0.63	0.63	1.37	0.60
Coal	4.82	4.17	3.51	4.19
Crude Oil	1.67	1.65	1.75	1.73
Natural Gas	0.63	0.63	1.37	0.60
Uranium	-	0.90	-	-
Primary Energy	**7.12**	**7.36**	**6.63**	**6.52**
Percentage Difference from lowest	**9**	**13**	**2**	**0**

Source: Derived from Leontief hybrid models for 2031

Table 7-12 Weighted average energy intensities for the urban water industry (MJ/ML)

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Direct	**Total**	**Direct**	**Total**	**Direct**	**Total**	**Direct**	**Total**
Electricity	2,732.40	3,371.70	3,936.98	4,391.89	1,923.64	2,751.69	1,571.45	2,075.35
Petroleum Refining	96.82	1,225.78	88.21	991.56	100.16	1,300.81	110.30	1,200.67
Gas Supply	26.22	516.19	23.97	445.34	27.13	1,560.22	29.88	476.65
Coal	-	4,961.33	-	3,505.41	-	4,351.73	-	4,137.64
Crude Oil	38.88	1,390.71	35.42	1,228.35	40.22	1,703.55	44.29	1,480.67
Natural Gas	-	514.98	-	444.30	-	1,556.79	-	475.52
Uranium	-	-	-	764.74	-	-	-	-
Primary Energy	**38.88**	**6,867.01**	**35.42**	**5,942.79**	**40.22**	**7,612.07**	**44.29**	**6,093.82**
Percentage Difference from lowest	**10**	**16**	**0**	**0**	**14**	**28**	**25**	**3**

Source: Derived from Leontief hybrid models for 2031

Electricity required by the water sectors is heavily influenced by water demand and the selection of treatment technologies, which is demonstrated by the four to 90 per cent difference in electricity consumption between the scenarios (refer to Table 7-11). For Scenarios 4 and 3, this demand is the lowest at 2.08 PJ and 2.17 PJ, respectively, because of rigorous demand management strategies applied in both scenarios. Scenarios 2 (3.96 PJ) and 1 (2.94 PJ) consumed the most electricity; both scenarios had the highest and second highest demand for water, which was met by recycled water from advanced wastewater treatment plants and seawater desalination. Both technologies are substantially more energy-intensive compared with the existing water infrastructure. This is evident in the electricity intensities in Appendix 8 . Electricity intensities for the Recycle sector range from 8,062 MJ/ML for Scenario 2 to 8,664 MJ/ML for Scenario 3. The intensities for Desalination were 14,391 MJ/ML for Scenario 1 and 13,604 MJ/ML for Scenario 2. In comparison, the electricity intensities for the Bulk & Retail Water sector range from 1,685 MJ/ML for Scenario 4 to 1,747 MJ/ML for Scenario 3, which are substantially lower. It appears that the water supply mix and the electricity generation mix cause variations in the total electricity intensities for the different water sectors between the scenarios by up to five per cent.

The results confirm that electricity is the dominant fuel source in the water industry. This is of particular concern, given that water shortages due to drought increased the wholesale price of electricity by 270 per cent in May 2007, which will have flow on effects to retail electricity customers, such as water utilities (refer to Chapters 2 and 4). The water sector’s recourse to renewable energy will also have an impact of water prices, because of the relatively higher cost of renewables compared to coal-fired electricity, which currently dominates in NSW. Water utilities are also drought-proofing their water supplies by investing in advanced wastewater treatment technologies and desalination, which are energy-intensive, as the results above demonstrate. Both the increase in the price of electricity and the increase in demand for electricity will undoubtedly raise the price of water in the future, even before factoring in the impact of carbon pricing. The scenario results are therefore useful for demonstrating how electricity demand – and in turn water prices – may be minimised in the future. Of course, a reduction in the consumption of electricity would have the environmental benefit of limiting the reliance on fossil fuels, as well as reducing the water sectors’ contribution to climate change.

Refined Petroleum required across the scenarios is relatively similar, from 1.34 PJ for Scenario 2 to 1.40 PJ for Scenario 4. A significant proportion of this consumption occurred in the Bulk & Retail Water and Sewage sectors. The corresponding intensities range from 1,178 – 1,218 MJ/ML for Bulk & Retail Water, and from 918 – 1,028 MJ/ML for Sewage. The Recycle sector exhibited the highest total intensities across the scenarios (from 1,536 MJ/ML for Scenarios 2 and 4 to 2,218 MJ/ML for Scenario 1), which suggests that a move towards recycled water use will increase the reliance on refined petroleum products. In addition, the difference in the intensities is attributed to the differences in the electricity generation mix, as all other petroleum assumptions are constant across the scenarios. Compared to the refined petroleum use in the economy as a whole (over 811 PJ), this increase is likely to be relatively minor.

Scenario 3 (1.37 PJ) exhibited the highest **Retail Gas Supply** requirements across the scenarios, which reflects the high proportion of gas fired technology in the electricity generation mix. In comparison, Scenarios 1, 2 and 4 had similar consumption levels of 0.63 PJ, 0.63 PJ and 0.60 PJ, respectively. Similarly, Retail Gas Supply intensities reflect the generation mix of each of the scenarios: Scenario 3, in which gas fired generation accounts for 25 per cent of the generation mix, has a Gas Supply intensity of 1,560 MJ/ML. In comparison, Scenario 2, in which gas fired generation accounts for 13 per cent of the generation mix, has an intensity of 445 MJ/ML.

Energy primary inputs

Raw Coal provided the bulk of primary energy (excluding renewable sources) across the scenarios, and in the case of Scenario 1, is generally in proportion to electricity consumption, as over 90 per cent of the generation mix is coal-fired. The remaining scenarios comprise baseload capacity from other primary energy sources (such as nuclear, biomass and geothermal) and therefore the reliance on Raw Coal is lower. These technologies offer distinct advantages to coal-fired generation, particularly in the absence of carbon capture and storage technologies, which are still under development.

Crude oil reflects refined petroleum use in the scenarios. Scenario 3 (1.75 PJ) had the highest crude oil consumption, largely by the BRW (0.89 PJ) and the SEW (0.72 PJ) sectors. The consumption of crude oil by the BRW sector in Scenario 3 is higher than in other scenarios, as a result of the generation mix in the electricity sectors in the scenarios. The Recycle sector for Scenario 3 (0.13 PJ) also consumed significantly more crude oil than the other sectors. Based on data from the Australian Bureau of Agricultural and Resource Economics (ABARE) and intensities derived earlier from the 2001 Leontief hybrid model, it appears that a significant proportion of crude oil consumption by the Recycle sector is embedded in consumption of gas from the Retail Gas Supply sector. The high reliance on gas in the electricity industry has resulted in the high indirect consumption of crude oil, relative to the other sectors. As stated above, however, the amount of refined petroleum, and therefore crude oil, consumed by the water sectors is minor compared to the consumption in the economy overall.

The consumption of the primary energy source, **Natural Gas,** reflects consumption of gas from the Retail Gas Supply sector. The differences in the results between Natural Gas and the Retail Gas Supply sector may be accounted for by other energy inputs – such as refined petroleum and electricity – consumed by the Gas Supply sector to refine and distribute gas to the production sectors. The total consumption values for Natural gas are therefore lower. This reflects the importance of converting energy sources to their primary energy equivalent, in order to avoid the double counting that would occur if final forms of energy were compared. Natural Gas is of particular importance to Scenario 3 (1.37 PJ), because of the high reliance on gas fired turbines in the electricity generation mix. The remaining three sectors consume natural gas to a lesser extent and its significance may be better realised when comparing the emission factors – and therefore carbon emissions – of the various fossil fuels, which is explored in more detail below.

In Scenario 2, it is assumed that enriched **Uranium** fuel is imported inter-state into NSW for nuclear power generation. Under this scenario, approximately eleven per cent of electricity is supplied by nuclear power. The other baseload technology which provides additional capacity is Supercritical coal. Consumption of Uranium would therefore offset the consumption of Raw Coal, and in turn reduce carbon emissions under this scenario.

In general, Scenario 4 (6.52 PJ) consumes the least amount of **Primary Energy** in total, followed by Scenario 3 (6.63 PJ), Scenario 1 (7.12 PJ) and lastly Scenario 2 (7.36 PJ). This represents an eleven per cent difference between the lowest and highest consuming scenarios, which is a product of both the generation mix and demand management strategies in the water industry.

The total weighted average intensities offer an alternative picture: Scenario 2 had the lowest intensity (5,943 MJ/ML), followed by Scenario 4 (6,094 MJ/ML), Scenario 1 (6,867 MJ/ML), and lastly Scenario 3 (7,612 MJ/ML). In Scenario 2, the Desalination sector supplies 70 per cent of new capacity and approximately 20 per cent of total capacity. It is assumed that this sector consumes electricity from the Other Renewables sector, and therefore there is no primary energy equivalent in terms of fossil fuels. If one were to consider the renewable energy as a primary energy source, the primary energy intensity of the Desalination sector and in turn Scenario 3, would be significantly higher. In Scenario 4, the rigorous application of electricity demand management has contributed to a lower total weighted average intensity. Whilst electricity demand management is also pursued in Scenario 3, it appears that the reliance on petroleum refining – and in turn crude oil – by the Geothermal sector has contributed to increasing the total weighted average primary energy intensity to higher than Scenario 1. In general the CF sector contributes most to the weighted average primary energy intensity in all of the sectors (refer to Appendix 8).

Carbon emissions

The primary energy consumed by the water sectors has been converted to the equivalent amount of CO_2, using the following carbon emission factors: 89.8 Gg CO_2/PJ for Black Coal, 67.4 Gg CO_2/PJ for Petroleum and 51.7 Gg CO_2/PJ for Gas (ACIL Tasman 2007; Australian Government 2007b). Tables 7-13 and 7-14 list the estimated carbon emissions and carbon intensities for each of the water sectors. It is evident that the calculated carbon emissions do not directly reflect energy consumption in each of the scenarios, because it is assumed that a portion of the electricity demand is met by renewables, such as wind.

Table 7-13 Estimated carbon emissions (Gg CO_2)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
IDW	4.36	4.09	3.86	3.95
BRW	267.68	236.17	236.78	242.22
SEW	226.48	219.30	180.93	224.38
RECYCLE	76.80	52.81	82.42	53.36
DESAL	2.53	6.17	0.00	0.00
TOTAL	**577.85**	**518.54**	**503.98**	**523.91**
Percentage difference from lowest	**15**	**3**	**00**	**4**

Source: Derived from Leontief hybrid models for 2031

Table 7-14 Carbon intensity (kg CO_2/ML)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
IDW	8.59	8.05	7.60	7.78
BRW	471.32	441.87	416.97	426.65
SEW	343.02	322.83	304.88	309.65
RECYCLE	1,804.47	1,597.32	1,583.10	1,613.85
DESAL	46.57	43.38	-	-
Weighted Average	**565.89**	**420.55**	**586.09**	**495.94**
Percentage difference from lowest	**35**	**0**	**39**	**18**

Source: Derived from Leontief hybrid models for 2031

The Bulk & Retail Water and Sewage sectors emit the most carbon, yet the Recycle sector has the highest carbon intensity. The Desalination sector has both the lowest carbon emissions and carbon intensity, because the scenarios assume that this sector is powered by electricity generated from renewable sources, such as wind.

In terms of the different scenarios, Scenario 2 emits the second lowest amount of carbon (519 Gg CO_2) because nuclear power, which supplies approximately fourteen per cent of electricity, does not directly emit carbon. Desalination, which supplies 70 per cent of new capacity in the water industry, sources renewable energy, which reduces the reliance on fossil fuels, yet the electricity and water demand in this scenario is the highest.

Scenario 3 emits the lowest amount of carbon (504 Gg CO_2). This result is a combination of the moderate demand management strategies adopted in both the water and electricity industries, and the high reliance on gas, which has a lower carbon emission factor compared with coal and petroleum. There is approximately a fifteen per cent difference between Scenario 3 and Scenario 1, which is the highest emitter. Scenario 1 relies significantly on coal for electricity generation (in total CF and USC supply 80 per cent of electricity) and there are no significant efficiency improvements.

Scenario 4 is the second highest carbon emitter, despite having the lowest demand for water and electricity. A possible explanation is that the Recycle sector, which is energy intensive, supplies 30 per cent of new capacity in the water industry. In addition, existing CF plants comprise a significant proportion of total capacity, and therefore the carbon intensity to produce 1 PJ of electricity under this scenario is high.

Further, under the proposed Carbon Pollution Reduction Scheme (discussed in Chapter 8), businesses that emit greater than 25,000 tonnes of carbon dioxide per year - which will include larger water utilities, such as Sydney Water – will be required to purchase carbon pollution permits. In readiness, water utilities have begun to implement carbon reduction strategies, as outlined in Chapter 4.

The above results highlight, however, that the efficacy of such strategies will be dependent on the extent of implementation of water efficiency strategies, the selection of treatment technologies (which have varying degrees of energy intensity), the extent of reliance on distributed generation, and the investment decisions in the electricity industry. For example, the weighted average carbon intensity for Scenario 3 (refer to Table 7-14) is the highest across the scenarios, because of its high reliance on energy-intensive recycled water to meet additional demand. This scenario also relies significantly on electricity generated by combined cycle gas turbine plants, which while not as carbon-intensive as black coal (89.8 Gg CO_2/PJ), still has a carbon emission factor of 51.7 Gg CO_2 /per PJ. However, due to the substantial implementation of water demand management in this sector (30 per cent of additional demand is offset in this manner - refer to Table 7-2), the scenario's total carbon emissions are the lowest. From a carbon perspective, if water efficiency strategies were implemented to a lesser degree, the benefits may be offset by investment decisions in the electricity industry that continue to favour fossil fuels.

In addition, it is likely that the carbon price paid by the larger water utilities will be passed on to end users, such as households and businesses. The variation between the carbon emissions across the scenarios (see percentage difference in Table 7-13) provide an indication of how customers might be affected under each of the scenarios.

Summary

The results presented above offer a relative indication of the energy requirements of the water sectors under four different scenarios and the resulting carbon emissions. The results show the energy and carbon impact of alternative scenarios in the water industry, arising from the choice of water treatment technologies, and implementation of demand management, and the source of electricity. Scenarios that limit the overall consumption of electricity, and the electricity required to treat and transport a ML of water, using a combination of these policies and investment decisions, would assist in reducing water costs in the future (scenario 3 & 4), even without factoring in carbon price. In terms of carbon, electricity generation technologies that consume energy-intensive inputs may increase the amount of carbon emitted in the water industry, and reduce efforts within the industry to improve its energy and carbon footprint.

Where both technology and demand management strategies appear to have a similar influence, the choice of strategy would depend on other priorities, such as the availability of water, social attitudes towards resource conservation, and corporate social responsibility.

Additional points regarding the individual water sectors now follow:

- Energy consumption of the Irrigation & Drainage Water sector was marginal compared with the other sectors. It is likely that irrigation water required to produce biomass for electricity, or the competition between irrigators and generators for water resources are more significant nexus issues for this sector, compared to its electricity consumption.
- The Bulk & Retail Water sector continues to supply a large percentage of water in the economy, and therefore the energy consumption in the scenarios is largely attributed to this sector. The scenarios assume that losses account for ten per cent of water that is treated by this sector. Leak reduction programs that reduce this percentage further would reduce energy consumption. In addition, improvements to pump efficiencies would also reduce energy consumption.
- The Sewage sector refers to existing sewerage treatment plants that supply recycled water. The sector represents a combination of different technologies that treat sewage to varying levels (such as primary treatment at the ocean outfalls, secondary treatment in inland plants, to tertiary treatment for recycled water applications). Because of the sewage volume that is treated by this sector, the energy consumption is relatively high compared to the other sectors, however the energy intensity, particularly for electricity, is low.
- The Recycle sector refers to advanced wastewater treatment plants developed after 2001. This sector supplies new capacity in all scenarios, yet the percentage of total capacity is low compared to the Bulk & Retail Water sector. Therefore, whilst the energy intensities are high for this sector, the energy consumption is low. Adaptive management strategies that focus on developing non-rainfall dependent water supplies will inevitably encourage the uptake of recycled water. Sourcing electricity from renewable or clean energy sources should be encouraged in order to limit the growth of carbon emissions.
- The Desalination sector provides new capacity in Scenarios 1 and 2. The electricity intensity for this sector is substantially higher than all other sectors. In Scenario 2, the electricity consumed by this sector is over double that of the Bulk & Retail Water sector;

however, due to the policy of using renewable energy, the carbon emissions are the lowest amongst the sectors.

7.4 Summary and conclusion

The findings reinforce the notion that the water and electricity industries are inextricably linked, and that the decisions in both industries need to be considered in the context of the systems to which they belong, in this case the NSW environment and economy. The findings also highlight the ubiquity of trade-offs between water and electricity and the challenges that such trade-offs would pose for policy development. An understanding of these trade-offs is invaluable, particularly as both industries seek to meet future demand and continue to reform. A summary of the insights gained from this analysis follows:

- Electricity generation technologies that appear to offer environmental benefits in terms of reduced water or energy consumption may have the reverse effect, because of indirect use of water and electricity that arise from inter-industry transactions. This was demonstrated by the contribution of the Geothermal sector in Scenario 3 to recycled water consumption in the electricity industry overall. The SEW and RECYCLE intensities for Geothermal were 20.91 ML/PJ and 12.75 ML/PJ, whereas the equivalent weighted average intensities for Scenario 3 were 10.17 ML/PJ and 4.33 ML/PJ. Similarly, the BIGCC sector significantly increased water consumption in Scenario 4, because of its high reliance on irrigation water. The total Raw Water and Irrigation & Drainage Water intensities were 5,370 ML/PJ and 14,199 ML/PJ for the BIGCC sector, and the equivalent weighted intensities for Sector 4 were 1,821 ML/PJ and 624 ML/PJ, respectively. In comparison, the same intensities were significantly lower for the other sectors, ranging from 132 – 262 ML/PJ and 3 – 4.2 ML/P.

- The choice of generation technologies can significantly reduce carbon emissions, even in relatively high demand scenarios, such as Scenario 2. In this scenario, nuclear and desalination – technologies that are traditionally shunned by environmental groups – contribute comparatively less to carbon emissions and put less pressure on freshwater. In the case of the Desalination sector, it is assumed that electricity is supplied by renewable sources. The total carbon emissions were considerably low, measuring 43 kg CO2/ML. In comparison the carbon emissions for the Recycle sector under the same scenario measured 1,597 CO2/ML. However, if grid power were used, the electricity consumption would be considerably larger. The total Raw Water intensities for the Nuclear sector and Scenario 2 are 40.88 ML/PJ and 132 ML/PJ, respectively. In comparison, the total Raw Water intensities for the other scenarios range from 212 ML/PJ to 1,812 ML/PJ. Whilst nuclear power reportedly directly emits zero carbon emissions, it is still material intensive to develop and operate, and would reinforce society's reliance on the technological fix to continue the status quo rather than encourage resource conservation.

- Water demand management strategies have the potential to reduce electricity consumption, and conversely electricity demand management strategies have the potential to reduce water consumption. The benefits of such strategies may be reduced by technological choices that are made without due consideration of the indirect water and energy consumption of the technologies.

- Current water management policies that favour rainfall independence will inevitably increase the demand for energy in the water industry. The use of renewable energy will lower the associated carbon emissions, yet the results suggest that such policies would increase the demand for other energy sources, such as Petroleum Refining, due to inter-industry transactions. For example, the total Petroleum Refining intensities for the Recycle sector, which represents new advanced wastewater treatment plants, were the highest compared to the other water sectors under each of the scenarios, and ranged from 1,536 MJ/ML for Scenario 2 and 2,218 MJ/ML for Scenario 1. The difference in intensities between the scenarios is attributed to differences in their electricity generation mix.

- Seawater has the potential to play a larger role in enabling the water and electricity industries to meet demand, whilst reducing the pressure on freshwater sources. Of course, such use would need to be balanced with the environmental impacts to aquatic ecosystems, which is beyond the scope of this research and therefore has not been analysed. The use of seawater may have a similar impact on freshwater consumption as the implementation of demand management strategies in the water industry.

The Scenarios developed in this research represent some of the strategies that may be implemented in the water and electricity industries in 2031. An optimum outcome is likely to be a combination of these strategies, which is mindful of the potential trade-offs that might occur. There is little benefit in investing in technologies that appear to offer environmental benefits, if in fact they indirectly contribute to increased water and energy consumption, and therefore offset gains made by demand management strategies.

Chapter 8

Policy implications and recommendations

There is a sufficiency in the world for man's need but not for man's greed

Mohandas Gandhi

This chapter synthesises the salient findings from the previous chapters in order to provide recommendations for integrating water and energy policies in NSW. Policy developments at both the State and Federal level moved at a rapid pace during 2008, beause of the ongoing drought, demand growth, climate change, and efforts to reinvigorate reforms. Section 8.1 provides an overview of these developments and the current policy settings for water, energy and climate change. Section 8.2 explores the implications of the nexus on the latest developments and current policies, under key themes. Section 8.3 puts forward recommendations that would assist with integrating water and energy policies in NSW.

8.1 Overview of the current policy setting

Water and energy policies have undergone continual change during the course of this research, and the pace has accelerated in 2008. In April 2008, the Federal Government announced the Water for the Future initiative, and in July 2008, the Federal Government released its Green Paper on a Carbon Pollution Reduction Scheme for Australia. Both initiatives form part of the

Government's climate change strategy that rests upon the three pillars of reducing carbon emissions, adapting to unavoidable climate change, and helping to shape a global climate change solution (Commonwealth of Australia 2008a). Table 8-1 lists these latest initiatives and the government departments responsible for their implementation, as well as other government institutions and measures with policy relevance to the water-energy nexus. A more detailed description of the Water for the Future initiative and the Carbon Pollution Reduction Scheme Green Paper follows the table.

Table 8-1 Summary of current policy settings

Departments	Institutions/measures
Council of Australian Governments	Climate Change and Water Working Group Ministerial Council on Energy – National Framework on Energy Efficiency
Commonwealth Department of Climate Change	Carbon Pollution Reduction Scheme – Climate Action Fund
Commonwealth Department of Environment, Water, Heritage and the Arts	National Water Commission
	Water for the Future Initiative – National Water Initiative – National Rainwater and Greywater Initiative ($250 million) – National Urban Water & Desalination Plan ($1 billion) – Sustainable Rural Water Use and Infrastructure Program ($5.8 billion) – Water Efficiency Opportunities Program
Commonwealth Department of Resources, Energy and Industry	Australian Electricity Market Commission, Australian Energy Market Operator (National Transmission Planner)
	Renewable Energy Demonstration Program ($435 million) Geothermal Drilling Program ($50 million) National Energy Security Assessment Energy Efficiency Opportunities Program Clean Business Australia Initiative – Re-tooling for Climate Change Program
NSW Department of Water and Energy	State Plan (water and electricity supply) Metropolitan Water Plan Non-metropolitan Water Inquiry Implementation of water reforms and development of Water Sharing Plans under the Water Management Act 2000 NSW Energy Efficiency Action Plan
NSW Department of Environment and Climate Change	State Plan (carbon reductions) Climate Change Fund – NSW Green Business Program

Notes: The table only lists select government measures that relate to the recommendations put forward later in Section 8.3. It is therefore not a complete summary of all government measures related to climate change, water and energy. This list is also subject to change, due to the evolving nature of climate change, water and energy policies.

Water for the Future

The Water for the Future initiative aims to reinvigorate the COAG water reform agenda and to secure the long-term water supply in both rural and urban Australia in the context of climate change (Commonwealth of Australia 2008e). The Federal Government has committed $12.9 billion over 10 years to this initiative, which focuses on four main priorities. The first priority is 'Taking Action on Climate Change'. It comprises the formation of the Murray Darling Basin Authority, which will identify the risks associated with climate change in the Murray Darling Basin. The $450 million Improving Water Information Program also forms part of this activity.

The second priority focuses on 'Using Water Wisely', in order to improve water efficiencies in both rural and urban Australia, and to support the uptake of more decentralised water systems. This priority comprises the $5.8 billion Sustainable Rural Water Use and Infrastructure Program, the $250 million National Rainwater and Greywater Initiative, and the Water Efficiency Opportunities Program to assist water-intensive businesses reduce consumption.

The third priority is 'Securing Water Supplies'. It includes the $1 billion National Urban Water and Desalination Plan, which aims to reduce the reliance on rainfall by supporting the uptake of desalination, water recycling and stormwater reuse. This priority also includes the $250 million National Water Security Plan for Cities and Towns, which will fund water infrastructure projects such as the construction of pipelines and treatment plants.

The fourth priority is 'Supporting Healthy Rivers'. The aim of the priority is to improve the environmental health of the Murray Darling Basin. It includes the $3.1 billion Restoring the Balance in the Murray-Darling Basin Program, in order to buy back water entitlements for environmental flows. A cap on groundwater extractions in the Basin will also be developed under this priority.

The Water for the Future initiative recognises that climate change is one of the biggest challenges facing both urban and rural Australia, which the above programs aim to address. However, most of these programs appear to focus on adaptation, rather than assisting the water industry and large water users with mitigating their contribution to climate change.

Carbon Pollution Reduction Scheme Green Paper

The Carbon Pollution Reduction Scheme Green Paper outlines the Federal Government's current policy thinking on a national emissions trading scheme (Commonwealth of Australia 2008a). The proposed scheme was developed in consultation with the former Federal Government's Task Group on Emissions Trading (TGET), State and Territories' National Emissions Trading Taskforce (NETT), and the Garnaut Review. It is scheduled to commence in 2010, and will have a long-term carbon reduction target of 60 per cent of 2000 levels by 2050. The scheme is based on a cap and trade approach and will be applicable to businesses that emit greater than 25,000 tonnes of carbon per year. These businesses will be required to report their emissions and purchase carbon pollution permits for each tonne that is emitted. It is envisaged that creating a price for carbon will provide the necessary incentives for businesses to invest in energy efficiency, if it is more cost effective than purchasing permits. The Federal Government reasons that its market-based approach is superior to purely regulatory approaches, because

> relying on regulation alone would require the Government to know exactly which emissions in which individual firms should be reduced and to implement specific targeted restrictions in specific sectors and sub-sectors of the economy…no government has sufficient information to implement this comprehensively across the economy. (p18)

The Green Paper identifies several initiatives to assist businesses and households to transition to emissions trading. The Climate Change Action Fund, for example, aims to promote

> energy efficiency in order to curb expenditure as a result of price increases, investment in innovative new low emissions processes, industrial energy efficiency projects with long payback periods, and best and innovative practice among small to medium sized enterprises. (p26)

Coal fired generators will also receive limited assistance in the form of free permits via the Electricity Sector Adjustment Scheme. The main rationale behind this assistance is to 'ameliorate the risk of adversely affecting the investment environment' (p30) in the industry.

The Federal Government has also pledged $500 million towards the Clean Coal Fund, in order to support research and development into clean coal technology, with a wider view to export this innovation to other countries that are similarly reliant on coal fired generation. The potential impact of the Scheme on the retail price regulation for electricity and gas consumers is currently under investigation by the Ministerial Council on Energy.

These major policy developments are a response to the growing sense of urgency in adapting to and mitigating the impacts of climate change. However, the documents reviewed in this section largely fail to connect energy use, climate change and water resources in a coherent and in-depth manner. The multidimensional and multiple feedback loops between water and energy (refer to Chapter 2) do not appear to be discussed in any great depth. This is clearly unhelpful, given the substantial links between water, energy and climate change.

8.2 Implications of the water-energy nexus

This section discusses the implications of the nexus on existing water and energy policies in NSW. The analysis in Chapters 4 to 7 form the basis of the discussion, which is structured according to key themes that have emerged from the analyses: 'The market mechanism and price regulation'; 'Decoupling water, energy and the economy'; 'Technological reinforcement'; 'Social change – an alternative to the technological fix?'; and 'Increasing social participation'.

The market mechanism and price regulation

The early phases of reform focused on improving the economic performance of both industries. This focus was underpinned by the belief that markets are the most efficient allocator of resources, which led to the formation of the National Electricity Market (NEM) and the pilot rural water market in the 1990s (refer to Sections 4.4.2 and 4.4.3). As the discussion in Chapter 4 highlights the impact of water shortages on the NEM, and the resulting consequences for the Environment and other water users was immense, particularly during 2007. While some commentators argue that the events of 2007 will prompt corrections in the market, as generators secure their water supplies and pass on the cost in the wholesale market, it is likely that the opportunity cost of securing the water – such as water forgone from potable supply or from protecting overstresses rivers – may not be completely internalised in the price of electricity (refer to Section 4.4.3). This suggests that other complementary policy instruments, such as regulation, would ensure that fragmented decisions do not occur to the detriment of water resources and other water users. The proposed Carbon Pollution Reduction Scheme continues the affinity with the market mechanism. The Green Paper reports that the market-based cap and trade approach is the most cost-effective way to deliver carbon reductions.

In contrast, the Water for the Future initiative appears to offer direct financial assistance to promote water treatment technologies and voluntary reduction programs, in order to improve the security of long-term supplies. It is likely that emissions trading will increase the cost of electricity (Commonwealth of Australia 2008a), therefore, whilst the voluntary programs will offset some of the cost increases incurred by end users of water, it is likely that energy-intensive technologies supported by the Water for the Future initiative will impose additional financial costs on water utilities. For example, the electricity intensities calculated for the four scenarios in Section 7.3.2 range from 13,604 to 14,391 MJ/ML for desalination, 8,061 - 8,664 MJ/ML for advanced wastewater treatment, and 1,685 to 1,747 MJ/ML for conventional water treatment (refer toTable A- 19 in Appendix 8 for further details). At least one water utility in NSW has reported that the electricity price increases – due to the drought – represented the biggest cost increase in the industry in 2007. Inevitably, the increases in costs will be passed on to end users.

In addition to direct initiatives, studies abroad report that price signals are a useful policy instrument to reduce the demand for water or energy (Kumar 2003; Schuck & Green 2002). The findings in this research also support this claim, particularly that water demand appears to be more responsive to changes in water and electricity prices (refer to Section 6.3). In addition to the price of water, policy makers could also consider the role of electricity prices when formulating policies to limit the growth in water demand.

Decoupling water, energy and economy

Decoupling water, energy and economic growth may be an important long-term strategy to reduce the trade-offs inherent in the links between water and energy; however, this may not be an easy task, particularly in the case of energy. The Primary Energy intensities and Output multipliers presented in Chapter 6 appear to be strongly correlated, indicating well-entrenched links between the two indicators. This relationship appears to be less evident for Raw Water intensities and the Output multipliers. In addition, as Primary Energy intensities increase, income generation and employment growth tend to decrease, which suggests that there are substitution possibilities between energy and labour (refer to Section 6.2.1). Australia has a highly developed capital economy and it is unlikely to retreat away from this general pattern to one that is more labour-intensive. Further, as discussed in Chapter 4, the water and electricity industry reforms are part of a wider program of reforms to improve the competitiveness of the Australian economy. Labour productivity improvements – which reflect a decrease in labour per unit of output – have been an important element of this wider program (refer to Section 5.1.1 for further details).

As the findings in Chapter 6 highlight, there are specific sectors that are both water- and energy-intensive, largely from the Manufacturing group. The roles of these sectors in the economy differ and therefore the impact of their water and energy use on other sectors will also differ. Those sectors with strong forward linkages would contribute substantially to the indirect consumption of water and energy in other sectors that further transform its outputs. A possibility therefore is to target those industries that are highly connected to others in the economy, and are also experiencing increasing growth rates.

There is little benefit in favouring the development of sectors with the lowest water and energy intensities as a means to decouple water and energy from economic growth. Many such sectors are from the Services group, and this approach would result in a distortion in the structure of the economy. Manufacturing sectors – particularly involving highly skilled processes or high use of the natural endowments of the state – is likely to continue to fulfil significant role in NSW (refer to Section 5.1.3). Many of these sectors also contribute the most to economic output – an increase in final demand for their products would stimulate increases in total economic output.

Based on the findings in Chapters 5 and 6, this research suggests that 'efficiency' is the most effective strategy to decouple water and energy from economic growth. Federal and State governments have implemented demand management programs in both industries, particularly within the last five years (refer to Chapter 4), however, there are still opportunities for further efficiency gains. The National Framework for Energy Efficiency reports potential reductions of 20 - 34 per cent to 40 - 74 per cent. The Climate Action Fund of the Carbon Pollution Reduction Scheme also aims to promote energy efficiency, yet it appears to be driven by economic considerations of reducing the impact of electricity price increases as a result of carbon trading, rather than a moral obligation to use resources wisely (refer to excerpt in Section 8.1).

The scenario models in Chapter 7 clearly demonstrate the impact of such policies on water and energy demand. For example, efficiency strategies can offset investment into new water and energy infrastructure. This is evident in the lower investment requirements of scenarios that implemented higher levels of demand management (refer to Tables 7-2 and 7-6). Such strategies are critically important for reducing the water and energy intensities of existing electricity and water infrastructure, considering that a significant proportion of existing infrastructure is likely to continue to be operational in the next decade and beyond. The scatter plots and indirect consumption findings in Chapters 5 and 6 reinforce the importance of energy efficiency, as the water required to generate electricity represents a substantial component of the indirect water use in the economy. In addition, water efficiency programs would offset the increases in energy consumption in the water industry. This is particularly important, given the substantial support assigned to energy-intensive technologies by the Water for the Future Initiative (refer to Section 8.1).

Technological reinforcement

Existing infrastructure is a legacy of the past. In the same way, our technological choices today will be legacies in the future, where climate change events are likely to increase in their severity and frequency. This further strengthens the importance of considering the wider implications of technologies, particularly as the operational life of these technologies spans a few decades.

In the electricity industry, Integrated Gasification Combined Cycle (IGCC), Ultrasupercritical Coal (USC) and Post Carbon Capture (PCC) technologies are under development because of the advantages of facilitating the capture and storage of carbon. These technologies would increase the auxiliary power requirement of the power stations and therefore present an energy trade-off (refer to Section 7.1.2). In addition, technologies, such as geothermal and biomass, that are considered to be more environmentally benign, may increase the water demand in the economy, because of the water embedded in the inputs required to operate and maintain such power stations (refer to Table A- 1). It is therefore important to consider the total water requirements of generation technologies in investment decisions. This information would also assist the National Transmission Planner with assessing scenarios for the long-term development of the national transmission network.

For the water industry, adapting to climate change is a necessity, yet this process is itself energy-intensive. As previously discussed in Chapter 4, the water industry has shifted its focus towards adaptive management, which includes non-rainfall dependent supplies, such as desalination and advanced wastewater treatment processes. Both technologies are extremely energy-intensive, and the energy source would influence the carbon emissions from these technologies (refer to Tables A–18 to A–21). As the scenarios in Chapter 7 suggest, desalination powered by renewable energy directly emits zero greenhouse gases compared with conventional water treatment processes that are powered by electricity generated from coal. The Water for the Future initiative and State governments are also providing incentives for end users to install rainwater tanks, despite the lower pump efficiencies attainable compared with commercial pumps (refer to Table 2-3).

Existing water sectors vary substantially in terms of their energy demands; the Bulk & Retail Water sector in general exhibited the highest intensities, followed by the Sewage sector. The intensities for the Irrigation & Drainage Water sector were minimal. Further, direct consumption of electricity accounts for a large proportion of energy use, whereas petroleum consumption is largely indirect, that is, embedded in the materials and services from other sectors. Given that both direct and indirect demand are significant, energy efficiency strategies could be complemented with strategies to examine the supply chains in the water sectors, in order to determine where substitution possibilities with less energy-intensive materials may exist. This would also reduce costs, if energy prices increase in the future, due to water shortages and the implementation of an emissions trading scheme. An alternative approach would be to determine the level of decentralisation that is most appropriate for a precinct. It may be more energy efficient to install a stormwater harvesting system for an entire precinct, for example, compared with installing rainwater tanks for individual dwellings (refer to Table 2-3). Post-occupant monitoring of a sustainable housing development in South East Queensland provides further corroboration for this observation (Beal et al. 2008). The rainwater tanks in the development consumed almost ten times more electricity per kL, compared to one kL of water from the town water supply, because of the high pumping heads, and the sensitivity of the pumps to pressure drops, which resulted in multiple pump start ups per day.

The water industry would also benefit from a greater understanding of the impact of decentralised systems on existing centralised infrastructure. For example, the capture and reuse of greywater on site would increase the concentration of sewage that is transported to the sewerage treatment plant. This may have implications for the plant infrastructure, in terms of overloading the treatment processes. Separation toilets that harvest the nutrients in the black water for reuse would reduce the load on sewerage treatment plants, and recent research suggests that this technology is beneficial from an energy perspective, as it offsets the energy required to produce fertilisers (Kenway 2008).

Social change – alternative to the technological fix?

Society's reliance on the 'technological fix' has endured since the Industrial Revolution. This 'fix' has become central to the western worldview that began at the time of Ancient Greece and evolved rapidly during the Age of Enlightenment (refer to Appendix 2). This western worldview placed 'man' (to the exclusion of women) on top of the hierarchy on Earth, and argued that nature had little intrinsic value until mixed with man's labour. Technology has no doubt advanced modern society in fundamental and important ways. Nevertheless, as we look towards the future, how we use and value natural resources needs to change to ensure the long-term 'sustainability' of our societies. More broadly, one could question the imperative of governments around the globe to achieve economic growth and prosperity in terms of the impacts on the Environment and society's wellbeing, when 'downsizing' material consumption could have fewer impacts on the Environment without compromising society's quality of life.

In the context of this research, strategies that improve how society values and uses its water and energy sources may have a similar impact to technologies that focus on reducing water demand and carbon emissions. For example, the scenario findings in Chapter 7 suggest that nuclear power using seawater and desalination powered by renewable energy has a similar impact compared to other strategies to reduce the demand for water and energy (in the case of the scenarios, efficiency improvements). Aside from similar water and energy impacts, however, the technological solutions would entail more materials consumption and therefore a higher reliance on natural resources. This research therefore argues that behaviour changing strategies – some of which would contest the traditional western worldview – such as voluntary reduction programs, efficiency strategies, and educational awareness programs, have a significant role in the future of both industries and should continue to receive government support. However, the findings in Chapter 7 also suggest that demand reductions in one industry may be easily be overridden by investment into resource-intensive technologies in the other. This further substantiates the importance of an integrated approach to policy development.

Increasing social participation

Chapter 4 details the historical trends in both industries, and highlights some of the similarities. For example, the involvement of early private operators (during the late 1700s in the water industry and late 1800s to early 1900s in the electricity industry) gave way to increasing local and state government involvement. This involvement paralleled technological advancements that enabled the development of more centralised control, such as steam power in the water industry that facilitated water pumping over longer distances from the mid 1800s, and long distance transmission networks in the electricity industry from the mid 1900s that enabled power stations to be located closer to primary energy sources. Today, Federal government involvement is well entrenched in both industries, to the extent that Australia has a national electricity market, a rural water market, and agreements to manage shared water resources, such as the Murray Darling Basin.

Concomitant with the evolution of these national frameworks in recent years has been a trend towards the decentralised supply of water and energy, such as by the use of energy-intensive rainwater tanks and embedded generation. End users now have greater influence over the selection of infrastructure to deliver their water and energy services. It is therefore important that appropriate regulation support the trend towards decentralisation, so that trade-offs do not ensue. An example already discussed above is the widespread installation of rainwater tanks.

The Water Sharing Plans developed under the *Water Management Act, 2000* is yet another example of increasing social participation. This appears to reinforce the 'think globally act locally'[20] mantra that accompanies the sustainable development paradigm. The increasing involvement of the end users within the water and electricity industries may reflect the characteristics of a maturing society. Whereas for most of the 20th century society left the delivery of water and energy to technically-staffed public utilities, it appears that the industries are more responsive to the input of society than ever before. As dicussed in Chapter 4, this has coincided with the increase in awareness of local and regional environmental issues, such as pollution, salinity, the hole in the ozone layer, to the ascent of sustainable development, implications of drought, and now climate change. The benefits that accompany such public scrutiny may also create barriers for the implementation of policies. An example is the recent

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[20] The origin of this phrase is contested; it has been attributed to, among other, David Bower who founded Friends of the Earth in 1969, and Rene Dubos, who was an advisor to the United Nations Conference on the Human Environment in 1972.

controversy in Queensland regarding the opposition by the end users to a recycled water scheme that proposed to introduce treated effluent to drinking water supplies (Burley 2008).

8.3 Policy recommendations

As with the earlier water and energy policies, the major policy developments of 2008 outlined in Section 8.1 fail to articulate to any depth the significance of the links between water and electricity, despite the fact that climate change – which has driven many of the recent policy developments – will in the future further reinforce the importance of the links between the two. Erratic rainfall, extended dry periods and drought, which already form part of Australia's climate, are likely to increase in severity in future years under the impact of climate change. It is therefore imperative that policy makers take considered action, in order to resolve the current practice that fails to integrate water and energy policies, before it becomes a matter of urgency with far greater ramifications at far greater costs.

This section provides some recommendations for consideration that would assist in improving the coordination and integration of water and energy policies in NSW. Chapters 4 to 7, the earlier sections of this chapter, and the researcher's philosophical tenets (refer to Section A 2.6 in Appendix 2) form the basis of the recommendations. In order to provide focussed policy inputs for decisionmakers in both industries, the recommendations refer to the government measures listed in Table 8-1. The following sections also identify which quadrant of Integral Theory's AQAL framework – psychological, cultural, behavioural and social – the recommendations belong (refer to Section 3.1.1 for a decription of the AQAL framework).

Institutional arrangements

As desribed in Chapter 4, water and energy policy reforms are currently driven by national reform agendas and implemented by State governments. This research therefore suggests that policy integration be considered at both the Federal and State government levels. Some recommendations to assist with policy integration now follows:

- The climate change, water and energy portfolios are managed by separate Federal Government departments, namely the Department of Climate Change, the Department of Environment, Water, Heritage and the Arts, and the Department of Resources, Energy and Tourism. Whilst one Federal Minister is responsible for both the climate change and water portfolios, the existing institutional arrangement do not readily support integration efforts between all three portfolios. A recommendation, therefore, is to establish a climate-water-energy dialogue under the auspices of the Council of Australian Government (COAG), potentially as part of the Climate Change and Water Working Group, to assist with the coordination of water and energy policies. A possible activity under this dialogue would be to ensure that the Australian Electricity Market Commission – which is responsible for the rule making and development of the NEM – co-ordinates with the National Water Commission, to develop regulatory arrangements that ensure electricity market trading does not compromise the short- and long-term health of water resources, particularly those under stress.

- Similar co-ordination is also recommended at the state level. As the name suggests, the NSW Department of Water and Energy (DWE) is responsible for implementing the water and energy reform agenda in the state. In the case of water, DWE grants water access licenses and, via the Water Sharing Plans, coordinates the water extractions from the Environment under the *Water Management Act, 2000*. In the case of electricity, DWE supports national energy market reforms through involvement with the Ministerial Council on Energy. This research recommends that the Water Sharing Plans consider the water used by electricity generators, so that scarce water is distributed between all water users and the Environment in a manner that accords priority to the Environment and citizens' rights. The motivation for this recommendation is to avoid water being traded through through the NEM – via water embedded in electricity generation – from regions experiencing water shortages and restrictions on potable water supply (refer to Sections 2.1.1 and 4.4.4).

- This researcher contends that the unintended consequences of the electricity market on water allocation may expose some of the limitations of markets in general, in 'efficiently' allocating scarce resources. Alternative, concurrent approaches, such as regulation may be requird to ensure that wider Environmental values are protected. This re-orientation in beliefs relates to the cultural quadrant of the AQAL framework. It would also require a deeper, personal shift in our individual beliefs, so that we make decisions beyond our individual interests (psychological quadrant), in order to realise a more sustainable path to the future.

Government measures

Table 8-1 summarises key water and energy policies that are relevant to the water-energy nexus. This section puts forward recommendations that would increase the consideration of the water-energy nexus in existing measures, and suggests additional measures.

- As part of the climate-water-energy dialogue recommended under "Institutional Arrangements", the Federal and State governments could consider developing a national 'Water for Power Reduction Scheme' that benchmarks power stations and sets water reduction targets within the NEM. Water efficiency grants could target projects in existing power stations that source water from over-allocated and stressed river systems. Such action would improve the stability of the electricity grid, by potentially reducing the number of plant shutdowns due to a lack of water, and large fluctuations in the spot price of electricity in the NEM, which experienced a 270 per cent increase in May 2007 due to drought. This action may also assist in reducing conflicts between power generators and other water users, such as irrigators and the Environment (refer to Sections 2.1.1and 4.4.4). This measure relates to the social (benchmarking and grants) and behavioural (action by individual plants) quadrants of the AQAL framework.

- The Federal Government has allocated significant support for the development of alternative energy technologies. As outlined in Table 8-1, the Department of Resources, Energy and Tourism administers the Renewable Energy Demonstration Program ($435 million) and the Geothermal Drilling Program ($50 million). The Department could consider introducing water eligibility criteria, to ensure that only technologies that have a neutral or net beneficial impact on water resources be supported. This could be determined by analysing the total water intensities for the various generation technologies, such as those quantified by this research. Based on the results in Chapter 7 and Appendix 8, there is a strong case for encouraging investment into wind power projects, because of its relatively low water intensity.

- In the case of the Geothermal Drilling Program, grant proposals could be submitted with a 'Water Impact Statement' to ensure that grants are not awarded to drilling projects in areas experiencing water shortages, or in such cases, that there are sufficient groundwater reserves to support the development of geothermal plants in the region without unduly compromising the health of the local ecosystem. The basis for the recommendation is the high water intensities calculated by this research for geothermal, which is being promoted as a future baseload technology because of its low carbon emissions. The results demonstrate that there are trade-offs between reducing carbon emissions and water consumption. This measure relates to individual plants and wold therefore be part of the behavioural quadrant of the AQAL framework.

- In July 2009, the Australian Energy Market Operator (AEMO) will replace the current National Electricity Market Management Company (NEMMCO) and take on the role as the National Transmission Planner. The National Transmission Planner will explore

  > the most efficient combination of transmission, generation, distribution and non-network options that will deliver reliable energy supply and minimum efficient cost to consumers under a range of credible future scenarios (Commonwealth of Australia 2008c p428).

  This research recommends that water use efficiency of technological options forms part of the assessment criteria for the scenarios, based on recent security concerns in the NEM that shut down several generation plants due to a lack of water. Climate change is likely to reduce the availability of water in many parts of the NEM; as discussed in Chapter 1, the IPCC (2001) predicts 20 per cent more drought months over most of the continent by 2030. This measure relates to the electricity industry as a whole and would therefore be part of the social quadrant of the AQAL framework.

- Similarly, the Department of Resources, Energy and Tourism is currently preparing the National Energy Security Assessment. The purpose of this assessement is to

  > identify key strategic energy security issues, including the electricity sectors and those likely to those likely to influence the level of security in 5 years (2013), 10 years (2018), and 15 years (2023). (Australian Government 2007b).

  Whilst the details of the assessment do not appear to be publicly available, this research strongly recommends that it considers the impact of extreme events under climate change – such as drought and floods – on the maintenance of infrastructure, as well as the impact of water shortages on generation capacity. In other words, energy security will be more dependent on water security in the future and should therefore be considered in any strategic assessments. This measure would also form part of the social quadrant of the AQAL framework, because it relates to the electricity industry as a whole.

- State government policies could encourage generators located within metropolitan areas to use recycled water, in order to reduce the reliance on mains supply. This is particularly important if additional combined cycle gas turbines in the future are embedded in the electricity distribution networks. Whilst recycled water is still energy-intensive compared to water that is treated by conventional methods, the intensity is subtantially lower than desalination (refer to Table 2-2). A possible avenue for support would be the Climate Change Fund administered by the NSW Department of Environment and Climate Change (DECC), and in particular the NSW Green Business Program that focuses on water recycling and stormwater harvesting. The basis for this recommendation is that citizens in Sydney, as in other parts of Australia, are experiencing water restrictions, which are triggered by the water levels in the city's main catchment dam. Restrictions improve the perceived value of water (social and psychological quadrants). Due to the long-term impact of investment decisions, electricity generators could also be encourage to conserve potable water supplies in metropolitan areas.

- It is recommended that new thermal power stations be located along coastal regions, in order to minimise future pressure on inland water resources, unless new thermal power plant proposals demonstrate zero net impact on regional water resources. Technological that would assist with this target include the use of recycled water, and hybrid and dry cooling technologies. This recommendation could be implemented via planning controls in the state, and forms part of the behavioural quadrant of the AQAL framework.

- This research strongly suggests that measures to support rainwater tanks as a means to reduce the reliance on mains supply should be reviewed. Support for such measures is prevalent at the Federal and State government levels. The National Rainwater and Greywater Initiative under the Water for the Future Initiative has been allocated $250 million to assist water-intensive businesses to reduce their water consumption. Similarly, the NSW Government's Climate Change Fund provides support for households and schools to install rainwater tanks. Rainwater tanks are highly decentralised and would reduce the reliance on centralised systems. Rainwater tanks, however, are also highly energy-intensive (refer to Table 2-3 and (Beal et al. 2008)). Given their political appeal, it is unlikely that current measures will cease in the near future. Governments could therefore set stringent criteria that ensures the most efficient pump that is suitable for the application is installed. Another solution is to provide additional funds for installations that use gravity to transport the collected water from a high level tank. The widespread installation of rainwater tanks in recent years reflects a shift in perception that water is a scarce resource that can be harvested at a local level (cultural quadrant), which has brought about a range of regulation requiring their installation for new housing developments (social quadrant). Some citizens may also be motivated by wanting to limit the environmental impact of their households (psychological quadrant). It is clear, however, that existing regulations need reconsideration or refinement, to limit the energy trade-offs that have arisen.

- This research suggests that precinct-level water systems may offer a better solution to supplying water in an energy-efficient manner, compared to energy-intensive large-scale centralised or highly dense energy-intensive decentralised systems. The NSW State Plan (NSW Government 2008d) identifies new growth centres in the north west and south west of Sydney that would suit such an approach. Furthermore, the current Inquiry into Secure and Sustainable Water Supply and Sewerage Services for Non-Metropolitan New South Wales being undertaken by DWE could consider this precinct level approach for greenfield sites in regional local government areas experiencing water shortages. This recommendation forms part of the social quadrant of the AQAL framework.

- There are numerous government measures to promote water and energy efficiency. At the Federal level, these measures include: the Water Efficiency Opportunities Program under the Water for the Future Initiative, the National Framework for Energy Efficiency under the Ministerial Council on Energy, the Energy Efficiency Opportunities Program under the Department for Resources, Energy and Tourism, and the Re-tooling for Climate Change Program under the Clean Business Australia Initiative. In NSW, similar programs include the NSW Green Business Program under the Climate Change Fund administered by DECC, and the NSW Energy Efficiency Action Plan under DWE. As identified in this research, water and energy efficiency offer significant advantages and can readily offset the requirement for new generation or water supply capacity in the future. It is important, however, that the measures target those sectors that exhibit the highest water and energy intensities, and are strongly linked with other sectors in the economy. Based on the findings of this research, sectors that would benefit most from direct water efficiency measures include: Agriculture, Other Mining & Services to Mining, Textile, Clothing, Leather & Footwear, and Other Commercial Services. Sectors that would benefit most from direct energy efficiency strategies include: Other Mining & Service to Mining, Chemicals, Non Metallic Mineral Products, Basic Metals & Products, and Fabricated Metal Products. The measures would also assist in reducing the embedded water and energy content of other sectors that rely heavily on outputs from these water and energy-intensive sectors.

- In addition to efficiency measures, DECC and DWE might consider educational awareness programs for school children that focus on the importance of using water and energy wisely, and in general on the importance of resource conservation as a means to care for the Environment. Such programs could also be integrated into school curricula, in order to mainstream the issues. This would greatly assist in changing behaviour towards water and energy consumption in the longer term. The basis for this recommendation is that Australia has historically low water and energy costs, compared to other parts of the world. Restrictions and demand management programs in both industries have improved the perceived value of both resources, but there are longer-term benefits for instilling this further in young children, who are society's future decisionmakers. This activity would form part of the pychological (values and beliefs) and behavioural (impact of individual actions) quadrants of the AQAL framework.
- Fuel switching has been identified as an important strategy to reduce demand on electricity supplies and therefore reduce carbon emissions under demand management initiatives of the Federal Department of Resources, Energy and Tourism, and under the NSW Green Business Program. Based on the results presented in Chapter 5, this research recommends that priority be accorded to projects that involve switching from electricity to gas, or from refined petroleum to gas, due to the lower water intensities exhibited by the GAS sector. Fuel switching is already taking place in Australia, due to the recent drought and the proposed emissions trading scheme (refer to Section 2.1.1).

Industry activities

- Water and electricity utilities have a significant role to play in reducing their energy and water consumption, respectively. In the water industry, strategies to reduce energy consumption could be tailored to the energy fuel type and pattern of consumption, as identified in Chapter 5. Sydney Water has already adopted a carbon neutral by 2010 policy (refer to Chapter 4), but there is scope for non-metropolitan water utilities to adopt similar carbon reduction policies, with funding support from the DWE, or with technical support from the Department of Commerce which provides consulting services to local water utilities. The basis for this recommendation is that energy reduction strategies could reduce the cost of water in the future, as energy prices increase due to the emissions trading scheme. It would also improve the corporate social responsibility of the utilities (linked to the cultural quadrant of the AQAL framework).

- Another significant realisation arising from the research is the importance of accurate and sufficiently disagreggated data. Historical energy supply and use data has been readily available from both the Energy Supply Association of Australia and the Australian Bureau of Agricultural and Resource Economics for the past several decades. The availability of data to the general public, however, has considerably reduced in recent years, due to commercial in confidence reasons arising from increased private sector involvement in the electricity industry. In the case of water, the Australian Bureau of Statistics has only published water supply and use data for six years in its Water Accounts, and only four of these years are consecutive. The latest Water Account is more aggregated than previous editions, and it appears that future Water Accounts will follow a 5-year publishing cycle (ABS 2006d). It is strongly recommended that future Water Accounts provide more disaggregated information, in line with the earlier publications. Along with a regular collection cycle, this would assist with time series comparisons useful for policy modelling.

The development of water and energy policies will no doubt take into consideration a range of factors and inputs. The recommendations outlined in this chapter represent one such set of inputs. Based on a comprehensive review of the water-energy nexus in the context of NSW, the recommendations identify several opportunities at both federal and state level to improve the integration of water and energy policies.

Chapter 9

Conclusions and further research

The outcome of any serious research can only be to make two questions grow where only one grew before

Thorstein Veblen

Water is critical for electricity generation, as electricity is critical for water provision. Each industry has influenced the historical development of the other. Drought – a natural part of Australia's climate – has been a constant reminder of the criticality of the links between water and electricity. In the past, electrification facilitated the construction of water storage dams that improved water security by providing a means to transport water to population centres. Improvements to water supplies enabled steam generators to continue to supply industries with power during times of drought. The most recent drought from 2002 to 2007 reinforced the importance of these links; the water industry is developing non-rainfall dependent supplies, which are also more energy-intensive, and electricity generators are taking measures to secure their water supplies, such as recycling water on-site and shifting to less water-intensive generation technologies.

Both industries have also undergone extensive reforms, commencing with internal reforms in the 1980s, to market reforms in the 1990s that aimed to improve the efficiency of the industries. These reforms have largely been carried out in isolation, with little regard to the links between water and electricity at the technology and policy levels. This is evident in some of the trade-offs that have occurred as a result of the establishment of markets in both industries (see below for further discussion).

The ascent of the climate change debate in the past few years has brought into sharper focus the links between water and electricity, and has lent a more environmental focus to the debate. It has also provided the stimulus for the latest water and energy policy developments and reviews by the Federal Government, such as the Water for the Future Initiative, and the proposed Carbon Pollution Reduction Scheme.

Despite the strong interdependencies between water and electricity that history and recent events highlight, current debate does not appear to be well informed by a deep understanding of the nature of the nexus. This research contends that this nature is multidimensional, comprising technological, environmental, economic, social and political dimensions that interact with each other. This research therefore argues that a deeper understanding of the nexus is fundamentally important for the future of the water and electricity industries.

Against this backdrop, this research has developed a methodological framework for developing a comprehensive understanding of the nature of the water-energy nexus. This framework, in recognition of its multidimensional nature, draws upon various academic disciplines. Integral Theory, and in particular Integral Methodological Pluralism (IMP), broadly guided the development of this framework. Integral Theory contends that different perspectives and worldviews are equally valid and offer alternative insights into an issue. IMP guides the integration of methodologies from the four quadrants of Integral Theory's AQAL framework.

An additional, deeper, reason for adopting Integral Theory is the researcher's own questioning of the adequacy of the western worldview. This worldview has developed a high reliance on the technological fix and has traditionally encouraged resource exploitation for the purpose of economic development. Modern society, under this worldview, has placed great emphasis on attaining economic development without questioning the wider ramifications on resource consumption, and more fundamentally, whether such goals actually enrich the human experience.

These philosophical arguments provided some of the motivation for this research, yet the terrain this research covers is more tangible. The objectives and methods have attempted to capture the 'breadth' of the links between water and electricity and the multidimensional nature of the nexus, whilst analysing specific links in sufficient 'depth' in order to provide useful inputs for policy development. Naturally, the objectives closely align with the research methods. This research employed: historical analysis to gain a deeper understanding of the evolution of the nexus and current nexus issues; input-output analysis and the analysis of substitution possibilities to empirically investigate the nature of the nexus for NSW; and scenario analysis to identify potential trade-offs arising from the nature of the nexus for the water and electricity industries in the longer term future. Section 9.1 summarises the main conclusions from this research and Section 9.2 provides recommendations for future research.

9.1 Conclusions

The conclusions presented below form the basis of the policy recommendations put forward in Chapter 8, which provided inputs for improving the integration of water and energy policies in NSW. These inputs comprise strategies to improve the current institutional arrangements, suggestions to strengthen existing government measures, proposals for additional measures, and suggestions for industry activities.

The conclusions are grouped according to the following headings, which broadly align with the specific objectives: 'Historical evolution of the water-energy nexus', 'Water in the electricity industry', 'Energy in the water industry', 'Water and energy in the wider economy'; and 'Future implications for the water and electricity industries'.

Historical evolution of the water-energy nexus

- The water and electricity industries have undergone similar institutional changes. In their formative years, the water and electricity industries comprised small private operators and municipal councils. During the mid to late 1800s, the Victorian aversion to public spending hampered investment, except in times of crisis such as drought. By the mid 20th century, both industries were under the control of local and State governments. It was deemed that governments were better positioned to develop infrastructure projects, as the private sector had neither the experience nor financial resources. Keynesianism underpinned government involvement, particularly during the mid 20th century. Water and electricity subsidies were socially and politically acceptable and considered critical to national development.

- Federal government involvement in the water and electricity industries' governance has increased since the end of the 20th century and has accompanied a shift of policy focus to economic rationalism. In contrast with Keynesianism, economic rationalism contends that the private sector is better positioned than governments to make cost-effective decisions over infrastructure investment, through the market mechanism.

- Technological advancements and institutional arrangements have progressed symbiotically and have been critical for the development of the other industry. The early water and electricity industries largely comprised decentralised or small-scale centralised systems: individual power stations would supply a local area or service, private water wells supplemented early centralised systems, and cesspits preceded sewerage systems.

- Over time, technological advancements gave rise to more centralised systems. Steam and later electricity enabled water and sewage networks to expand in urban areas and groundwater use to expand in rural areas. High voltage transmission networks using three-phase alternating current (AC) and larger scale generation units enabled coal fired power stations to be built adjacent to coal fields, away from the demand centres in the cities. Centralised technologies continue to form an integral part of the industries.

- Decentralised technologies, such as rainwater tanks and embedded generation, have become more commonplace in recent years. The increase in the uptake of these technologies parallels changes to the structure of the industries, which comprised a separation of the bulk, retail and network functions for the purpose of introducing competition. The uptake of decentralised technologies has also coincided with an increased involvement of end users as decision makers in both industries.

- The decision-making boundaries of both industries have expanded in recent decades, to include active participation of end users. There is greater public scrutiny of and involvement in the development of water and energy policies, which has coincided with an increase in awareness of local, regional and global environmental issues. The benefits that accompany such public scrutiny will also created some barriers for the implementation of policies and projects, such as the use of recycled water for potable consumption and the construction of energy-intensive desalination plants.

Water in the electricity industry

- The Coal Fired sector is the most water-intensive in the electricity industry in NSW, in terms of consumptive use. The total Raw Water intensities were approaching 161 ML/PJ in 1996 and 352 ML/PJ in 2001 (some of this difference may be attributed to improvements in data collection between the two Water Accounts). Drought therefore has significant implications for inland coal-fired power plants.
- The Combined Cycle Gas Turbine sector is highly reliant on mains water supply: for example, the total Bulk & Retail Water intensity for the Combined Cycle Gas Turbine sector in 2001 was nearly 303 ML/PJ. In order to reduce the pressure on drinking water supplies, this sector could consider using recycled water. Although the Recycled Water sector is more energy-intensive than the existing Bulk & Retail Water sector that supplies mains water, it is significantly less intensive than the Desalination sector that may have to supplement mains supply in the event of water shortages.
- The Gas Turbine, Cogeneration and Other Renewables sectors were the least water-intensive. In 2001 their total Raw Water intensities were in the order of 67 ML/PJ, 5 ML/PJ and 98 ML/PJ, respectively. These sectors also have fewer carbon emissions compared to the Coal Fired sector. Policies to encourage investment in the Gas Turbine, Cogeneration and Other Renewables sectors would therefore offer the dual benefit of reducing water consumption as well as carbon emissions. Further, if these technologies are ‘embedded’ in the distribution networks, they will offset the demand for more expensive peak electricity from the National Electricity Market, and will have no transmission losses.
- The Hydropower sector exhibited the highest Instream Use intensities, which were 180,187. ML/PJ in 1996 and 616,803 ML/PJ in 2001 (again, some of the difference may be attributed to improvements in data collection between the two Water Accounts). Instream Use is non-consumptive and therefore the water is available for downstream users once discharged. However, temporal water needs typically differ between hydropower generators and other users, which has already brought about trade-offs in rural areas reliant on irrigation.
- The total Raw Water intensities for the Retail Gas Supply sector were 5.58 ML/PJ and 5.14 ML/PJ in 1996 and 2001, respectively. This sector had the lowest water intensities of all energy sectors. Assuming that gas supplies are sufficient to meet demand, substitution of electricity with gas would reduce carbon emissions and water consumption.

Energy in the water industry

- Direct consumption of electricity accounts for a large proportion of the total Electricity intensities for the water sectors in both years, ranging from 73 per cent for SEW to 87 per cent for the Bulk & Retail Water sector in 1996. Electricity used to pump water accounts for a significant proportion of this figure. The direct Electricity intensities for the Bulk & Retail Water sector decreased from 1,419 MJ/ML in 1996 to 1,393 MJ/ML in 2001, which reflects the importance of the implementation of leak reduction programs between the two time periods. In contrast, the direct Electricity intensities for the Sewage sector increased substantially from 629 MJ/ML in 1996 to 929 MJ/ML in 2001. The commencement of the Water Reclamation and Management Scheme in Sydney in July 2000 and the Rouse Hill Recycled Water Scheme in 2001 would have contributed to the increase.
- Refined petroleum is the second most dominant fuel source after electricity. A significant proportion of the Petroleum Refining intensities is from indirect consumption. In 2001, refined petroleum accounted for approximately 20 per cent and 25 per cent of primary energy consumed by the Bulk & Retail Water and Sewage sectors. There is scope to further examine the supply chains of both sectors, in order to determine the possibility of substituting existing materials and services with those that rely less on refined petroleum. The direct component of the Refined Petroleum intensities is from motor vehicle use. Procuring vehicles that use natural gas rather than petroleum would therefore further reduce the carbon emissions.
- The Retail Gas Supply intensities increased between 1996 and 2001, although the contribution of gas to the overall energy consumption was relatively minor. Whilst it is not clear in the results, this increase may have actually offset increases in the Electricity intensities. A significant proportion of this gas would have been consumed for heating in offices, where substitution possibilities with electricity exist. Substitution of electricity with gas should be encouraged, because gas consumption emits comparatively fewer greenhouse gases and the Retail Gas Supply sector consumes less water.
- The energy intensities for the Irrigation & Drainage Water sector were minimal compared to the Bulk & Retail Water and Sewage sectors, because a significant proportion of irrigation water in NSW is delivered by gravity. A water market has been established in the rural water industry, which will enable licences to be traded between users. In order to function

properly, the market will require technology that can meter the water delivered to users. Improvements to onsite irrigation practices, with a view to reduce water consumption, may require more sophisticated technology. Both activities will increase electricity consumption. A proportion of this electricity demand could be offset by installing additional micro and mini hydro turbines in weirs along irrigation channels.

Water and energy in the wider economy

- Interindustry linkages influence the effectiveness of policy instruments. The indirect components of the water and energy intensities for some sectors, such as services, are most significant and therefore these sectors would benefit from efficiency improvements in water- and energy-intensive sectors with which they have strong backward linkages. In other sectors, particularly the manufacturing sectors, more direct instruments such as regulation or voluntary demand management strategies should be encouraged in order to decouple energy, and to a lesser extent, water intensities from economic output. This is of particular importance to energy-intensive sectors, given the current debate over climate change and emphasis on reducing carbon emissions.
- Where energy-intensive sectors depend predominantly on electricity, reductions in energy consumption would also lower the indirect water intensities for these sectors. This physical correlation is evident in the scatter plots for Raw Water and Primary Energy (page 208), when water-intensive sectors such as Agriculture are excluded from the plots.
- There is a general trend towards an increasing role for the Services sectors in the economy, and concomitantly a decreasing role for Manufacturing sectors. This would augur well in terms of water and energy use, given the generally low water and energy intensities of the Services sectors, and their increasing contribution to income generation and employment growth. The ability to stimulate economic output is highest amongst the Manufacturing sectors; strategies to decouple energy consumption from their economic output are therefore important for economic and environmental sustainability in the longer-term.
- Water demand appears to be more responsive to water and electricity price changes, and therefore the price mechanism may be an appropriate policy instrument to reduce water demand. In contrast, electricity appears to be less responsive to the changes in the price of both water and electricity.

Future implications for the water and electricity industries

This research developed four long-term scenarios for the year 2031, in order to analyse the future implications of the water-energy nexus on the water and electricity industries. The scenarios adopt different technologies and demand management strategies, so that potential trade-offs can be explored. The main findings from the analysis are summarised below.

- Electricity generation technologies that consume energy-intensive inputs may increase the amount of greenhouse gases emitted in the water industry, and therefore limit the effectiveness of strategies within the water industry to reduce its energy consumption and carbon emissions. This is reflected in the different intensities recorded for the same water sector, under the four different scenarios. Similarly, the different water supply scenarios result in different water intensities for electricity sectors. Therefore, where both technology and efficiency strategies appear to have a similar influence, the choice of strategy would depend on other priorities, such as the availability of water or social attitudes towards resource conservation.

- Demand management strategies to reduce electricity consumption can significantly reduces water consumption. However, the benefits from such strategies may be offset by the installation of additional generation technologies that require significant material inputs from water- and energy- intensive sectors. For example, Geothermal does not directly rely on primary energy from fossil fuels to produce electricity, yet the water and electricity embedded in a geothermal power plant are quite substantial. Most of the water use is related to the electricity embedded in material inputs used to operate and maintain a geothermal power plant.

- Biomass would appear to reduce the reliance on fossil fuels and therefore reduce carbon emissions in the electricity industry, but there is a significant water trade-off, reflected in the high Irrigation & Drainage Water and Raw Water intensities for the Biomass Integrated Gasification Combined Cycle sector. For Biomass Integrated Gasification Combined Cycle sector to play a significant role in the electricity sector in the future, biomass crops with multiple uses should be selected, in order to extract additional value from the water required to grow the crops.

- The Coal Fired sector, which represents subcritical coal fired power plants that were installed prior to 2001, continues to have a significant influence on water consumption in

2031. One of the main strategies to reduce the pressure on water resources from existing electricity sectors is the implementation of rigorous demand management strategies.

- Other baseload generation sectors, such as Ultrasupercritial, Supercritical, Nuclear and baseload Combined Cycle Gas Turbine plants are not substantially more water-efficient compared to the existing Coal Fired sector. Investment in these technologies in the future will do little to reduce water consumption in the electricity industry. This strengthens the recommendation for the implementation of rigorous demand management strategies. Future baseload power stations should be constructed in coastal locations in order to reduce the pressure on freshwater sources; hybrid and dry cooling technology, as well as the use of recycled water could also be considered.

- The intensities for intermediate and peaking plants are generally lower compared to the baseload sectors. These plants include Other Renewables and Cogeneration plants that were installed prior to 2001, as well as new Open Cycle Gas Turbine plants and Wind plants. Several Open Cycle Gas Turbine plants are under development by the private sector in NSW. Further, there is a strong case – from the perspective of reducing water consumption and carbon emissions – to improve assistance for investment in Wind technology. Networks of wind farms that span different 'wind' regions would improve the reliability of this technology.

- The water industry has shifted its focus towards adaptive management – as articulated in the 2006 Metropolitan Water Plan for NSW – which includes non-rainfall dependent supplies, such as desalination and advanced wastewater treatment processes. Federal government policies, such as the Water for the Future initiative, are providing additional support for these technologies, as well as decentralised technologies such as rainwater tanks. These technologies will substantially increase the demand for energy in the water industry. This gives further impetus for the implementation of rigorous demand management strategies that would reduce the reliance on energy-intensive technologies.

- Energy consumption in the Irrigation & Drainage Water sector in 2031 is likely to be marginal compared with the Bulk & Retail Water and Sewage sectors. It is likely therefore that irrigation water required to produce biomass for electricity, or the competition between irrigators and generators for water resources are more significant nexus issues for this sector, compared to its own energy consumption.

- The existing Bulk & Retail Water sector continues to supply a large percentage of water in 2031, and therefore the energy consumption in the scenarios is largely attributed to this sector. The new Desalination and Recycle sectors are the most energy-intensive: the total Electricity intensities in 2031 for the Desalination and Recycle sectors range between 13,604-14,391 MJ/ML and 8,062-8,663 MJ/ML, respectively.

- In comparison, the total Electricity intensities for the BRW sector range between 1,685-1,747 MJ/ML. The intensity range for each sector reflects the differences in the electricity generation mix under each scenario. Further, the actual greenhouse gas emissions would depend on the energy source. The NSW Government has committed to powering the new desalination plant with renewable energy, if and when it is operational.

- In addition to the environmental benefit, energy efficiency strategies in the water industry would assist in reducing operating costs in the industry, by offseting electricity price increases due to carbon pricing and water shortages.

- The total Petroleum Refining intensities for the Recycle sector (1,536-2,218 MJ/ML) are higher compared to all other sectors. Indirect consumption comprises a significant proportion of these intensities. This suggests that an increase in the use of recycled water would increase the amount of refined petroleum consumed in the industry. As with the Electricity intensities above, the intensity range is related to the electricity generation mix under each scenario.

The conclusions demonstate the ubiquity of trade-offs between water and electricity in NSW, and the need for policy integration in light of reforms, drought and impending climate change. The empirical analysis has comprised the development of quantitative indicators — intensities, multipliers and elasticities — which has been complemented by qualitative insights into the historical evolution of the nexus. The future implications of these trade-offs have been demonstrated through an analysis of long-term scenarios for the water and electricity industries in 2031. Based on this comprehensive analysis, Chapter 8 puts forward recommendations — that align with one or more of the four quadrants of Integral Theory's AQAL framework — to improve the integration of water and energy policies, focusing on institutional arrangements, government measures and industry activities.

9.2 Recommendations for further research

This section presents some possible recommendations for further research.

- This research took place during a time of significant change in the water and electricity industries. In particular, the climate change debate gained considerable momentum in the final twelve months of the research. Exploring the links between climate change, water resources and energy consumption was not part of the initial scope. A deeper understanding of the feedback loops between all three should be central to any future research into this topic. One possible solution would be to adopt a systems analysis approach in order to capture the feedback loops. Such approach would fit within the lower right hand quadrant of the AQAL framework. Systems analysis, for example, could be adopted to examine the interaction between centralised and decentralised water and electricity systems.

- There are inherent trade-offs between the decentralised and centralised supply and electricity and water. Further research could examine the implications of such trade-offs for a particular locality, given that decentralised supply is dependent on the local water and energy system.

- This research applies input-output analysis, which is a disaggregated, yet essentially a top-down modelling approach. The water and electricity sectors in the input-output models have been disaggregated in order to quantify the links between the various sectors. A possible suggestion would be to complement the analysis with a bottom-up model so that the links between water and electricity in end use applications may be examined, for example, the amount of electricity versus gas used for domestic hot water, or the amount of water required for industrial processes versus their energy consumption.

- Three sets of input-output models were developed for 1996 and 2001: a Leontief hybrid model, a Leontief monetary model and a Ghosh monetary model. A price vector and income equation linked the Leontief hybrid and monetary models. The price of water and electricity is not consistent across different customer groups, such as businesses and households. Based on personal communication with Duchin (2005), it was decided that this approach would offer a reasonable approximation whilst reducing the data burden of creating water and energy price matrices. An alternate approach would be to keep the

Leontief model in its monetary form and develop separate water and energy use matrices in physical units. This would remove the need to balance the hybrid and monetary models with an income equation and potentially improve the accuracy of the water and energy intensities. The approach developed by this research offers the advantage of representing balanced water and energy flows, and enables the quantification of intensities for both water and energy sectors, as well as water and energy primary inputs. This is of particular importance, given that primary inputs capture primary energy losses and water directly extracted from the Environment by all sectors and end users.

- The input-output tables separate the electricity industry according to generation sectors. The input and output data for the transmission and distribution segments of the industry were therefore apportioned to the generation sectors, according to the generation mix and location in the grid. An alternative would be to create separate transmission and distribution sectors, so that material, water and energy flows within the electricity industry can be more accurately quantified. This research explored this approach in the early stages, but could not resolve how to thermodynamically preserve the energy balance of the input-output models.

- The input-output data for the water and electricity sectors were disaggregated largely according to the operational expenses, and in the case of some electricity sectors, the generation mix as well. The energy and water inputs were the main features differentiating the sectors. A more accurate approach would be to obtain actual operation and maintenance data for the different generation technologies and water sectors (note this approach was undertaken for most of the new electricity sectors in the scenario analysis).

- The 1996 and 2001 input-output models are static and therefore provide a snapshot of the relationships between water and electricty (and energy more broadly). There were two main reasons for adopting this approach. Firstly, the original input output tables had highly aggregated final demand categories that precluded the addition of variables to capture the dynamic relationship between investment and increases in capacity. Secondly, a dynamic approach requires a series of input-output models at regular time intervals, ideally on an annual basis. However, there was a lack of sectoral water use data for Australia. As water data collection activities improve, there may be scope to develop dynamic models in the future.

- The empirical analysis focuses on NSW, and in the case of the input-output models, on the Australian Capital Territory as well. Given the national focus of water and energy policies in recent years, and the operation of national water and energy markets, this research may be extended by developing an Australian-wide multi-regional input-output model. Such a model would capture the unique primary energy endowments in each of the States and Territories, as well as provide a framework for analysing the impact of water and energy trades in the country.

- The scenario modelling for 2031 is based on a Leontief hybrid model, because of the absence of water price data required to develop a monetary model. A monetary model would provide additional insights into the links between water and electricity, such as the impact of price increases on the demand for water and electricity, the impact of investment into different water and electricity sectors on economic output, income generation and employment, or the impact of various tax regimes.

- The new water and electricity sectors in the 2031 Leontief hybrid model were developed with the intention of using the most accurate engineering and input-output data available to the researcher at the time. The operational and maintenance profiles of some sectors, such as the Geothermal sector, are not readily available for the Australian context, because the technology is still in pilot phase. Therefore, the input-output data for some of the new sectors would require revision once more accurate data becomes available.

- The scenarios presented in this research are based on existing water and energy policies and information regarding future investment plans in both industries. Due to the evolving nature of developments in both industries, the scenarios may require refining in the future, in order to be in line with future policy settings. There is also scope to expand the analysis to include an investigation into the trade-offs between water and other forms of energy, for example, natural gas; and other types of infrastructure.

- The calculation of the own and cross price elasticities were hampered by a lack of sectoral water use data, and it was not possible to develop time series or panel data within the resource constraints of this research. As water data collection activities improve, there will be greater scope for adopting more complex econometric methods. An alternative approach would be to focus on a specific locality and sector, in order to confine the data collection efforts to a manageable size, with the cooperation of specific water and energy providers. Such a study could focus on water and electricity in the residential sector, or the interactions between surface water, groundwater and electricity in the rural water market.

Water and energy will continue to be critical for economic development and social wellbeing, and therefore understanding the links between the two is of utmost importance. It is hoped that this research provides a foundation for further research into this policy issue of contemporary importance. At a deeper level, it is hoped that this research demonstrates that isolated human actions do not have isolated consequences; that an integrated, holistic approach may lead to better and more sustainable outcomes for the greater good of society.

Appendix 1 Twenty tenets of Integral Theory

1. Reality as a whole is not composed of things or processes, but of holons.
2. Holons display four fundamental capacities:

   (a) self-preservation (principle of autonomy or agency);

   (b) self-adaptation (principle of communion);

   (c) self-transcendence (ability to go beyond the given); and

   (d) self-dissolution (ability to break down to its sub-holons).
3. Holons emerge.
4. Holons emerge holarchically.
5. Each emergent holon transcends and includes its predecessor(s).
6. The lower sets the possibilities of the higher; the higher sets the probabilities of the lower.
7. The number of levels which a hierarchy comprises determines whether it is 'shallow' or 'deep'; the number of holons on any given level we shall call its 'span'.
8. Each successive level of evolution produces greater depth and less span.
9. Addition I. The greater the depth of a holon, the greater its degree of consciousness. [9]
10. Destroy any type of holon, and you will destroy all of the holons above it and none of the holons below it. [10]
11. Holarchies co-evolve. [11]
12. The micro is in relational exchange with the macro at all levels of its depth. [12]
13. Evolution has directionality. [13]
14. a) increasing complexity; [14]
    b) increasing differentiation/integration; [15]
    c) increasing organisation/structuration; [16]
    d) increasing relative autonomy; [17]
    e) increasing telos. [18]
15. Addition II. Every holon issues an IOU to the Kosmos. [19]
16. Addition III. All IOUs are redeemed in Emptiness. [20]

Appendix 2 An exploration into philosophy

Integral Theory motivated the researcher to better understand the philosophical legacies of modern society, and the implications for contemporary issues, such as the water-energy nexus. This necessitated an exploration into the foundations of the western worldview, which began with the early philosophers of Ancient Greece. A second related theme is how the same legacies have influenced the practice of research, in particular what constitutes valid knowledge claims in various disciplines. In exploring these legacies, the researcher concluded that the western worldview – and research informed by such a worldview on water-energy nexus – are narrow and offer a partial perspective on reality. This research suggests that a more inclusive and comprehensive perspective may be attained by exploring alternative philosophies, such as eastern traditions, indigenous wisdom and 20th century western paradigms.

This Appendix is the synthesis of these philosophical deliberations, which have directly influenced the worldview of the researcher and indirectly informed the development of the methodological framework presented in Chapter 3.

A 2.1 Foundations of western thought

The foundations of western thought have origins in the philosophers of Ancient Greece. Ancient Greek civilisation relied on mythology – traditional tales about supernatural beings or events – to explain natural phenomena. Thales of Miletus (585 BC), one of the first Greek philosophers who belonged to a group of pre-Socratic philosophers called the naturalists, challenged this tradition by arguing that natural events are instead explicable by observation and reason. This argument represented a major shift in thinking that has influenced western thought ever since (Johnston, Gostelow & Jones 1999).

Over a century later, Socrates (470~399 BC) – commonly regarded as the father of political philosophy – introduced the dialectic method of inquiry. This method is based on the idea that truth is attainable by questioning and modifying one’s underlying beliefs, in order to eliminate inconsistencies and contradictions. Socrates’ life and philosophy have been preserved mainly through the works of two contemporaries, Xenophon and particularly his student Plato (Blackburn 1996).

Plato (429~347 BC) is considered the founder of philosophical argument. He reasoned that reality comprises two worlds – the world of senses and the world of forms. He believed that knowledge gained from the five senses – in the world of senses – is incomplete, as reality is impermanent and flowing. Instead, it is the forms behind what is sensed – in the world of forms – that is eternal, provides true knowledge about reality, and leads to enlightenment. The aim of 'being' is to move closer to the world of forms, where true reason resides.

Aristotle (384~322 BC) agreed with Plato's world of the senses, but not with the world of forms. Rather, he was more concerned with what 'substance' the forms comprised. Accordingly, Aristotle applied rigorous classification systems to the natural world he observed, and his ideas are considered the precursor to the scientific method (Ross & ebrary Inc. 1995). Aristotle also concluded that there is a purpose behind everything in nature, and that 'man' was top of the natural world (Gaard 1993). Further, he postulated that 'reason' was a characteristic of men (in contrast with Plato who postulated that reason belonged to the world of forms), which distinguished men from all other beings on Earth, including women.

Legacies from antiquity have re-emerged over the course of history, as philosophers deliberated over ontology and epistemology. The development of western ontological and epistemological positions that have influenced the practice of research are now discussed.

A 2.2 Ontological and epistemological positions

Western philosophical perspectives on ontology and epistemology have dominated the practice of research. These perspectives have also influenced what is considered valid knowledge claims in different academic disciplines. The pivotal issue in ontology is whether reality exists regardless of our knowledge of it, or whether it is constructed from our perceptions. Both views represent the two dominant ontological positions in western thought. The former, termed **foundationalist,** purports that reality is founded on basic beliefs or universal truths. This position became popular during the Enlightenment from the mid 17th century when science began to emerge as an alternative authority to the Church and the Monarchies. It was believed that science held the keys to discovering universal truths. The opposing view – termed **anti-foundationalist** – developed as a reaction against the foundationalist notion of universal truths. Instead, it claims that reality is based on context and therefore is a construction of one's perceptions (Grix 2004).

The pivotal epistemological issue concerns what is considered a valid knowledge claim. A related issue in academia is whether knowledge claims in one discipline are transferable to another. An example in research is whether the procedures from the natural sciences can be applied to the social sciences (Bryman 2004). Various epistemological positions have emerged that are underpinned by the two ontological positions of foundationalism and anti-foundationalism.

The dominant epistemological position is **positivism**, which is based on a foundationalist ontology (Grix 2004). Several perspectives fall under the banner of positivism, including empiricism, rationalism, and naturalism. All of these perspectives focus on 'explaining' reality. Rationalism is based on the ideas of Socrates and Plato and asserts that universal truths may be derived from reason. ***A priori*** knowledge, which purports that reality can be known prior to any sense experience, is the principle knowledge claim. Rationalists include the Continental European philosophers Rene Descartes (1596~1650), Benedict de Spinoza (1632~1677) and Gottfried Wilhelm Leibniz (1646~1716) (Blackburn 1996).

Empiricism follows the legacy of Aristotle, and claims that only ***a posteriori*** knowledge, which is experienced through the senses in an objective manner, is valid (Blackburn 1996; Grix 2004). Empiricists reject the notion that ideas are innate, but rather that ideas are learnt through experience. An early empiricist was Christian philosopher St Thomas Aquinas (1225~1274), who separated faith from reason, and 'explained' the existence of God from his observations of the world. Other later empiricists include British philosophers Sir Frances Bacon (1561~1626), Thomas Hobbes (1588~1679), John Locke (1632~1704) , and David Hume (1711~1776) (Johnston, Gostelow & Jones 1999).

Naturalism is concerned with the application of science to the social sciences. French naturalist Auguste Comte (1798~1857), who was influenced by Aristotle, argued that society could be analysed empirically and that 'all genuine knowledge is based on information gained by experience through senses', that is, *a posteriori* knowledge (Walliman & Baiche 2001). Comte first coined the term 'sociology' and is considered the first person to apply the scientific method to social analysis. Emile Durkheim (1858~1917), another French positivist, claimed that by rejecting popular conceptions and looking at society as if for the first time, 'social facts' may be discovered using scientific observation. Durkheim also argued that social structures determine the actions of individuals (Abercrombie, Turner & Hill 2006).

Counter to the positivist position is **interpretivism,** which is based on an antifoundationalist ontology. Interpretivists assert that there are differences between people and objects in the natural world, and therefore the study of the social world requires a different approach. In particular, interpretivists claim that researchers cannot objectively observe, because they are bound to the situation under observation. Truth is interpreted by the researcher, based on their individual beliefs, experiences and social context and is therefore subjective (Walliman & Baiche 2001). Interpretivists also seek to 'understand' reality, particularly the interrelations between society and the individual. This position is associated with qualitative research methods.

Three main schools have emerged under the interpretivist banner: phenomenology, ethnomethodology and symbolic interactionism (Bryman 2004). Phenomenology is based on the works of Edmund Husserl (1859~1938). It refers to the study of phenomena from a first-person point of view; in particular how we experience phenomena and the meanings attached to them during the experience (Smith 2003). This school is linked with hermeneutics, which is a theory and method of interpreting text – originally biblical – from the perspective of the author, taking into account the social and historical context within which it was produced (Abercrombie, Turner & Hill 2006). Ethnomethodology on the other hand – developed by Harold Garfinkel (1917~) – focuses on the methods people use to construct their world, so that their own activities make sense to others and produces a social order in which they live (Abercrombie, Turner & Hill 2006). Lastly, symbolic interactionism – based on the works of George Herbert Mead (1863~1931) – asserts that an individual is 'continually interpreting the symbolic meaning of the Environment (including the actions of others) and acts on the basis of this imputed meaning' (Bryman 2004).

In order to reconcile the 'explanation' of positivism with the 'understanding' of interpretivism, other epistemological positions have emerged, in particular **postpositivism.** Postpositivism postulates that an external world exists, but that it is subject to the interpretations of the observer. Postpositivists also believe that 'theory' both shapes reality and follows it. In the academic context, for example, research may be deductive (theory-driven) and inductive (derives theory).

One postpositive perspective is critical realism, which contends that causal links or mechanisms are not always directly observable and may require interpretation. Context is also important when interpreting these links. Similar to positivism, critical realism accepts that social structures exist, but a point of departure is that individuals can transform these structures (Grix

2004). Another postpositive perspective is pragmatism, which was developed by American John Dewey (1859~1952), based on the works of Charles Sanders Peirce (1839~1914) and William James (1842~1910). Several versions of pragmatism have evolved, but all generally agree with the critical realist view of the importance of context. Pragmatists also believe that there is an external reality, but unlike critical realists, do not seek to discover or explain the mechanisms that exist, in an effort to get closer to what is 'real'. Rather, pragmatists focus on acting on beliefs and observing consequences to determine whether the beliefs worked or were 'real', and what is considered 'real' in one occasion may not hold true in the future (Cherryholmes 1992).

A 2.3 Western worldview – a philosophical legacy

The aforementioned discussion focuses on the influence of traditional western philosophy on the development of ontological and epistemological positions in research. Western philosophers, however, have also significantly contributed to other branches of philosophy, culminating in the development of a western worldview. This worldview emerged largely during the Age of Enlightenment in the 17th and 18th centuries. It has been suggested that the impetus behind The Enlightenment was the desire to eliminate the all-pervading authority vested in the Church and the divine rule of Monarchies that characterised the preceding Middle Ages. The keys to truths about the universe, it was deemed, no longer rested in these established hierarchies, but rather in an alternative and more independent authority – science (Skolimowski 1981; Wilber 2000b).

This shift towards science was promulgated early on by Descartes, who separated the mind from the body and asserted that the human mind is the measure of all things. Descartes further asserted that universal truths may be revealed by stripping reality down to its basic components (Blackburn 1996). Descartes' reductionist philosophy was complemented by Isaac Newton's (1642 – 1727) mechanistic explanation of the world. Newton believed that the universe was based on natural, rationally understandable laws, which were epitomised by his laws of motion (Hooker 2006). These thinkers made way for the **ascendency of the scientific method**. Many scientific discoveries and technological advancements were made during this period and indeed the modern **concept of technology** itself emerged based on the works of Bacon. This concept may be described as the 'union of rational theory and empirical practice and its application to human welfare' (Johnston, Gostelow & Jones 1999). To the present day, society has maintained a faith in science and technology, which is captured by the phrase 'technological fix' (Skolimowski 1993). Technology is considered the solution to many issues of global importance, including current issues of climate change and water shortages.

Another important tenet that emerged during this period was the **rights of the individual**, put forward by Locke. Locke argued that humans had natural rights of 'life, liberty and estate' regardless of social circumstances (Johnston 2006). A person's estate was defined as whatever land was mixed with their labour for meaningful gain, provided there was sufficient property left for others to appropriate. Land was otherwise held in common. The advent of land enclosures, however, surpassed this fundamental property right of the individual, entailing the establishment of an authority to maintain a system of justice. In so doing, the 'state' came into being, as a social contract between individuals. A system of government was proposed by Locke based on three independent arms – legislative, executive and judicial – to maintain the individual rights of life, liberty and estate that he advocated. Locke's political philosophy provided the impetus for the formation of a constitutional monarchy in Britain in the late 17th century and the American and French Revolutions in the late 18th century.

Economic ideology also transitioned during this period, from mercantilism to a **growing interest in the market economy**. Mercantilism was founded on the belief that the wealth of a nation is measured by the amount of precious metals it owns. Colonialisation flourished as a result and brought the double benefit of securing raw materials and precious metals for the colonial power, and a ready market for finished products. Governments favoured the mercantilist class, because of the revenue they generated via taxes and levies. In exchange, Governments provided mercantilists with capital for new industries and exempted these industries from paying tax (LaHaye 2006).

Towards the end of the 18th century, opposition to mercantilism grew. In his treatise of 1776 titled *Wealth of Nations*, Scottish economist Adam Smith (1723~1790) favoured a market economy over mercantilism by asserting that collusion between government and industry was detrimental to the interests of the general population (LaHaye 2006). Instead, he theorised that if individuals pursued their self interests, the 'invisible hand' of the market would ensure that the collective welfare of society was maximised. The market, according to Smith, was therefore the most efficient allocator of resources.

Smith's work provided the **rationale for Capitalism**. Whilst alternate systems of organising the means of production developed over the years (such as Communism), Capitalism has emerged as the dominant economic system in the western world. In recent times, however, it has been argued that capitalism requires constant growth to sustain itself and therefore encourages excessive consumption, leading to a wasteful use of Earth's resources (Mies & Shiva 1993). This argument further suggests that affluent societies may be aware of the negative impacts of their lifestyles, yet fail to act on this knowledge, instead relying on the technological fix to mitigate these impacts.

Indeed the relationship between humans and Earth in the western world has been described by some as one of dominance. According to this worldview, nature was to be tamed and conquered (Brady 1999). From the beginnings of western philosophy in Ancient Greece, Aristotle asserted that men (to the exclusion of women) were at the top of the hierarchy in the natural world, which was to be used for their benefit. Much later, Bacon and Descartes reinforced this notion by asserting that humans were free to exploit nature for their purpose (Dovers 1994). Locke's (1690) rights of the individual further implied that **nature had no intrinsic value**, until mixed with labour for productive gain. The gigantic harnessing of Earth's resources to fuel industrialisation and Capitalist expansion in the western world has, under the legacy of this worldview, created widespread environmental degradation. Further, the reductionist perspective and focus on technology left little room to appreciate the intrinsic value and needs of ecosystems. Rather, the Environment and the resources it provided were considered limitless (Doyle 2000).

A 2.3.1 Legacies on the water-energy nexus

Whilst the advancement of modern society owes much to past philosophical deliberations, it may be argued that the ensuing legacies have created a worldview that is untenable in the longer-term. Firstly, one of the premises of the creation of water and electricity markets in Australia is that individuals acting in their self interest will maximise social welfare, as mentioned above. The introduction of the market mechanism to the water and electricity industries was brought about by the microeconomic reforms that began in the mid 1990s in Australia and continue to this day. The reforms, as previously outlined in Section 4.4, introduced competition to the industries, as a means to promote private investment and private 'individual' decisions unencumbered by government control. This, the proponents of reform argue, would result in the most efficient allocation of water and electricity. This research contends, however, that the role of water and electricity as fundamental infrastructure industries, and the criticality of the links between the two, should be considered in the design and operation of such markets. However, recent events in the National Electricity Market (NEM) suggest that this has not occurred; fragmented 'individual' actions have led to perverse outcomes (refer to Sections 2.1.1 and 4.4.3 for further details).

Secondly, technology has been important for the development of modern societies and for the water and electricity industries. The technological fix continues in the water and electricity industries, which is evident in the development of large-scale centralised systems (for example Sydney's desalination plant and the requirement for future baseload power stations identified in the Owen Inquiry). Fortunately, policy developments in 2008 suggest that the industries are placing greater emphasis on efficiency opportunities (refer to Table 8-1). Additional emphasis should be placed on 'soft' measures that aim to increase the value that society places on water and energy, and more broadly, to increase the emphasis on the quality of life rather than the pursuit of prosperity, which is the hallmark of a Capitalist society.

Thirdly, despite significant inroads into managing and protecting the Environment, the health of ecosystems continues to be compromised during times of crisis. For example, the drought which affected much of Australia from 2001 to 2007, severly reduced the generation capacity in the NEM, and prompted calls by industry for governments to assign priority to electricity generation over environmental flows. The Californian Energy Crisis in 2001 also led to widespread killing of salmon in neighbouring states that were required to generate hydropower to support the failing energy market in California (refer to Section 2.1.1).

The legacies of the western worldview on the water and electricity industries are clearly evident. This contends that the philosophies underpinning this worldview have limited capacity to resolve some of the contemporary issues that society currently faces, such as the trade-offs that arise due to the inherent links between water and electricity.

A 2.4 Alternative philosophical perspectives

The western worldview only offers a partial perspective on reality which, according to this researcher, is highly fragmented. In search for integration and wholeness, individuals are looking beyond traditional western philosophy that can provide alternative perspectives on the human experience. Such perspectives may also assist with developing alternative ways of viewing society and contemporary issues. This section explores some of these alternative perspectives from eastern traditions, indigenous wisdom and holistic paradigms.

A 2.5 Eastern traditions

Eastern philosophy contains some of the oldest recorded traditions on earth and is closely linked with spiritual practices. Many share the principle that individuals must be their own saviour and lead a virtuous path, rather than seeking salvation from an external God (Skolimowski 1993). The most prominent traditions include Hinduism and Buddhism from India, and Daoism and Confucianism from China.

Hinduism

Hinduism is considered the longest surviving philosophical tradition in India and is documented in the religious scriptures of the Vedas, Upanishads and Bhagavad Gita. Whilst the practice of Hinduism is diverse, Hindus believe in one reality – termed *Brahma* – that comprises a transcendental aspect (impersonal) and an immanent aspect (personal). The transcendental aspect has no attributes – it is immutable, formless and absolute, and cannot be comprehended by the human mind. The immanent aspect has attributes and is worshipped in the form of deities. Hindus believe that all beings are manifestations of the one supreme being and contain *Atman* (a spiritual essence or soul) (Pandit 2001). Hinduism therefore fosters respect for rather than domination over the natural world. This is further strengthened by what Hindu apologist Rajagopal Ryali terms 'organic solidarity'. This refers to the belief that humans may once have been lesser animals (reincarnation) and the worship of lesser gods that often take on natural forms, such as animals (polytheism) (Callicott 1994).

Buddhism

Buddhism developed from the teachings of Siddartha Gautama (563~483BC), who is widely known as Buddha, or the 'Enlightened One'. Buddha followed a path of moderation, after he observed that neither the pursuit of pleasure and wealth, nor asceticism, lead to happiness. Indeed, he believed they caused mental suffering and trapped humans in *samsara*, or the cycle of birth and death. Renouncing worldly pursuits eliminates unhappiness. Buddha also believed that our actions might cause good karma that helps us along the way, or bad karma that may hinder our spiritual progress. Following the Buddhist teachings of the Four Noble Truths and the Noble Eightfold Path – which advocate the renouncement of worldly pursuits – a person may eliminate unhappiness and in doing so be closer to attaining Enlightenment. Buddhism stresses self-responsibility, and unlike the Abrahamic religions of the West, does not believe in a God who controls the universe or provides salvation. It is based on the tenets of non-violence, of 'being' as opposed to greed and possession, and spiritual development as opposed to economic development (Kalland 2003). Similar to Hinduism, Buddhist practices use meditation – what Wilber describes as a 'state' of consciousness – to access wisdom or insights.

Taoism

Taoism, along with Confucianism, has had a significant influence on Chinese culture and philosophy. Founded on the thinking of Lao Tze around 600BC, Daoism is based on the principal of *Tao*, which translates to 'The Way'. The Way refers to the way in which things exist, the way in which things change in the world, and how we should exist. Tao is considered mysterious and may only be experienced though its twin forces of *yin* and *yang*, the passive and active principles of the universe that are often ascribed feminine and masculine qualities respectively. These principals govern nature and its progression. By living in harmony with nature, one may experience *Te* (the power of the Tao that allows individuals to act according to their nature) and therefore begin to understand Tao. The balance and harmony of natural processes provides a model for human action, which some have likened to the concept of appropriate technology (Callicott 1994).

Confucianism

Confucianism is based on the teachings of Chinese scholar Confucius (551~479 BC). Concerned largely with social philosophy, it offers a moral code for people to live harmoniously together. This is represented by the twin concepts of *jen* – loving kindness through piety and obedience – and *li* – correct conduct. Confucianism contends that there are five relationships, which form the basis for human interaction. These are father and son, husband and wife, older brother and younger brother, older friend and younger friend, and ruler and subject. By observing *jen* and *li* in these relationships, individuals may achieve order in their lives, which extends to order in society. Confucius further emphasised the importance of effective and benevolent leaders, as well as self-cultivation through education (Billington & ebrary Inc. 1997). Confucianism appears to emphasise a person's place within a social context, which contrasts with the western focus on the individual.

Indigenous wisdom

Indigenous cultures of the world are as diverse as the landscapes they inhabit yet many share an affinity with nature that is central to their cosmologies. This affinity is founded on the beliefs that creation is interconnected and that nature is sacred. Humans, therefore, are not superior to other beings, but rather have the responsibility to preserve the natural order in the land of which they are an integral part. This view is fundamental to Australian Aborigines, who although they comprise many ethnic groups, share a common belief that all are connected (Sveiby & Skuthorpe 2006). Native Americans feel a similar kinship with other living beings, and believe that earth is a living conscious being that must be treated with respect (Booth & Jacobs 1990).

20th century western paradigms

Some paradigms have emerged in the west over the past few decades that offer an alternative to the reductionist tendencies of the dominant western worldview. Many of these paradigms were developed in response to the environmental degradation of the past few decades, and suggest that such degradation can only be curtailed if humans change their worldview.

One such paradigm is Deep Ecology, which is founded on the belief that human and non-human life are equally valid, and therefore humans have no right to reduce nature's diversity, except to satisfy vital needs. It advocates a shift in policies to promote life quality, rather than higher standards of living. It also asserts that a substantial decrease in the human population is required for other beings to thrive (Drengson 2006).

Ecofeminism is similarly critical of the western worldview that humans are superior to other beings and suggests that the exploitation of nature is closely linked with the subjugation of the feminine (Mies & Shiva 1993). Masculine traits remain the hallmarks of the western worldview that, according to ecofeminists, are the root cause of environmental degradation. Ecofeminists believe that degradation of the Environment may be curtailed by creating a holistic paradigm that acknowledges the feminine. This paradigm, ecofeminists argue, would comprise decentralised and non-hierarchical organisational models, simpler living styles involving lesspolluting 'soft' technologies, and economic systems that are more people-, rather than technology-oriented (Merchant 1989).

The concept of sustainable development is another western paradigm, which has been broadly adopted by institutions worldwide since its inception in the *Our Common Future* (1987) report by the United Nations World Commission on Environment and Development. This report – commonly referred to as the Brundtland report – defines sustainable development as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (1987 p. 43). The three principles of sustainable development are often defined as social progress, ecological balance and economic growth, or 'people planet profits'. This concept has undeniably re-oriented modern society's view on development. However, it can be argued that society's captivation with *homo economicus* continues, which is explored in Chapter 4.

A 2.6 Insights into the researcher's worldview

The following section documents some of the main tenets underpinning the researcher's worldview, which largely draw upon the philosophies previously discussed.

Tenet 1: Whilst technology is critically important for the water and electricity industries, this researcher contends that changes to behaviour and values are also necessarily important. Linked to these changes is the need for individuals to **look within themselves** and take **self-responsibility for their actions,** which appears to align more closely with eastern traditions. That is, changes to the external world require corresponding changes to the internal world of individuals. In other words, changes in the behavioural quadrant of the AQAL framework require changes in the psychological quadrant, which would also bring forth changes in the social and cultural quadrants.

Tenet 2: This research contends that actions motivated by the **greater good for society** may be better suited than pursuing self-interests, because individual actions may lead to fragmented decisions and less than optimal outcomes. Community-oriented actions are evident in indigenous cultures, such as the Australian Aborigines and North American Indians. In a different manner, Confucianism positions the role of the individual within a larger social order and in doing so places more emphasis on social relationships rather than individual interests.

Tenet 3: Related to the point above is the **interconnectedness of all** things on Earth. This is evident in indigenous cultures which view themselves as custodians of Earth. This researcher does not necessarily argue the need to resort to the pre-modern era or tribal societies but rather to acknowledge these perspectives and to integrate them with the levels of development that are prevalent in modern society (refer to the cultural quadrant of the AQAL framework in Figure 3-2.

Tenet 4: Since Enlightenment, western society has extolled the virtues of rationalism, objectivity, hierarchy and logic, which has also underpinned much of academic theory and praxis. This has significantly advanced our understanding of the scientific functioning of the world. These virtues, however, are only partial to any human experience. Further, the opposite virtues of emotion, sensitivity, community and receptivity appear to have been suppressed. These two sets of virtues may also be described as masculine and feminine traits. This researcher contends that the **balance of masculine and feminine traits** is important, as both offer different and complementary insights. Taoism's *ying* and *yan* symbol is a well-recognised representation of this balance. Ecofeminism is also viewed as a reaction against the imbalance of masculine and feminine perspectives over the past centuries.

The four tenets significantly influenced the researcher's approach to the topic. Firstly, the selection of the topic itself is a reflection of the wider belief that there are interconnections between society, the Environment and the economy that are not always encapsulated in the development of policies. This is not surprising, given the dominant and narrow economic context within which policy development occurs, and the narrow focus of research that supports this development. Secondly, by adopting the AQAL framework to guide the methodological framework, this researcher sought to acknowledge that diverse perspectives on Earth are equally valid and necessary in order to capture the whole sum of the human experience. The integration of these perspectives, and harnessing the collective wisdom on Earth may assist in developing more robust solutions to contemporary issues that modern societies face. The researcher also acknowledges that there are clear academic boundaries – particularly within technologically-focused university faculties – that place limits upon what is a 'valid' research methodology. Nevertheless, it is hoped that the views articulated in this thesis and the methodology adopted will push some of these boundaries, and contribute to the growing body of multidisciplinary research in academic institutions. Thirdly, the tenets influenced the selection of research methods from various disciplines, in order to capture the multidimensional nature of the nexus. In addition, the scenario framework was selected because it incorporated quadrants in the left hand side of the AQAL framework. Lastly, in analysing the results and putting forward recommendations, the research did not necessarily focus on the optimum technological solution, but attempted to demonstrate that there are several ways to reduce the potential trade-offs between water and electricity; technology is but one path.

Appendix 3 Input-output model construction

The original NSW input-output tables from the Centre for Agricultural and Regional Economics (CARE) comprised 107 (1996) and 106 (2001) sectors, and were of the industry x industry type. These tables were extensively modified by this research project using water, energy and financial data from government agencies, utilities, industry bodies and the private sector, to form 32-sector Leontief hybrid, Leontief monetary and Ghosh monetary models for each year. The resulting monetary input-output table was then converted to a Ghosh monetary model in the usual manner, as described in Section 3.4.1.

Replacing water and energy sector outputs to form the Leontief hybrid model required careful consideration, to ensure the tables remained balance. Additional notes regarding the construction of the input-output models now follow.

i) The total output for the water and energy sectors in the Leontief hybrid model equaled the amount of water that was extracted by the sectors, and the amount of electricity they generated, respectively. The total output data was apportioned to the intermediate sectors in the inter-industry table and the final demand sectors, based on water and energy use data from the Australian Bureau of Statistics (ABS), the Australian Bureau of Agricultural and Resource Economics, utilities, and various industry bodies. This data formed the row vectors for the water and energy sectors.

(ii) The column vectors for the water and energy sectors in the original tables were apportioned to the revised water and energy sectors in the research models, based on their operation and maintenance expense data. For example, the original Water, Sewage and Drainage sector column vector was apportioned to the Irrigation & Drainage Water, Bulk & Retail Water Supply, and Sewage sectors, according to the expenses for each of the sectors for the particular year of analysis.

iii) The price vector for the Leontief and Ghosh monetary models was compiled from expense and price data for the water and energy sectors. It is not uncommon for different production sectors to pay different prices for water and energy, and the same is true for the final demand sectors, such as Households. This research, however, adopted an average price vector for water and energy sector outputs for simplicity, following advice from Prof Faye Duchin at Rensselaer Polytechnic Institute (2005).

(iv) The Leontief hybrid and monetary models are linked via the price vector (Eqn 3.5 in thesis). That is, the Leontief hybrid model multiplied by the price vector equals the Leontief monetary model. Where discrepancies remained between the Leontief hybrid and monetary models, the rows and columns of the individual sectors were balanced manually, by modifying the Other Value Added (OVA) primary input category. Note, the OVA category served as a balancing term during the construction of the original tables (Powell 2005).

Appendix 4 Matrices of input-output coefficients

This appendix presents the input-output coefficients for this research. Table A- 1 lists the sectoral classification adopted by this research and used in the input-output coefficient matrices in this appendix.

Table A- 1 Sectoral classification and hybrid model units

Production Sector		Hybrid model units
1	Agriculture	$000
2	Coal Mining	PJ
3	Other mining & services to mining	$000
4	Food, beverages & tobacco	$000
5	Textile, clothing, footwear & leather	$000
6	Wood, paper & printing products	$000
7	Petroleum refining	PJ
8	Petroleum & coal products NEC	PJ
9	Chemicals	$000
10	Non-metallic mineral products	$000
11	Basic metals & products	$000
12	Fabricated metal products	$000
13	Transport equipment	$000
14	Other machinery & equipment	$000
15	Miscellaneous manufacturing	$000
16	Electricity – Coal-fired	PJ
17	Electricity – Gas turbine	PJ
18	Electricity – Internal combustion (1996 only)	PJ
18	Electricity – Combined cycle gas turbine (2001 only)	PJ
19	Electricity – Cogeneration	PJ
20	Electricity – Hydropower	PJ
21	Electricity – Other renewables	PJ
22	Retail gas supply	PJ
23	Water – Irrigation & drainage water	ML
24	Water – Bulk & retail water	ML
25	Water – Sewerage	ML
26	Construction	$000
27	Wholesale & retail trade	$000
28	Transport & storage	$000
29	Finance, property & business services	$000
30	Government administration & defence	$000
31	Education, health & community services	$000
32	Other commercial services	$000

Table A-2 1996 Leontief hybrid model direct coefficients

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.1093	1.0338	0.0001	0.1652	0.0234	0.0124	0.0673	0.0673	0.0030	0.0010	0.0005	0.0003	0.0001	0.0001	0.0025	0.2389
2	-	0.0000	-	0.0000	0.0000	0.0000	-	-	0.0000	0.0000	0.0000	0.0000	-	-	0.0000	2.6575
3	0.0001	25.5803	0.1081	0.0000	0.0000	0.0004	6.4129	6.4129	0.0084	0.0667	0.0149	0.0010	0.0001	0.0035	0.0225	0.0861
4	0.0213	0.7868	0.0015	0.0986	0.0183	0.0016	0.4778	0.4778	0.0100	0.0003	0.0002	0.0005	0.0007	0.0002	0.0012	2.0289
5	0.0018	0.3998	0.0005	0.0024	0.1166	0.0013	0.8446	0.8446	0.0040	0.0011	0.0011	0.0051	0.0010	0.0009	0.0114	1.3000
6	0.0045	2.3264	0.0029	0.0226	0.0166	0.0970	5.5349	5.5349	0.0220	0.0190	0.0026	0.0173	0.0116	0.0105	0.1291	8.8239
7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0636	0.0009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0037
8	-	-	-	-	-	-	0.0719	-	0.0000	0.0000	0.0000	0.0000	-	-	-	-
9	0.0355	9.1552	0.0183	0.0256	0.0254	0.0265	80.0934	80.0934	0.2430	0.0307	0.0173	0.0204	0.0245	0.0256	0.0462	58.9212
10	0.0011	0.6287	0.0035	0.0083	0.0002	0.0038	0.7096	0.7096	0.0061	0.1159	0.0109	0.0092	0.0041	0.0027	0.0054	83.0030
11	0.0003	6.4694	0.0100	0.0015	0.0012	0.0039	0.7715	0.7715	0.0118	0.0129	0.2510	0.1981	0.0558	0.0942	0.0991	11.6531
12	0.0033	6.4782	0.0129	0.0241	0.0040	0.0085	3.3527	3.3527	0.0167	0.0164	0.0048	0.1373	0.0370	0.0270	0.0495	27.0508
13	0.0009	5.0311	0.0018	0.0001	0.0000	0.0002	0.4164	0.4164	0.0001	0.0001	0.0005	0.0003	0.1046	0.0014	0.0013	0.4030
14	0.0095	14.5298	0.0255	0.0019	0.0009	0.0103	2.3007	2.3007	0.0014	0.0021	0.0050	0.0086	0.0155	0.1140	0.0049	343.7427
15	0.0014	0.9901	0.0016	0.0004	0.0018	0.0005	0.2837	0.2837	0.0011	0.0006	0.0006	0.0042	0.0061	0.0016	0.0070	0.5205
16	0.0000	0.0016	0.0000	0.0000	0.0000	0.0000	0.0038	0.0009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0719
18	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
19	-	-	-	-	-	-	-	-	-	-	0.0000	-	-	-	-	-
20	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
21	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
22	-	-	-	0.0000	0.0000	-	0.0068	0.0011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
23	0.3116	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	0.7019	0.0020	0.0020	0.0059	0.0019	2.1198	-	0.0017	0.0012	0.0036	0.0025	0.0006	0.0007	0.0021	93.8255
25	0.0009	1.4669	0.0020	-	-	-	-	-	-	-	0.0000	-	-	-	-	3.6296
26	0.0042	2.2180	0.0063	0.0001	0.0001	0.0003	0.2018	0.2018	0.0001	0.0005	0.0002	0.0001	0.0002	0.0001	0.0001	15.7472
27	0.0580	20.1406	0.0320	0.0500	0.0459	0.0488	83.0823	83.0823	0.0502	0.0232	0.0340	0.0408	0.0676	0.0746	0.0692	170.6720
28	0.0354	15.6845	0.0470	0.0382	0.0159	0.0286	281.2450	281.2450	0.0203	0.0932	0.0330	0.0174	0.0131	0.0126	0.0211	392.2687
29	0.0533	67.0564	0.1311	0.0589	0.0481	0.0664	65.2400	65.2400	0.0806	0.0520	0.0652	0.0524	0.0455	0.0331	0.0352	404.9578
30	0.0006	0.2441	0.0002	0.0007	0.0001	0.0028	2.8573	2.8573	0.0005	0.0004	0.0007	0.0006	0.0008	0.0003	0.0004	1.8055
31	0.0030	1.2023	0.0012	0.0020	0.0041	0.0066	0.5306	0.5306	0.0085	0.0003	0.0001	0.0002	0.0013	0.0002	0.0003	13.0559
32	0.0082	4.2672	0.0046	0.0074	0.0065	0.0240	4.8469	4.8469	0.0161	0.0064	0.0024	0.0092	0.0087	0.0062	0.0069	10.5335

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1. Continued on next page.

Table A-2 1996 Leontief hybrid model direct coefficients (continued)

96HA	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	0.2409	0.2409	0.2388	0.0888	0.2905	0.0034	0.0000	0.0000	0.0000	0.0004	0.0000	0.0002	0.0001	0.0011	0.0002	0.0107
2	-	-	-	-	-	-	-	-	-	-	-	0.0000	-	0.0000	0.0000	0.0000
3	0.0869	0.0869	0.0861	0.0320	0.1048	0.0208	0.0000	0.0013	0.0021	0.0048	0.0000	0.0000	0.0002	0.0004	0.0002	0.0013
4	2.0461	2.0461	2.0283	0.7544	2.4678	0.4321	0.0000	0.0005	0.0008	0.0003	0.0011	0.0003	0.0008	0.0048	0.0016	0.0258
5	1.3110	1.3110	1.2996	0.4833	1.5812	0.4163	0.0000	0.0002	0.0003	0.0012	0.0012	0.0010	0.0005	0.0037	0.0025	0.0037
6	8.8987	8.8987	8.8212	3.2808	10.7326	4.9449	0.0001	0.0026	0.0043	0.0249	0.0460	0.0056	0.0137	0.0397	0.0107	0.0253
7	3.6067	3.1937	-	-	-	0.0019	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	59.4207	59.4207	58.9037	21.9076	71.6670	24.3683	0.0007	0.0188	0.0310	0.0087	0.0039	0.0059	0.0045	0.0094	0.0209	0.0134
10	83.7066	83.7066	82.9783	30.8616	100.9582	5.3464	0.0002	0.0057	0.0094	0.0517	0.0025	0.0002	0.0018	0.0024	0.0014	0.0037
11	11.7519	11.7519	11.6496	4.3328	14.1739	1.7027	0.0001	0.0015	0.0025	0.0110	0.0012	0.0004	0.0017	0.0012	0.0002	0.0008
12	27.2801	27.2801	27.0428	10.0578	32.9024	6.0144	0.0006	0.0176	0.0289	0.0432	0.0039	0.0102	0.0041	0.0086	0.0030	0.0051
13	0.4064	0.4064	0.4029	0.1498	0.4902	0.0805	0.0000	0.0001	0.0002	0.0004	0.0028	0.0152	0.0001	0.0180	0.0001	0.0004
14	346.6567	346.6567	343.6405	127.8078	418.1011	2.0580	0.0001	0.0033	0.0054	0.0258	0.0043	0.0020	0.0063	0.0109	0.0045	0.0121
15	0.5249	0.5249	0.5203	0.1935	0.6331	0.4439	0.0000	0.0001	0.0002	0.0012	0.0014	0.0005	0.0002	0.0020	0.0008	0.0011
16	-	-	-	-	-	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	0.0725	-	-	-	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	-	0.0725	-	-	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	0.0012	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	-	-	-	-	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	-	-	-	-	-	0.0284	-	-	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	4.1983	4.1983	0.2552	2.9160	-	2.9956	0.0000	0.0002	0.0003	0.0004	0.0005	0.0005	0.0004	0.0006	0.0008	0.0013
25	-	-	-	-	-	-	-	-	-	0.0000	-	-	-	-	-	0.0003
26	15.8807	15.8807	15.7425	5.8550	19.1536	1.4864	0.0000	0.0002	0.0004	0.0005	0.0005	0.0019	0.0492	0.0116	0.0005	0.0034
27	172.1189	172.1189	170.6213	63.4580	207.5918	22.2729	0.0004	0.0107	0.0176	0.0532	0.0372	0.0488	0.0143	0.0223	0.0171	0.0366
28	395.5941	395.5941	392.1521	145.8504	477.1243	275.2871	0.0002	0.0056	0.0093	0.0238	0.0314	0.1022	0.0132	0.0358	0.0110	0.0228
29	408.3907	408.3907	404.8374	150.5684	492.5583	192.0210	0.0013	0.0362	0.0596	0.0917	0.2004	0.1048	0.1772	0.1790	0.0885	0.1377
30	1.8208	1.8208	1.8049	0.6713	2.1960	0.1532	0.0000	0.0008	0.0012	0.0007	0.0010	0.0005	0.0007	0.0237	0.0010	0.0005
31	13.1666	13.1666	13.0520	4.8543	15.8802	6.5937	0.0000	0.0004	0.0007	0.0002	0.0007	0.0006	0.0008	0.0027	0.0084	0.0030
32	10.6228	10.6228	10.5303	3.9165	12.8121	7.3261	0.0001	0.0025	0.0042	0.0031	0.0168	0.0130	0.0140	0.0162	0.0084	0.0419

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1.

Table A-3 1996 Leontief hybrid model total coefficients

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.1287	1.8002	0.0013	0.2081	0.0351	0.0170	1.9948	1.7113	0.0088	0.0026	0.0017	0.0021	0.0015	0.0013	0.0068	9.1890
2	0.0000	1.0055	0.0000	0.0000	0.0000	0.0000	0.0130	0.0035	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	2.8844
3	0.0014	29.6600	1.1231	0.0021	0.0010	0.0020	10.6656	9.0400	0.0144	0.0863	0.0256	0.0090	0.0035	0.0084	0.0300	99.1537
4	0.0282	1.5919	0.0030	1.1159	0.0250	0.0041	3.3735	2.9042	0.0164	0.0020	0.0015	0.0023	0.0023	0.0016	0.0039	11.5447
5	0.0031	0.8824	0.0015	0.0044	1.1327	0.0024	2.7514	2.3749	0.0069	0.0024	0.0024	0.0079	0.0024	0.0022	0.0147	7.7229
6	0.0159	7.8388	0.0135	0.0396	0.0291	1.1168	24.8485	21.3982	0.0431	0.0327	0.0127	0.0330	0.0260	0.0239	0.1569	79.1646
7	0.0000	0.0004	0.0000	0.0000	0.0000	0.0000	1.0732	0.0055	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0125
8	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0776	1.0007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0022
9	0.0586	16.6283	0.0341	0.0542	0.0443	0.0445	131.0411	113.8272	1.3302	0.0547	0.0378	0.0449	0.0450	0.0468	0.0776	174.6762
10	0.0037	2.4320	0.0074	0.0131	0.0021	0.0067	4.5895	3.6151	0.0118	1.1339	0.0188	0.0178	0.0087	0.0074	0.0114	119.5715
11	0.0072	15.9824	0.0279	0.0154	0.0067	0.0136	11.0006	9.1424	0.0317	0.0314	1.3429	0.3133	0.1029	0.1552	0.1558	144.9463
12	0.0098	11.0983	0.0227	0.0368	0.0093	0.0151	15.5807	13.2108	0.0303	0.0281	0.0127	1.1659	0.0530	0.0400	0.0654	102.6251
13	0.0024	6.3235	0.0038	0.0019	0.0009	0.0014	7.6616	6.5853	0.0013	0.0029	0.0024	0.0018	1.1179	0.0029	0.0030	29.5959
14	0.0149	19.9160	0.0367	0.0081	0.0040	0.0160	9.9990	7.3240	0.0068	0.0091	0.0134	0.0168	0.0236	1.1328	0.0125	489.4497
15	0.0020	1.3101	0.0023	0.0013	0.0024	0.0010	1.1478	0.9791	0.0020	0.0012	0.0012	0.0055	0.0075	0.0024	1.0080	6.7177
16	0.0000	0.0020	0.0000	0.0000	0.0000	0.0000	0.0048	0.0012	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0844
17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0003	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004
21	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0080	0.0015	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0015
23	0.3517	0.5609	0.0004	0.0648	0.0109	0.0053	0.6216	0.5332	0.0027	0.0008	0.0005	0.0007	0.0005	0.0004	0.0021	2.8632
24	0.0005	1.1980	0.0030	0.0028	0.0071	0.0026	3.5644	0.8246	0.0030	0.0022	0.0057	0.0046	0.0016	0.0018	0.0037	106.8906
25	0.0011	1.5463	0.0023	0.0002	0.0000	0.0000	0.0663	0.0348	0.0001	0.0002	0.0002	0.0001	0.0000	0.0000	0.0001	8.4010
26	0.0108	7.8351	0.0181	0.0083	0.0055	0.0072	11.3923	9.6443	0.0094	0.0081	0.0083	0.0075	0.0062	0.0055	0.0068	77.9887
27	0.0821	30.7992	0.0545	0.0861	0.0668	0.0694	135.9111	117.4717	0.0850	0.0491	0.0627	0.0742	0.0958	0.1042	0.1024	379.6102
28	0.0552	25.5591	0.0706	0.0682	0.0305	0.0457	380.1352	328.9526	0.0466	0.1344	0.0667	0.0469	0.0317	0.0327	0.0487	603.0036
29	0.1175	107.0107	0.2183	0.1426	0.1034	0.1311	204.1131	173.7684	0.1801	0.1346	0.1524	0.1413	0.1153	0.1034	0.1246	1,056.6584
30	0.0011	0.4655	0.0006	0.0014	0.0005	0.0035	4.0560	3.5265	0.0012	0.0009	0.0013	0.0013	0.0014	0.0008	0.0014	5.1837
31	0.0044	1.6577	0.0021	0.0039	0.0056	0.0082	2.6610	2.2217	0.0122	0.0016	0.0010	0.0012	0.0024	0.0011	0.0025	21.9995
32	0.0156	8.0162	0.0123	0.0175	0.0131	0.0332	19.9125	17.1118	0.0292	0.0150	0.0094	0.0181	0.0165	0.0135	0.0184	67.1547

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1. Continued on next page.

Table A-3 1996 Leontief hybrid model total coefficients (continued)

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	11.7633	10.8749	3.6810	1.3723	4.4785	1.2409	0.0000	0.0006	0.0009	0.0017	0.0018	0.0012	0.0012	0.0039	0.0014	0.0193
2	0.0556	0.0498	0.0045	0.0017	0.0054	0.0018	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	55.5124	50.7619	12.8946	4.8091	15.6878	1.6599	0.0001	0.0027	0.0042	0.0111	0.0010	0.0008	0.0015	0.0017	0.0009	0.0027
4	20.0342	18.5317	6.3537	2.3692	7.7301	2.1364	0.0000	0.0012	0.0019	0.0013	0.0026	0.0016	0.0020	0.0071	0.0028	0.0312
5	15.8713	14.6459	4.7526	1.7714	5.7822	1.6017	0.0000	0.0006	0.0010	0.0023	0.0020	0.0018	0.0011	0.0051	0.0033	0.0051
6	153.0925	142.0250	51.8866	19.3393	63.1274	18.3396	0.0002	0.0065	0.0106	0.0383	0.0605	0.0154	0.0238	0.0551	0.0173	0.0386
7	4.1804	3.7025	0.0066	0.0025	0.0080	0.0064	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.3030	0.2685	0.0013	0.0005	0.0016	0.0006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	634.4230	576.0573	114.6660	42.7758	139.5035	41.9109	0.0010	0.0275	0.0450	0.0216	0.0119	0.0147	0.0112	0.0209	0.0309	0.0259
10	130.6741	128.6299	103.7040	38.6377	126.1724	9.0653	0.0003	0.0076	0.0124	0.0611	0.0052	0.0022	0.0068	0.0060	0.0029	0.0068
11	141.8281	136.9285	91.0295	33.9236	110.7509	10.2709	0.0003	0.0096	0.0155	0.0364	0.0074	0.0084	0.0087	0.0121	0.0041	0.0084
12	129.7055	122.7659	63.4585	23.6929	77.2019	15.8390	0.0008	0.0223	0.0365	0.0559	0.0092	0.0169	0.0107	0.0167	0.0061	0.0115
13	41.3080	37.8955	10.5840	3.9425	12.8772	5.9676	0.0000	0.0005	0.0007	0.0016	0.0042	0.0194	0.0008	0.0218	0.0006	0.0014
14	474.6457	470.1921	400.6213	149.1945	487.4269	7.4402	0.0002	0.0055	0.0084	0.0330	0.0092	0.0057	0.0117	0.0176	0.0071	0.0179
15	7.4179	6.9066	2.7149	1.0119	3.3031	1.0140	0.0000	0.0003	0.0005	0.0018	0.0018	0.0010	0.0005	0.0026	0.0010	0.0015
16	0.0199	0.0177	0.0010	0.0004	0.0012	0.0006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	1.0782	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	0.0000	1.0782	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.0012	0.0011	0.0001	1.0012	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	0.0322	0.0286	0.0011	0.0004	0.0013	1.0295	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	3.6653	3.3885	1.1470	0.4276	1.3954	0.3867	1.0000	0.0002	0.0003	0.0005	0.0006	0.0004	0.0004	0.0012	0.0004	0.0060
24	20.7002	19.1127	2.3791	3.7120	2.5839	3.7465	0.0000	1.0006	0.0007	0.0011	0.0010	0.0010	0.0008	0.0011	0.0011	0.0019
25	0.3187	0.2892	0.0558	0.0208	0.0679	0.0156	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003
26	99.9769	94.9028	51.1753	19.0653	62.2630	17.6550	0.0001	0.0033	0.0053	1.0086	0.0144	0.0107	0.0613	0.0250	0.0069	0.0141
27	820.2661	759.7314	268.1600	99.9033	326.2600	53.5674	0.0006	0.0173	0.0278	0.0726	1.0531	0.0673	0.0280	0.0420	0.0258	0.0550
28	2,010.1782	1,840.8662	489.0062	182.1236	594.9613	329.3982	0.0004	0.0116	0.0182	0.0444	0.0463	1.1270	0.0245	0.0530	0.0183	0.0384
29	1,543.8901	1,452.9783	689.4554	256.8986	838.8294	311.9089	0.0021	0.0591	0.0955	0.1575	0.2780	0.1727	1.2420	0.2602	0.1270	0.2093
30	19.5479	17.7413	3.4672	1.2936	4.2181	0.7746	0.0000	0.0009	0.0015	0.0012	0.0016	0.0009	0.0011	1.0248	0.0012	0.0010
31	27.6638	26.4786	15.9172	5.9294	19.3659	7.9186	0.0000	0.0008	0.0013	0.0010	0.0017	0.0012	0.0013	0.0038	1.0090	0.0041
32	121.4373	112.5682	40.4362	15.0714	49.1964	19.5697	0.0002	0.0050	0.0082	0.0102	0.0252	0.0202	0.0203	0.0251	0.0126	1.0505

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1.

Table A-4 1996 Leontief monetary model direct coefficients

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.1093	0.0007	0.0001	0.1652	0.0234	0.0124	0.0000	0.0001	0.0030	0.0010	0.0005	0.0003	0.0001	0.0001	0.0025	0.0000
2	-	0.0000	-	0.0004	0.0002	0.0002	-	-	0.0004	0.0035	0.0247	0.0000	-	-	0.0001	0.2219
3	0.0001	0.0168	0.1081	0.0000	0.0000	0.0004	0.0007	0.0049	0.0084	0.0667	0.0149	0.0010	0.0001	0.0035	0.0225	0.0000
4	0.0213	0.0005	0.0015	0.0986	0.0183	0.0016	0.0000	0.0004	0.0100	0.0003	0.0002	0.0005	0.0007	0.0002	0.0012	0.0001
5	0.0018	0.0003	0.0005	0.0024	0.1166	0.0013	0.0001	0.0006	0.0040	0.0011	0.0011	0.0051	0.0010	0.0009	0.0114	0.0001
6	0.0045	0.0015	0.0029	0.0226	0.0166	0.0970	0.0006	0.0043	0.0220	0.0190	0.0026	0.0173	0.0116	0.0105	0.1291	0.0005
7	0.0073	0.0000	0.0001	0.0007	0.0007	0.0004	0.0636	0.0070	0.0127	0.0018	0.0013	0.0005	0.0001	0.0004	0.0001	0.0019
8	-	-	-	-	-	-	0.0098	-	0.0032	0.0000	0.0079	0.0000	-	-	-	-
9	0.0355	0.0060	0.0183	0.0256	0.0254	0.0265	0.0084	0.0616	0.2430	0.0307	0.0173	0.0204	0.0245	0.0256	0.0462	0.0032
10	0.0011	0.0004	0.0035	0.0083	0.0002	0.0038	0.0001	0.0005	0.0061	0.1159	0.0109	0.0092	0.0041	0.0027	0.0054	0.0045
11	0.0003	0.0042	0.0100	0.0015	0.0012	0.0039	0.0001	0.0006	0.0118	0.0129	0.2510	0.1981	0.0558	0.0942	0.0991	0.0006
12	0.0033	0.0042	0.0129	0.0241	0.0040	0.0085	0.0003	0.0026	0.0167	0.0164	0.0048	0.1373	0.0370	0.0270	0.0495	0.0015
13	0.0009	0.0033	0.0018	0.0001	0.0000	0.0002	0.0000	0.0003	0.0001	0.0001	0.0005	0.0003	0.1046	0.0014	0.0013	0.0000
14	0.0095	0.0095	0.0255	0.0019	0.0009	0.0103	0.0002	0.0018	0.0014	0.0021	0.0050	0.0086	0.0155	0.1140	0.0049	0.0188
15	0.0014	0.0006	0.0016	0.0004	0.0018	0.0005	0.0000	0.0002	0.0011	0.0006	0.0006	0.0042	0.0061	0.0016	0.0070	0.0000
16	0.0049	0.0197	0.0279	0.0060	0.0079	0.0078	0.0073	0.0126	0.0095	0.0223	0.0638	0.0066	0.0097	0.0053	0.0003	0.0719
17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
18	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
19	-	-	-	-	-	-	-	-	-	-	0.0020	-	-	-	-	-
20	0.0003	0.0013	0.0018	0.0004	0.0005	0.0005	0.0005	0.0008	0.0006	0.0014	0.0041	0.0004	0.0006	0.0003	0.0000	-
21	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	-
22	-	-	-	0.0089	0.0064	-	0.0138	0.0165	0.0365	0.0784	0.0485	0.0053	0.0027	0.0019	0.0017	-
23	0.0049	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	0.0005	0.0022	0.0022	0.0064	0.0021	0.0002	-	0.0018	0.0013	0.0039	0.0027	0.0006	0.0007	0.0023	0.0056
25	0.0017	0.0017	0.0036	-	-	-	-	-	-	-	0.0001	-	-	-	-	0.0004
26	0.0042	0.0015	0.0063	0.0001	0.0001	0.0003	0.0000	0.0002	0.0001	0.0005	0.0002	0.0001	0.0002	0.0001	0.0001	0.0009
27	0.0580	0.0132	0.0320	0.0500	0.0459	0.0488	0.0087	0.0639	0.0502	0.0232	0.0340	0.0408	0.0676	0.0746	0.0692	0.0093
28	0.0354	0.0103	0.0470	0.0382	0.0159	0.0286	0.0293	0.2163	0.0203	0.0932	0.0330	0.0174	0.0131	0.0126	0.0211	0.0215
29	0.0533	0.0439	0.1311	0.0589	0.0481	0.0664	0.0068	0.0502	0.0806	0.0520	0.0652	0.0524	0.0455	0.0331	0.0352	0.0221
30	0.0006	0.0002	0.0002	0.0007	0.0001	0.0028	0.0003	0.0022	0.0005	0.0004	0.0007	0.0006	0.0008	0.0003	0.0004	0.0001
31	0.0030	0.0008	0.0012	0.0020	0.0041	0.0066	0.0001	0.0004	0.0085	0.0003	0.0001	0.0002	0.0013	0.0002	0.0003	0.0007
32	0.0082	0.0028	0.0046	0.0074	0.0065	0.0240	0.0005	0.0037	0.0161	0.0064	0.0024	0.0092	0.0087	0.0062	0.0069	0.0006

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1. Continued on next page.

Table A-4 1996 Leontief monetary model direct coefficients (continued)

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0004	0.0000	0.0002	0.0001	0.0011	0.0002	0.0107
2	-	-	-	-	-	-	-	-	-	-	-	0.0000	-	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0031	0.0012	0.0012	0.0048	0.0000	0.0000	0.0002	0.0004	0.0002	0.0013
4	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0012	0.0005	0.0005	0.0003	0.0011	0.0003	0.0008	0.0048	0.0016	0.0258
5	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0004	0.0001	0.0001	0.0012	0.0012	0.0010	0.0005	0.0037	0.0025	0.0037
6	0.0001	0.0003	0.0005	0.0002	0.0006	0.0003	0.0061	0.0024	0.0023	0.0249	0.0460	0.0056	0.0137	0.0397	0.0107	0.0253
7	0.4152	1.1717	-	-	-	0.0009	0.0014	0.0013	0.0003	0.0031	0.0004	0.1164	0.0000	0.0004	0.0004	0.0000
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	0.0007	0.0023	0.0032	0.0012	0.0039	0.0013	0.0443	0.0174	0.0170	0.0087	0.0039	0.0059	0.0045	0.0094	0.0209	0.0134
10	0.0010	0.0032	0.0045	0.0017	0.0055	0.0003	0.0135	0.0053	0.0052	0.0517	0.0025	0.0002	0.0018	0.0024	0.0014	0.0037
11	0.0001	0.0004	0.0006	0.0002	0.0008	0.0001	0.0035	0.0014	0.0013	0.0110	0.0012	0.0004	0.0017	0.0012	0.0002	0.0008
12	0.0003	0.0010	0.0015	0.0006	0.0018	0.0003	0.0413	0.0162	0.0159	0.0432	0.0039	0.0102	0.0041	0.0086	0.0030	0.0051
13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0001	0.0001	0.0004	0.0028	0.0152	0.0001	0.0180	0.0001	0.0004
14	0.0042	0.0133	0.0188	0.0070	0.0229	0.0001	0.0077	0.0030	0.0029	0.0258	0.0043	0.0020	0.0063	0.0109	0.0045	0.0121
15	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0001	0.0001	0.0012	0.0014	0.0005	0.0002	0.0020	0.0008	0.0011
16	-	-	-	-	-	0.0003	0.0231	0.0209	0.0055	0.0001	0.0050	0.0021	0.0019	0.0056	0.0042	0.0039
17	0.0725	-	-	-	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	-	0.0725	-	-	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	0.0012	-	0.0000	0.0015	0.0013	0.0004	0.0000	0.0003	0.0001	0.0001	0.0004	0.0003	0.0002
21	-	-	-	-	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	-	-	-	-	-	0.0284	-	-	-	0.0002	0.0039	0.0007	0.0000	0.0023	0.0026	0.0003
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	0.0001	0.0002	0.0000	0.0002	-	0.0002	0.0005	0.0002	0.0002	0.0004	0.0005	0.0006	0.0004	0.0006	0.0008	0.0014
25	-	-	-	-	-	-	-	-	-	0.0000	-	-	-	-	-	0.0005
26	0.0002	0.0006	0.0009	0.0003	0.0010	0.0001	0.0006	0.0002	0.0002	0.0005	0.0005	0.0019	0.0492	0.0116	0.0005	0.0034
27	0.0021	0.0066	0.0093	0.0035	0.0114	0.0012	0.0251	0.0098	0.0096	0.0532	0.0372	0.0488	0.0143	0.0223	0.0171	0.0366
28	0.0047	0.0151	0.0214	0.0080	0.0261	0.0142	0.0132	0.0052	0.0051	0.0238	0.0314	0.1022	0.0132	0.0358	0.0110	0.0228
29	0.0049	0.0156	0.0221	0.0082	0.0269	0.0099	0.0851	0.0334	0.0327	0.0917	0.2004	0.1048	0.1772	0.1790	0.0885	0.1377
30	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0018	0.0007	0.0007	0.0007	0.0010	0.0005	0.0007	0.0237	0.0010	0.0005
31	0.0002	0.0005	0.0007	0.0003	0.0009	0.0003	0.0009	0.0004	0.0004	0.0002	0.0007	0.0006	0.0008	0.0027	0.0084	0.0030
32	0.0001	0.0004	0.0006	0.0002	0.0007	0.0004	0.0060	0.0023	0.0023	0.0031	0.0168	0.0130	0.0140	0.0162	0.0084	0.0419

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1. The electricity shares are not completely the same, because some manufacturing sectors obtain electricity directly from embedded power plants, as well as the grid.

Table A-5 1996 Leontief monetary model total coefficients

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.1287	0.0012	0.0013	0.2081	0.0351	0.0170	0.0002	0.0013	0.0088	0.0026	0.0017	0.0021	0.0015	0.0013	0.0068	0.0005
2	0.0022	1.0055	0.0092	0.0036	0.0032	0.0034	0.0021	0.0041	0.0055	0.0124	0.0547	0.0152	0.0074	0.0083	0.0077	0.2409
3	0.0014	0.0194	1.1231	0.0021	0.0010	0.0020	0.0011	0.0070	0.0144	0.0863	0.0256	0.0090	0.0035	0.0084	0.0300	0.0054
4	0.0282	0.0010	0.0030	1.1159	0.0250	0.0041	0.0004	0.0022	0.0164	0.0020	0.0015	0.0023	0.0023	0.0016	0.0039	0.0006
5	0.0031	0.0006	0.0015	0.0044	1.1327	0.0024	0.0003	0.0018	0.0069	0.0024	0.0024	0.0079	0.0024	0.0022	0.0147	0.0004
6	0.0159	0.0051	0.0135	0.0396	0.0291	1.1168	0.0026	0.0165	0.0431	0.0327	0.0127	0.0330	0.0260	0.0239	0.1569	0.0043
7	0.0167	0.0024	0.0096	0.0119	0.0056	0.0070	1.0732	0.0403	0.0242	0.0199	0.0112	0.0078	0.0050	0.0056	0.0078	0.0066
8	0.0004	0.0001	0.0004	0.0004	0.0002	0.0003	0.0105	1.0007	0.0047	0.0006	0.0108	0.0027	0.0010	0.0014	0.0015	0.0002
9	0.0586	0.0109	0.0341	0.0542	0.0443	0.0445	0.0137	0.0876	1.3302	0.0547	0.0378	0.0449	0.0450	0.0468	0.0776	0.0096
10	0.0037	0.0016	0.0074	0.0131	0.0021	0.0067	0.0005	0.0028	0.0118	1.1339	0.0188	0.0178	0.0087	0.0074	0.0114	0.0065
11	0.0072	0.0105	0.0279	0.0154	0.0067	0.0136	0.0011	0.0070	0.0317	0.0314	1.3429	0.3133	0.1029	0.1552	0.1558	0.0079
12	0.0098	0.0073	0.0227	0.0368	0.0093	0.0151	0.0016	0.0102	0.0303	0.0281	0.0127	1.1659	0.0530	0.0400	0.0654	0.0056
13	0.0024	0.0041	0.0038	0.0019	0.0009	0.0014	0.0008	0.0051	0.0013	0.0029	0.0024	0.0018	1.1179	0.0029	0.0030	0.0016
14	0.0149	0.0130	0.0367	0.0081	0.0040	0.0160	0.0010	0.0056	0.0068	0.0091	0.0134	0.0168	0.0236	1.1328	0.0125	0.0268
15	0.0020	0.0009	0.0023	0.0013	0.0024	0.0010	0.0001	0.0008	0.0020	0.0012	0.0012	0.0055	0.0075	0.0024	1.0080	0.0004
16	0.0089	0.0234	0.0381	0.0123	0.0123	0.0125	0.0092	0.0174	0.0189	0.0346	0.0966	0.0329	0.0215	0.0198	0.0164	1.0844
17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0027	0.0006	0.0002	0.0003	0.0003	0.0000
20	0.0005	0.0014	0.0023	0.0007	0.0007	0.0007	0.0005	0.0010	0.0011	0.0021	0.0058	0.0020	0.0013	0.0012	0.0010	0.0004
21	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
22	0.0039	0.0013	0.0040	0.0150	0.0103	0.0035	0.0161	0.0221	0.0538	0.0960	0.0707	0.0258	0.0116	0.0132	0.0145	0.0016
23	0.0055	0.0000	0.0000	0.0010	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24	0.0005	0.0009	0.0032	0.0031	0.0077	0.0028	0.0004	0.0007	0.0032	0.0024	0.0062	0.0049	0.0017	0.0020	0.0040	0.0063
25	0.0020	0.0018	0.0041	0.0004	0.0001	0.0001	0.0000	0.0000	0.0001	0.0004	0.0003	0.0001	0.0001	0.0001	0.0002	0.0008
26	0.0108	0.0051	0.0181	0.0083	0.0055	0.0072	0.0012	0.0074	0.0094	0.0081	0.0083	0.0075	0.0062	0.0055	0.0068	0.0043
27	0.0821	0.0202	0.0545	0.0861	0.0668	0.0694	0.0142	0.0904	0.0850	0.0491	0.0627	0.0742	0.0958	0.1042	0.1024	0.0208
28	0.0552	0.0167	0.0706	0.0682	0.0305	0.0457	0.0396	0.2530	0.0466	0.1344	0.0667	0.0469	0.0317	0.0327	0.0487	0.0330
29	0.1175	0.0701	0.2183	0.1426	0.1034	0.1311	0.0213	0.1337	0.1801	0.1346	0.1524	0.1413	0.1153	0.1034	0.1246	0.0578
30	0.0011	0.0003	0.0006	0.0014	0.0005	0.0035	0.0004	0.0027	0.0012	0.0009	0.0013	0.0013	0.0014	0.0008	0.0014	0.0003
31	0.0044	0.0011	0.0021	0.0039	0.0056	0.0082	0.0003	0.0017	0.0122	0.0016	0.0010	0.0012	0.0024	0.0011	0.0025	0.0012
32	0.0156	0.0052	0.0123	0.0175	0.0131	0.0332	0.0021	0.0132	0.0292	0.0150	0.0094	0.0181	0.0165	0.0135	0.0184	0.0037

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1. Continued on next page.

Table A-5 1996 Leontief monetary model total coefficients (continued)

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	0.0001	0.0004	0.0002	0.0001	0.0002	0.0001	0.0013	0.0005	0.0005	0.0017	0.0018	0.0012	0.0012	0.0039	0.0014	0.0193
2	0.0010	0.0029	0.0004	0.0001	0.0005	0.0001	0.0071	0.0057	0.0019	0.0026	0.0020	0.0015	0.0012	0.0025	0.0015	0.0019
3	0.0007	0.0019	0.0007	0.0003	0.0009	0.0001	0.0061	0.0025	0.0023	0.0111	0.0010	0.0008	0.0015	0.0017	0.0009	0.0027
4	0.0002	0.0007	0.0003	0.0001	0.0004	0.0001	0.0027	0.0011	0.0010	0.0013	0.0026	0.0016	0.0020	0.0071	0.0028	0.0312
5	0.0002	0.0006	0.0003	0.0001	0.0003	0.0001	0.0014	0.0005	0.0005	0.0023	0.0020	0.0018	0.0011	0.0051	0.0033	0.0051
6	0.0018	0.0054	0.0028	0.0011	0.0035	0.0009	0.0151	0.0060	0.0058	0.0383	0.0605	0.0154	0.0238	0.0551	0.0173	0.0386
7	0.4812	1.3584	0.0035	0.0013	0.0042	0.0032	0.0059	0.0032	0.0020	0.0095	0.0066	0.1404	0.0035	0.0075	0.0032	0.0055
8	0.0047	0.0134	0.0001	0.0000	0.0001	0.0000	0.0004	0.0002	0.0002	0.0004	0.0002	0.0015	0.0001	0.0002	0.0002	0.0002
9	0.0076	0.0220	0.0063	0.0023	0.0076	0.0022	0.0644	0.0254	0.0247	0.0216	0.0119	0.0147	0.0112	0.0209	0.0309	0.0259
10	0.0016	0.0049	0.0057	0.0021	0.0069	0.0005	0.0177	0.0070	0.0068	0.0611	0.0052	0.0022	0.0068	0.0060	0.0029	0.0068
11	0.0017	0.0052	0.0050	0.0019	0.0061	0.0005	0.0223	0.0088	0.0085	0.0364	0.0074	0.0084	0.0087	0.0121	0.0041	0.0084
12	0.0016	0.0047	0.0035	0.0013	0.0042	0.0008	0.0522	0.0205	0.0200	0.0559	0.0092	0.0169	0.0107	0.0167	0.0061	0.0115
13	0.0005	0.0015	0.0006	0.0002	0.0007	0.0003	0.0011	0.0004	0.0004	0.0016	0.0042	0.0194	0.0008	0.0218	0.0006	0.0014
14	0.0057	0.0180	0.0219	0.0082	0.0267	0.0004	0.0122	0.0051	0.0046	0.0330	0.0092	0.0057	0.0117	0.0176	0.0071	0.0179
15	0.0001	0.0003	0.0001	0.0001	0.0002	0.0001	0.0008	0.0003	0.0003	0.0018	0.0018	0.0010	0.0005	0.0026	0.0010	0.0015
16	0.0044	0.0124	0.0010	0.0004	0.0012	0.0006	0.0292	0.0243	0.0076	0.0066	0.0081	0.0059	0.0042	0.0096	0.0062	0.0073
17	1.0782	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	0.0000	1.0782	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.0003	0.0007	0.0001	1.0012	0.0001	0.0000	0.0017	0.0014	0.0005	0.0004	0.0005	0.0004	0.0003	0.0006	0.0004	0.0004
21	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	0.0075	0.0212	0.0011	0.0004	0.0014	1.0295	0.0056	0.0022	0.0021	0.0086	0.0057	0.0044	0.0018	0.0050	0.0046	0.0030
23	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
24	0.0003	0.0008	0.0001	0.0002	0.0002	0.0002	0.0013	1.0006	0.0004	0.0012	0.0010	0.0011	0.0008	0.0012	0.0012	0.0020
25	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	1.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006
26	0.0012	0.0036	0.0028	0.0010	0.0034	0.0009	0.0076	0.0030	0.0029	1.0086	0.0144	0.0107	0.0613	0.0250	0.0069	0.0141
27	0.0098	0.0291	0.0147	0.0055	0.0178	0.0028	0.0400	0.0159	0.0153	0.0726	1.0531	0.0673	0.0280	0.0420	0.0258	0.0550
28	0.0241	0.0704	0.0267	0.0100	0.0325	0.0170	0.0263	0.0107	0.0100	0.0444	0.0463	1.1270	0.0245	0.0530	0.0183	0.0384
29	0.0185	0.0556	0.0377	0.0140	0.0459	0.0161	0.1371	0.0545	0.0525	0.1575	0.2780	0.1727	1.2420	0.2602	0.1270	0.2093
30	0.0002	0.0007	0.0002	0.0001	0.0002	0.0000	0.0021	0.0008	0.0008	0.0012	0.0016	0.0009	0.0011	1.0248	0.0012	0.0010
31	0.0003	0.0010	0.0009	0.0003	0.0011	0.0004	0.0019	0.0007	0.0007	0.0010	0.0017	0.0012	0.0013	0.0038	1.0090	0.0041
32	0.0015	0.0043	0.0022	0.0008	0.0027	0.0010	0.0117	0.0046	0.0045	0.0102	0.0252	0.0202	0.0203	0.0251	0.0126	1.0505

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1.

Table A-6 1996 Ghosh monetary model direct coefficients

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.1093	0.0003	0.0000	0.2918	0.0106	0.0166	0.0000	0.0000	0.0031	0.0003	0.0006	0.0002	0.0000	0.0001	0.0007	0.0000
2	-	0.0000	-	0.0016	0.0003	0.0007	-	-	0.0009	0.0030	0.0676	0.0001	-	-	0.0000	0.2178
3	0.0007	0.0336	0.1081	0.0002	0.0000	0.0029	0.0014	0.0004	0.0416	0.1152	0.0820	0.0028	0.0001	0.0155	0.0316	0.0000
4	0.0121	0.0001	0.0002	0.0986	0.0047	0.0012	0.0000	0.0000	0.0057	0.0001	0.0001	0.0002	0.0001	0.0001	0.0002	0.0000
5	0.0040	0.0002	0.0002	0.0094	0.1166	0.0038	0.0001	0.0000	0.0090	0.0009	0.0027	0.0064	0.0007	0.0018	0.0073	0.0001
6	0.0034	0.0005	0.0004	0.0298	0.0056	0.0970	0.0002	0.0001	0.0166	0.0050	0.0022	0.0073	0.0025	0.0071	0.0278	0.0001
7	0.0170	0.0000	0.0000	0.0029	0.0007	0.0011	0.0636	0.0003	0.0298	0.0014	0.0035	0.0007	0.0001	0.0009	0.0001	0.0018
8	-	-	-	-	-	-	0.2587	-	0.1965	0.0002	0.5446	0.0001	-	-	-	-
9	0.0351	0.0024	0.0037	0.0448	0.0113	0.0351	0.0036	0.0010	0.2430	0.0108	0.0192	0.0114	0.0071	0.0228	0.0132	0.0013
10	0.0030	0.0005	0.0020	0.0414	0.0002	0.0143	0.0001	0.0000	0.0174	0.1159	0.0345	0.0147	0.0034	0.0070	0.0044	0.0052
11	0.0003	0.0015	0.0018	0.0023	0.0005	0.0047	0.0000	0.0000	0.0106	0.0041	0.2510	0.0996	0.0146	0.0756	0.0254	0.0002
12	0.0058	0.0031	0.0047	0.0754	0.0032	0.0201	0.0003	0.0001	0.0298	0.0103	0.0096	0.1373	0.0192	0.0432	0.0252	0.0011
13	0.0030	0.0046	0.0013	0.0006	0.0001	0.0008	0.0001	0.0000	0.0003	0.0001	0.0018	0.0007	0.1046	0.0044	0.0013	0.0000
14	0.0106	0.0043	0.0058	0.0036	0.0004	0.0153	0.0001	0.0000	0.0016	0.0008	0.0062	0.0054	0.0051	0.1140	0.0016	0.0084
15	0.0048	0.0009	0.0011	0.0025	0.0028	0.0025	0.0000	0.0000	0.0040	0.0007	0.0024	0.0083	0.0062	0.0049	0.0070	0.0000
16	0.0121	0.0201	0.0141	0.0262	0.0088	0.0259	0.0078	0.0005	0.0238	0.0196	0.1776	0.0093	0.0071	0.0119	0.0002	0.0719
17	0.0122	0.0203	0.0143	0.0264	0.0089	0.0261	0.0079	0.0005	0.0240	0.0198	0.1791	0.0093	0.0071	0.0120	0.0002	-
18	0.0122	0.0203	0.0143	0.0264	0.0089	0.0261	0.0079	0.0005	0.0240	0.0198	0.1791	0.0093	0.0071	0.0120	0.0002	-
19	-	-	-	-	-	-	-	-	-	-	1.0000	-	-	-	-	-
20	0.0131	0.0218	0.0154	0.0284	0.0096	0.0281	0.0085	0.0006	0.0258	0.0213	0.1929	0.0100	0.0077	0.0129	0.0002	-
21	0.0147	0.0244	0.0172	0.0318	0.0107	0.0314	0.0095	0.0006	0.0289	0.0238	0.2160	0.0113	0.0086	0.0144	0.0003	-
22	-	-	-	0.0710	0.0130	-	0.0267	0.0012	0.1663	0.1251	0.2454	0.0136	0.0036	0.0079	0.0022	-
23	0.8976	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	0.0017	0.0038	0.0316	0.0240	0.0235	0.0009	-	0.0155	0.0037	0.0361	0.0125	0.0015	0.0055	0.0055	0.0186
25	0.0118	0.0049	0.0051	-	-	-	-	-	-	-	0.0006	-	-	-	-	0.0010
26	0.0022	0.0003	0.0007	0.0001	0.0000	0.0002	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0002
27	0.0119	0.0011	0.0013	0.0181	0.0042	0.0134	0.0008	0.0002	0.0104	0.0017	0.0078	0.0047	0.0041	0.0138	0.0041	0.0008
28	0.0142	0.0017	0.0039	0.0270	0.0029	0.0153	0.0051	0.0014	0.0082	0.0132	0.0148	0.0039	0.0015	0.0045	0.0024	0.0035
29	0.0062	0.0021	0.0031	0.0121	0.0025	0.0104	0.0003	0.0001	0.0095	0.0021	0.0086	0.0035	0.0016	0.0035	0.0012	0.0010
30	0.0005	0.0000	0.0000	0.0010	0.0000	0.0028	0.0001	0.0000	0.0004	0.0001	0.0006	0.0003	0.0002	0.0002	0.0001	0.0000
31	0.0012	0.0001	0.0001	0.0014	0.0007	0.0035	0.0000	0.0000	0.0034	0.0000	0.0001	0.0000	0.0002	0.0001	0.0000	0.0001
32	0.0038	0.0005	0.0004	0.0061	0.0014	0.0150	0.0001	0.0000	0.0076	0.0011	0.0012	0.0024	0.0012	0.0026	0.0009	0.0001

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1. Continued on next page.

Table A-6 1996 Ghosh monetary model direct coefficients (continued)

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0008	0.0002	0.0006	0.0009	0.0014	0.0006	0.0229
2	-	-	-	-	-	-	-	-	-	-	-	0.0000	-	0.0000	0.0002	0.0000
3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0007	0.0008	0.0438	0.0005	0.0002	0.0081	0.0025	0.0019	0.0130
4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0030	0.0005	0.0038	0.0036	0.0023	0.0311
5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0049	0.0131	0.0054	0.0090	0.0108	0.0145	0.0177
6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0003	0.0351	0.1680	0.0105	0.0879	0.0395	0.0205	0.0404
7	0.0000	0.0000	-	-	-	0.0005	0.0000	0.0004	0.0001	0.0138	0.0050	0.6748	0.0001	0.0012	0.0021	0.0001
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0002	0.0021	0.0025	0.0163	0.0189	0.0145	0.0382	0.0123	0.0529	0.0282
10	0.0000	0.0000	0.0000	0.0001	0.0000	0.0002	0.0002	0.0018	0.0021	0.2753	0.0347	0.0015	0.0445	0.0089	0.0104	0.0221
11	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0185	0.0052	0.0009	0.0129	0.0014	0.0005	0.0015
12	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0004	0.0035	0.0041	0.1442	0.0335	0.0451	0.0625	0.0202	0.0134	0.0193
13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0026	0.0459	0.1291	0.0043	0.0818	0.0011	0.0026
14	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0004	0.0005	0.0539	0.0233	0.0056	0.0596	0.0162	0.0126	0.0287
15	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0078	0.0241	0.0042	0.0064	0.0094	0.0071	0.0079
16	-	-	-	-	-	0.0002	0.0003	0.0063	0.0020	0.0003	0.0602	0.0132	0.0403	0.0186	0.0270	0.0206
17	0.0725	-	-	-	-	0.0002	0.0003	0.0063	0.0020	0.0003	0.0607	0.0133	0.0407	0.0187	0.0272	0.0207
18	-	0.0725	-	-	-	0.0002	0.0003	0.0063	0.0020	0.0003	0.0607	0.0133	0.0407	0.0187	0.0272	0.0207
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	0.0012	-	0.0002	0.0003	0.0068	0.0022	0.0004	0.0654	0.0143	0.0438	0.0202	0.0293	0.0223
21	-	-	-	-	-	0.0002	0.0004	0.0076	0.0024	0.0004	0.0733	0.0161	0.0491	0.0226	0.0328	0.0250
22	-	-	-	-	-	0.0284	-	-	-	0.0014	0.0856	0.0076	0.0008	0.0140	0.0304	0.0027
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	0.0000	0.0000	0.0000	0.0000	-	0.0003	0.0000	0.0002	0.0002	0.0066	0.0212	0.0122	0.0310	0.0066	0.0180	0.0253
25	-	-	-	-	-	-	-	-	-	0.0000	-	-	-	-	-	0.0079
26	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.0012	0.0025	0.2234	0.0082	0.0007	0.0038
27	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0002	0.0003	0.0205	0.0372	0.0250	0.0251	0.0061	0.0090	0.0160
28	0.0000	0.0000	0.0000	0.0001	0.0000	0.0013	0.0000	0.0003	0.0003	0.0179	0.0613	0.1022	0.0453	0.0191	0.0113	0.0195
29	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0001	0.0005	0.0006	0.0202	0.1143	0.0306	0.1772	0.0279	0.0265	0.0343
30	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0010	0.0037	0.0009	0.0048	0.0237	0.0019	0.0008
31	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0014	0.0006	0.0025	0.0014	0.0084	0.0025
32	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0027	0.0384	0.0152	0.0560	0.0101	0.0100	0.0419

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1.

Table A-7 1996 Ghosh monetary model total coefficients

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.1287	0.0005	0.0003	0.3677	0.0159	0.0227	0.0001	0.0000	0.0089	0.0009	0.0019	0.0012	0.0004	0.0012	0.0020	0.0002
2	0.0054	1.0055	0.0046	0.0154	0.0035	0.0110	0.0022	0.0002	0.0136	0.0107	0.1496	0.0209	0.0053	0.0182	0.0054	0.2364
3	0.0071	0.0390	1.1231	0.0184	0.0021	0.0131	0.0023	0.0006	0.0711	0.1491	0.1402	0.0247	0.0050	0.0371	0.0423	0.0107
4	0.0159	0.0002	0.0003	1.1159	0.0064	0.0031	0.0001	0.0000	0.0094	0.0004	0.0010	0.0007	0.0004	0.0008	0.0006	0.0001
5	0.0069	0.0005	0.0007	0.0173	1.1327	0.0071	0.0003	0.0001	0.0154	0.0019	0.0059	0.0098	0.0016	0.0044	0.0094	0.0004
6	0.0118	0.0016	0.0021	0.0522	0.0098	1.1168	0.0008	0.0002	0.0326	0.0086	0.0107	0.0140	0.0057	0.0161	0.0338	0.0013
7	0.0387	0.0023	0.0046	0.0487	0.0059	0.0217	1.0732	0.0015	0.0568	0.0164	0.0292	0.0103	0.0034	0.0118	0.0052	0.0061
8	0.0249	0.0035	0.0053	0.0444	0.0069	0.0260	0.2790	1.0007	0.2916	0.0136	0.7471	0.0935	0.0181	0.0791	0.0275	0.0039
9	0.0579	0.0044	0.0069	0.0946	0.0198	0.0589	0.0058	0.0014	1.3302	0.0192	0.0420	0.0251	0.0131	0.0418	0.0221	0.0038
10	0.0105	0.0018	0.0043	0.0655	0.0027	0.0253	0.0006	0.0001	0.0336	1.1339	0.0596	0.0285	0.0072	0.0188	0.0092	0.0075
11	0.0064	0.0038	0.0051	0.0242	0.0027	0.0162	0.0004	0.0001	0.0285	0.0099	1.3429	0.1576	0.0269	0.1246	0.0400	0.0028
12	0.0173	0.0053	0.0082	0.1150	0.0075	0.0357	0.0012	0.0003	0.0542	0.0176	0.0253	1.1659	0.0275	0.0638	0.0333	0.0040
13	0.0082	0.0058	0.0027	0.0114	0.0014	0.0064	0.0012	0.0003	0.0046	0.0035	0.0091	0.0035	1.1179	0.0089	0.0029	0.0022
14	0.0166	0.0059	0.0083	0.0159	0.0020	0.0238	0.0005	0.0001	0.0076	0.0036	0.0167	0.0105	0.0077	1.1328	0.0040	0.0120
15	0.0069	0.0012	0.0016	0.0078	0.0038	0.0047	0.0002	0.0000	0.0071	0.0015	0.0049	0.0109	0.0076	0.0075	1.0080	0.0005
16	0.0221	0.0239	0.0193	0.0536	0.0138	0.0414	0.0098	0.0007	0.0474	0.0304	0.2691	0.0461	0.0156	0.0443	0.0117	1.0844
17	0.0223	0.0241	0.0195	0.0541	0.0139	0.0418	0.0099	0.0007	0.0478	0.0307	0.2715	0.0465	0.0158	0.0447	0.0118	0.0069
18	0.0223	0.0241	0.0195	0.0541	0.0139	0.0418	0.0099	0.0007	0.0478	0.0307	0.2715	0.0465	0.0158	0.0447	0.0118	0.0069
19	0.0064	0.0038	0.0051	0.0242	0.0027	0.0162	0.0004	0.0001	0.0285	0.0099	1.3429	0.1576	0.0269	0.1246	0.0400	0.0028
20	0.0223	0.0241	0.0195	0.0541	0.0139	0.0418	0.0099	0.0007	0.0478	0.0307	0.2715	0.0465	0.0158	0.0447	0.0118	0.0069
21	0.0249	0.0269	0.0218	0.0605	0.0156	0.0467	0.0111	0.0008	0.0535	0.0343	0.3038	0.0520	0.0176	0.0500	0.0132	0.0078
22	0.0174	0.0024	0.0036	0.1190	0.0210	0.0212	0.0313	0.0016	0.2449	0.1531	0.3581	0.0656	0.0153	0.0536	0.0188	0.0029
23	1.0131	0.0004	0.0002	0.3300	0.0143	0.0204	0.0001	0.0000	0.0080	0.0008	0.0017	0.0011	0.0004	0.0011	0.0018	0.0002
24	0.0043	0.0029	0.0055	0.0449	0.0289	0.0315	0.0014	0.0001	0.0270	0.0071	0.0576	0.0232	0.0042	0.0149	0.0096	0.0212
25	0.0135	0.0052	0.0058	0.0047	0.0003	0.0006	0.0000	0.0000	0.0007	0.0009	0.0027	0.0004	0.0001	0.0005	0.0003	0.0023
26	0.0057	0.0011	0.0020	0.0078	0.0013	0.0051	0.0003	0.0001	0.0051	0.0015	0.0050	0.0022	0.0010	0.0026	0.0010	0.0009
27	0.0168	0.0017	0.0023	0.0311	0.0062	0.0190	0.0013	0.0003	0.0176	0.0036	0.0144	0.0086	0.0058	0.0192	0.0060	0.0017
28	0.0221	0.0028	0.0058	0.0482	0.0055	0.0244	0.0068	0.0016	0.0188	0.0190	0.0300	0.0106	0.0037	0.0118	0.0056	0.0053
29	0.0137	0.0034	0.0052	0.0294	0.0055	0.0205	0.0011	0.0003	0.0213	0.0056	0.0200	0.0093	0.0040	0.0109	0.0042	0.0027
30	0.0008	0.0001	0.0001	0.0019	0.0002	0.0035	0.0001	0.0000	0.0009	0.0002	0.0011	0.0006	0.0003	0.0005	0.0003	0.0001
31	0.0017	0.0002	0.0002	0.0027	0.0010	0.0043	0.0000	0.0000	0.0048	0.0002	0.0005	0.0003	0.0003	0.0004	0.0003	0.0002
32	0.0073	0.0010	0.0012	0.0145	0.0028	0.0208	0.0004	0.0001	0.0138	0.0025	0.0049	0.0048	0.0023	0.0057	0.0025	0.0007

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1. Continued on next page.

Table A-7 1996 Ghosh monetary model total coefficients (continued)

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0031	0.0090	0.0030	0.0104	0.0052	0.0036	0.0412
2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0017	0.0007	0.0119	0.0239	0.0094	0.0248	0.0081	0.0096	0.0098
3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0014	0.0017	0.1025	0.0236	0.0099	0.0628	0.0114	0.0118	0.0279
4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0014	0.0073	0.0022	0.0096	0.0054	0.0041	0.0378
5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0096	0.0222	0.0100	0.0210	0.0149	0.0190	0.0243
6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0001	0.0005	0.0006	0.0541	0.2209	0.0287	0.1521	0.0549	0.0331	0.0616
7	0.0000	0.0001	0.0000	0.0001	0.0000	0.0016	0.0001	0.0009	0.0007	0.0416	0.0743	0.8142	0.0693	0.0233	0.0189	0.0271
8	0.0000	0.0000	0.0000	0.0001	0.0000	0.0006	0.0001	0.0013	0.0015	0.0520	0.0479	0.2280	0.0727	0.0192	0.0254	0.0264
9	0.0000	0.0000	0.0000	0.0001	0.0000	0.0005	0.0003	0.0030	0.0036	0.0404	0.0573	0.0364	0.0949	0.0275	0.0782	0.0547
10	0.0000	0.0000	0.0000	0.0001	0.0000	0.0003	0.0003	0.0024	0.0028	0.3255	0.0718	0.0153	0.1654	0.0226	0.0213	0.0411
11	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0009	0.0011	0.0611	0.0320	0.0187	0.0663	0.0143	0.0094	0.0159
12	0.0000	0.0000	0.0000	0.0001	0.0000	0.0003	0.0005	0.0044	0.0052	0.1864	0.0794	0.0746	0.1627	0.0394	0.0278	0.0435
13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0002	0.0002	0.0104	0.0694	0.1652	0.0236	0.0990	0.0054	0.0101
14	0.0000	0.0000	0.0001	0.0002	0.0000	0.0001	0.0001	0.0007	0.0007	0.0690	0.0498	0.0159	0.1113	0.0260	0.0201	0.0423
15	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0119	0.0303	0.0084	0.0159	0.0121	0.0090	0.0110
16	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0004	0.0073	0.0027	0.0309	0.0976	0.0366	0.0898	0.0318	0.0393	0.0388
17	1.0782	0.0000	0.0000	0.0000	0.0000	0.0003	0.0004	0.0073	0.0028	0.0311	0.0985	0.0369	0.0906	0.0321	0.0397	0.0391
18	0.0000	1.0782	0.0000	0.0000	0.0000	0.0003	0.0004	0.0073	0.0028	0.0311	0.0985	0.0369	0.0906	0.0321	0.0397	0.0391
19	0.0000	0.0000	1.0000	0.0000	0.0000	0.0001	0.0001	0.0009	0.0011	0.0611	0.0320	0.0187	0.0663	0.0143	0.0094	0.0159
20	0.0000	0.0000	0.0000	1.0012	0.0000	0.0003	0.0004	0.0073	0.0028	0.0311	0.0985	0.0369	0.0906	0.0321	0.0397	0.0391
21	0.0000	0.0000	0.0000	0.0000	1.0000	0.0004	0.0004	0.0082	0.0031	0.0348	0.1102	0.0413	0.1013	0.0359	0.0444	0.0438
22	0.0000	0.0000	0.0000	0.0000	0.0000	1.0295	0.0001	0.0012	0.0014	0.0732	0.1259	0.0497	0.0675	0.0298	0.0533	0.0291
23	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0001	0.0001	0.0028	0.0081	0.0027	0.0094	0.0047	0.0033	0.0370
24	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0001	1.0006	0.0005	0.0184	0.0420	0.0219	0.0582	0.0135	0.0247	0.0358
25	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0008	0.0009	0.0004	0.0014	0.0003	0.0003	0.0091
26	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0002	0.0002	1.0086	0.0373	0.0142	0.2784	0.0176	0.0094	0.0159
27	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0004	0.0005	0.0280	1.0531	0.0344	0.0492	0.0115	0.0135	0.0240
28	0.0000	0.0000	0.0000	0.0001	0.0000	0.0015	0.0001	0.0005	0.0006	0.0335	0.0904	1.1270	0.0837	0.0283	0.0188	0.0327
29	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0001	0.0008	0.0009	0.0347	0.1586	0.0504	1.2420	0.0405	0.0380	0.0522
30	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0017	0.0057	0.0017	0.0074	1.0248	0.0024	0.0015
31	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0007	0.0032	0.0012	0.0045	0.0020	1.0090	0.0034
32	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0003	0.0003	0.0090	0.0577	0.0236	0.0812	0.0157	0.0151	1.0505

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1.

Table A-8 2001 Leontief hybrid model direct coefficients

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.0849	0.4323	0.0005	0.1228	0.0345	0.0099	0.0072	0.0028	0.0030	0.0000	0.0001	0.0000	0.0000	0.0001	0.0029	0.8808
2	-	0.0000	-	0.0000	0.0000	0.0000	-	-	0.0000	0.0000	0.0000	0.0000	-	-	0.0000	2.6150
3	0.0003	13.2960	0.0609	0.0009	0.0000	0.0001	7.6216	3.0078	0.0008	0.0249	0.0302	0.0011	0.0001	0.0006	0.0029	3.5585
4	0.0309	0.3913	0.0007	0.0900	0.0085	0.0004	2.3974	0.9461	0.0057	0.0001	0.0001	0.0002	0.0003	0.0001	0.0003	4.6349
5	0.0019	0.7520	0.0009	0.0022	0.0919	0.0016	3.4517	1.3622	0.0022	0.0011	0.0016	0.0065	0.0013	0.0006	0.0111	6.4999
6	0.0050	3.8285	0.0047	0.0160	0.0108	0.1591	38.8044	15.3139	0.0123	0.0098	0.0033	0.0130	0.0061	0.0047	0.0868	50.5697
7	0.0000	0.0010	0.0000	0.0000	0.0000	0.0000	0.0694	0.0008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-	0.0012
8	-	-	-	-	-	-	-	-	0.0000	0.0000	0.0000	0.0000	-	-	-	-
9	0.0492	21.2616	0.0273	0.0244	0.0156	0.0414	302.0902	119.2180	0.1817	0.0168	0.0138	0.0221	0.0235	0.0116	0.0337	143.6714
10	0.0017	0.9457	0.0027	0.0064	0.0002	0.0013	0.0696	0.0275	0.0015	0.1244	0.0086	0.0101	0.0032	0.0027	0.0059	164.3191
11	0.0001	5.7322	0.0091	0.0002	0.0013	0.0021	0.2115	0.0835	0.0026	0.0080	0.2248	0.1880	0.0587	0.0506	0.0565	22.3548
12	0.0039	7.9729	0.0159	0.0100	0.0031	0.0065	9.4044	3.7114	0.0036	0.0138	0.0040	0.0875	0.0153	0.0108	0.0201	57.9052
13	0.0014	2.9514	0.0034	0.0001	0.0001	0.0002	2.1248	0.8385	0.0002	0.0009	0.0004	0.0004	0.1701	0.0011	0.0018	7.5979
14	0.0154	45.6054	0.0595	0.0028	0.0022	0.0091	9.7898	3.8635	0.0031	0.0038	0.0051	0.0154	0.0345	0.0836	0.0034	538.5295
15	0.0007	3.6811	0.0044	0.0004	0.0041	0.0004	0.7679	0.3030	0.0021	0.0011	0.0047	0.0045	0.0034	0.0004	0.0078	4.1640
16	0.0000	0.0015	0.0000	0.0000	0.0000	0.0000	0.0038	0.0009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0536
17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
18	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
19	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
20	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
21	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
22	-	-	-	0.0000	0.0000	-	0.0155	0.0021	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
23	0.2938	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	0.0001	0.3997	0.0025	0.0016	0.0006	0.0005	13.3643	5.9830	0.0008	0.0006	0.0011	0.0011	0.0001	0.0001	0.0001	36.0177
25	0.0003	0.8765	0.0011	-	-	0.0000	-	-	-	-	-	-	-	-	-	5.2788
26	0.0029	1.4983	0.0075	0.0001	0.0001	0.0002	0.6095	0.2405	0.0001	0.0002	0.0001	0.0001	0.0001	0.0000	0.0001	19.4332
27	0.0550	36.4541	0.0469	0.0514	0.0531	0.0456	153.6985	60.6561	0.0429	0.0242	0.0141	0.0372	0.0239	0.0301	0.0605	627.7162
28	0.0372	51.0214	0.0375	0.0620	0.0289	0.0431	550.3282	217.1836	0.0279	0.1218	0.0395	0.0299	0.0092	0.0101	0.0224	322.8981
29	0.0617	65.4008	0.0877	0.0552	0.0470	0.0851	173.8284	68.6003	0.0810	0.0452	0.0628	0.0595	0.0437	0.0305	0.0348	1,903.0643
30	0.0010	2.6679	0.0047	0.0015	0.0004	0.0040	25.9214	10.2297	0.0006	0.0007	0.0011	0.0014	0.0013	0.0003	0.0006	8.9627
31	0.0019	15.2630	0.0008	0.0016	0.0037	0.0018	8.3119	3.2802	0.0032	0.0007	0.0006	0.0006	0.0009	0.0005	0.0003	33.9151
32	0.0082	12.2754	0.0108	0.0246	0.0107	0.0162	80.8047	31.8891	0.0137	0.0079	0.0037	0.0125	0.0062	0.0041	0.0058	154.8539

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1. Continued on next page.

Table A-8 2001 Leontief hybrid model direct coefficients (continued)

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	0.9100	0.6658	0.6874	0.7872	0.9982	0.0012	0.0000	0.0001	0.0001	0.0006	0.0010	0.0002	0.0003	0.0008	0.0002	0.0067
2	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0000	0.0000	0.0000
3	3.6763	2.6899	2.7771	3.1804	4.0325	0.7313	0.0001	0.0024	0.0028	0.0050	0.0001	0.0001	0.0002	0.0004	0.0002	0.0009
4	4.7884	3.5036	3.6172	4.1424	5.2524	1.0716	0.0000	0.0012	0.0014	0.0002	0.0102	0.0004	0.0010	0.0024	0.0012	0.0487
5	6.7151	4.9133	5.0726	5.8092	7.3658	0.8871	0.0000	0.0005	0.0005	0.0020	0.0019	0.0012	0.0007	0.0027	0.0039	0.0058
6	52.2444	38.2263	39.4656	45.1964	57.3069	11.0731	0.0002	0.0069	0.0080	0.0497	0.0423	0.0057	0.0150	0.0371	0.0096	0.0194
7	2.1009	-	-	-	-	0.0019	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	-	-	-	-	-	-	-	-	-	0.0000	-	0.0000	-	0.0000	-	-
9	148.4292	108.6030	112.1241	128.4056	162.8121	59.0317	0.0017	0.0575	0.0666	0.0147	0.0047	0.0057	0.0053	0.0120	0.0100	0.0140
10	169.7606	124.2108	128.2380	146.8594	186.2105	0.5317	0.0005	0.0152	0.0176	0.0848	0.0026	0.0002	0.0012	0.0018	0.0006	0.0012
11	23.0951	16.8982	17.4461	19.9795	25.3330	2.5526	0.0001	0.0040	0.0047	0.0166	0.0009	0.0004	0.0011	0.0026	0.0001	0.0005
12	59.8228	43.7713	45.1904	51.7525	65.6197	14.6294	0.0008	0.0258	0.0299	0.0492	0.0033	0.0091	0.0030	0.0044	0.0017	0.0032
13	7.8495	5.7434	5.9296	6.7906	8.6102	0.4082	0.0000	0.0002	0.0003	0.0003	0.0054	0.0217	0.0004	0.0134	0.0002	0.0008
14	556.3635	407.0812	420.2795	481.3082	610.2754	10.2869	0.0005	0.0172	0.0199	0.0560	0.0069	0.0087	0.0103	0.0118	0.0157	0.0217
15	4.3019	3.1476	3.2497	3.7215	4.7187	0.4310	0.0000	0.0003	0.0004	0.0015	0.0015	0.0004	0.0007	0.0062	0.0014	0.0038
16	-	-	-	-	-	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	0.0323	-	-	-	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	-	0.0541	-	-	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	-	-	0.0011	-	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	-	-	-	0.0015	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	-	-	-	-	0.0015	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	-	2.1911	-	-	-	0.0393	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	-	-	-	-	-	-	0.0029	-	-	-	-	-	-	-	-	-
24	3.3907	275.5558	2.1180	4.5725	3.3530	1.7722	0.0000	0.0002	0.0003	0.0004	0.0005	0.0006	0.0004	0.0005	0.0011	0.0040
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0000	0.0002
26	20.0767	14.6898	15.1661	17.3683	22.0222	4.3908	0.0000	0.0005	0.0006	0.0007	0.0007	0.0014	0.0056	0.0087	0.0003	0.0020
27	648.5037	474.4985	489.8826	561.0184	711.3441	71.5128	0.0017	0.0577	0.0668	0.0527	0.0403	0.0466	0.0160	0.0160	0.0227	0.0313
28	333.5912	244.0827	251.9963	288.5886	365.9164	93.3131	0.0005	0.0155	0.0180	0.0214	0.0614	0.1179	0.0200	0.0343	0.0089	0.0164
29	1,966.0861	1,438.5500	1,485.1904	1,700.8547	2,156.6011	802.9796	0.0050	0.1649	0.1910	0.1084	0.2626	0.1234	0.2243	0.1605	0.0680	0.1449
30	9.2595	6.7750	6.9947	8.0104	10.1568	0.4814	0.0001	0.0032	0.0037	0.0012	0.0017	0.0076	0.0017	0.0478	0.0014	0.0007
31	35.0382	25.6368	26.4680	30.3114	38.4334	4.3308	0.0000	0.0012	0.0014	0.0004	0.0008	0.0013	0.0020	0.0032	0.0104	0.0022
32	159.9821	117.0560	120.8512	138.4000	175.4844	12.2826	0.0002	0.0075	0.0087	0.0048	0.0197	0.0091	0.0202	0.0205	0.0100	0.0470

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1.

Table A-9 2001 Leontief hybrid model total coefficients

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.0989	1.4496	0.0018	0.1497	0.0440	0.0142	6.6625	2.4305	0.0062	0.0010	0.0010	0.0015	0.0009	0.0007	0.0058	17.8460
2	0.0000	1.0048	0.0000	0.0000	0.0000	0.0000	0.0132	0.0031	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	2.7826
3	0.0009	15.0051	1.0662	0.0018	0.0004	0.0006	10.5741	3.8509	0.0015	0.0312	0.0425	0.0107	0.0037	0.0033	0.0062	57.3648
4	0.0399	2.6346	0.0034	1.1076	0.0140	0.0040	16.8617	6.1517	0.0103	0.0022	0.0018	0.0028	0.0020	0.0014	0.0030	43.7752
5	0.0033	1.7423	0.0022	0.0041	1.1020	0.0031	8.8596	3.2333	0.0037	0.0023	0.0031	0.0092	0.0027	0.0013	0.0135	22.8706
6	0.0170	13.1554	0.0173	0.0323	0.0226	1.1995	92.5814	33.7525	0.0265	0.0218	0.0134	0.0274	0.0160	0.0111	0.1133	229.8939
7	0.0000	0.0019	0.0000	0.0000	0.0000	0.0000	1.0824	0.0037	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0130
8	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0007	1.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0011
9	0.0734	32.8299	0.0441	0.0488	0.0282	0.0660	425.5934	156.0988	1.2281	0.0314	0.0301	0.0408	0.0410	0.0196	0.0530	352.5689
10	0.0039	2.8220	0.0063	0.0097	0.0014	0.0031	5.7909	1.9781	0.0033	1.1436	0.0146	0.0167	0.0065	0.0048	0.0089	224.7240
11	0.0049	15.6449	0.0251	0.0062	0.0048	0.0083	15.8941	5.6986	0.0074	0.0195	1.2958	0.2703	0.1011	0.0756	0.0817	159.3396
12	0.0082	12.1168	0.0228	0.0159	0.0060	0.0113	27.4946	9.9497	0.0072	0.0213	0.0096	1.1002	0.0228	0.0145	0.0255	141.0504
13	0.0043	6.1743	0.0069	0.0039	0.0021	0.0030	25.2033	9.2196	0.0023	0.0064	0.0034	0.0031	1.2063	0.0025	0.0043	51.7607
14	0.0237	56.6052	0.0770	0.0120	0.0072	0.0176	40.2970	14.1742	0.0091	0.0132	0.0179	0.0263	0.0498	1.0945	0.0099	846.7928
15	0.0014	4.3977	0.0055	0.0013	0.0051	0.0012	4.1099	1.4893	0.0031	0.0021	0.0068	0.0068	0.0051	0.0011	1.0089	24.2146
16	0.0000	0.0018	0.0000	0.0000	0.0000	0.0000	0.0049	0.0012	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0634
17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
19	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
20	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0003	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004
21	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0185	0.0026	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0022
23	0.3238	0.4271	0.0005	0.0441	0.0130	0.0042	1.9630	0.7161	0.0018	0.0003	0.0003	0.0005	0.0003	0.0002	0.0017	5.2581
24	0.0006	0.8402	0.0032	0.0022	0.0009	0.0010	16.5522	6.7593	0.0013	0.0012	0.0020	0.0019	0.0006	0.0004	0.0006	44.6785
25	0.0003	0.9127	0.0012	0.0001	0.0000	0.0000	0.0830	0.0255	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	8.2056
26	0.0043	2.6778	0.0094	0.0018	0.0011	0.0016	6.1675	2.1928	0.0014	0.0016	0.0017	0.0014	0.0010	0.0006	0.0010	48.4697
27	0.0789	53.0639	0.0702	0.0835	0.0732	0.0711	260.1433	94.6757	0.0657	0.0482	0.0370	0.0614	0.0420	0.0413	0.0813	998.6927
28	0.0655	72.6185	0.0650	0.1016	0.0506	0.0741	739.3686	271.0026	0.0531	0.1730	0.0761	0.0663	0.0285	0.0240	0.0493	803.2930
29	0.1487	138.4760	0.1859	0.1589	0.1172	0.1880	584.0382	208.0668	0.1748	0.1368	0.1626	0.1612	0.1118	0.0761	0.1159	3,560.9957
30	0.0024	4.0825	0.0066	0.0035	0.0014	0.0063	38.0332	13.9597	0.0019	0.0030	0.0030	0.0032	0.0025	0.0010	0.0021	35.9275
31	0.0030	16.2713	0.0019	0.0031	0.0048	0.0031	14.0639	5.0876	0.0047	0.0018	0.0020	0.0018	0.0018	0.0010	0.0013	92.1725
32	0.0181	19.9527	0.0210	0.0381	0.0188	0.0285	128.2799	46.8237	0.0246	0.0175	0.0131	0.0231	0.0136	0.0086	0.0149	335.6978

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1. Continued on next page.

Table A-9 2001 Leontief hybrid model total coefficients (continued)

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	28.3743	17.3055	10.1793	11.6654	14.7887	2.7824	0.0000	0.0015	0.0018	0.0023	0.0044	0.0013	0.0015	0.0029	0.0012	0.0165
2	0.0345	0.0109	0.0044	0.0050	0.0063	0.0022	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	38.8464	17.6689	11.6276	13.3297	16.8933	2.0038	0.0001	0.0039	0.0045	0.0096	0.0007	0.0007	0.0006	0.0012	0.0004	0.0015
4	73.2847	45.2574	26.8409	30.7593	38.9947	7.1716	0.0001	0.0041	0.0047	0.0026	0.0145	0.0028	0.0036	0.0055	0.0028	0.0584
5	37.3950	22.0615	13.2903	15.2297	19.3082	3.4456	0.0001	0.0017	0.0019	0.0037	0.0033	0.0024	0.0016	0.0042	0.0047	0.0076
6	395.5550	259.5644	142.3796	163.1628	206.8507	46.6148	0.0006	0.0205	0.0236	0.0714	0.0635	0.0181	0.0272	0.0565	0.0165	0.0345
7	2.3562	0.0139	0.0047	0.0054	0.0069	0.0038	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0023	0.0011	0.0006	0.0007	0.0008	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	1,184.7338	431.0606	190.8256	218.7875	277.2472	92.1584	0.0023	0.0774	0.0894	0.0309	0.0156	0.0180	0.0122	0.0240	0.0156	0.0267
10	230.9218	180.5637	159.7849	183.1008	232.1362	4.9709	0.0006	0.0193	0.0223	0.0993	0.0048	0.0017	0.0031	0.0044	0.0014	0.0033
11	151.1266	126.4849	85.3392	97.8041	123.9827	14.9187	0.0005	0.0160	0.0184	0.0426	0.0060	0.0082	0.0050	0.0101	0.0029	0.0058
12	167.0228	147.5203	78.5354	90.0427	114.1027	25.0639	0.0010	0.0315	0.0364	0.0592	0.0076	0.0141	0.0060	0.0088	0.0033	0.0071
13	89.6492	41.1795	25.5649	29.2934	37.1406	6.2141	0.0001	0.0022	0.0025	0.0029	0.0097	0.0311	0.0019	0.0190	0.0011	0.0026
14	783.8365	602.4727	509.5961	583.8800	740.3334	31.7758	0.0008	0.0262	0.0298	0.0689	0.0162	0.0170	0.0174	0.0210	0.0201	0.0305
15	21.0528	14.6020	8.8768	10.1724	12.8962	2.2288	0.0000	0.0012	0.0014	0.0026	0.0023	0.0011	0.0012	0.0072	0.0017	0.0045
16	0.0125	0.0036	0.0013	0.0015	0.0019	0.0008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	1.0333	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	0.0002	1.0573	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	0.0001	0.0000	1.0011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.0007	0.0002	0.0001	1.0015	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	0.0000	0.0000	0.0000	0.0000	1.0016	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	0.0418	2.4134	0.0012	0.0014	0.0018	1.0412	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	8.3601	5.0988	2.9992	3.4370	4.3573	0.8198	1.0029	0.0005	0.0005	0.0007	0.0013	0.0004	0.0005	0.0009	0.0004	0.0049
24	43.7297	301.4852	5.2611	8.1791	7.9214	2.9083	0.0000	1.0007	0.0008	0.0010	0.0010	0.0011	0.0007	0.0009	0.0013	0.0046
25	0.2860	0.1328	0.0774	0.0887	0.1124	0.0206	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003
26	54.7789	58.7969	30.2888	34.7057	44.0034	11.7179	0.0001	0.0023	0.0026	1.0022	0.0033	0.0032	0.0076	0.0108	0.0011	0.0037
27	1,422.0799	938.5392	627.3769	718.9256	911.4561	118.5235	0.0023	0.0768	0.0883	0.0762	1.0614	0.0673	0.0288	0.0337	0.0306	0.0505
28	2,211.3633	831.9153	443.6471	508.3545	644.5286	158.2360	0.0012	0.0399	0.0456	0.0596	0.0912	1.1555	0.0365	0.0572	0.0181	0.0386
29	4,466.9690	5,206.6499	2,341.0245	2,682.6029	3,401.0471	1,179.8744	0.0082	0.2721	0.3129	0.2107	0.3968	0.2259	1.3198	0.2618	0.1123	0.2400
30	107.2294	30.6502	18.0462	20.6847	26.2183	4.6897	0.0001	0.0046	0.0053	0.0029	0.0038	0.0103	0.0029	1.0516	0.0021	0.0020
31	78.1089	54.7397	34.8170	39.8938	50.5819	7.9456	0.0001	0.0025	0.0028	0.0015	0.0022	0.0024	0.0030	0.0044	1.0110	0.0033
32	561.0076	323.7859	206.7469	236.9015	300.3609	46.1575	0.0006	0.0186	0.0213	0.0160	0.0336	0.0198	0.0301	0.0316	0.0148	1.0591

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1.

Table A-10 2001 Leontief monetary model direct coefficients

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.0849	0.0003	0.0005	0.1228	0.0345	0.0099	0.0000	0.0000	0.0030	0.0000	0.0001	0.0000	0.0000	0.0001	0.0029	0.0001
2	-	0.0000	-	0.0003	0.0001	0.0002	-	-	0.0002	0.0021	0.0151	0.0001	-	-	0.0000	0.2522
3	0.0003	0.0080	0.0609	0.0009	0.0000	0.0001	0.0004	0.0004	0.0008	0.0249	0.0302	0.0011	0.0001	0.0006	0.0029	0.0002
4	0.0309	0.0002	0.0007	0.0900	0.0085	0.0004	0.0001	0.0001	0.0057	0.0001	0.0001	0.0002	0.0003	0.0001	0.0003	0.0003
5	0.0019	0.0005	0.0009	0.0022	0.0919	0.0016	0.0002	0.0002	0.0022	0.0011	0.0016	0.0065	0.0013	0.0006	0.0111	0.0004
6	0.0050	0.0023	0.0047	0.0160	0.0108	0.1591	0.0020	0.0020	0.0123	0.0098	0.0033	0.0130	0.0061	0.0047	0.0868	0.0029
7	0.0331	0.0118	0.0307	0.0002	0.0001	0.0001	0.0694	0.0020	0.0055	0.0028	0.0011	0.0002	0.0000	0.0002	-	0.0013
8	-	-	-	-	-	-	0.0179	-	0.0083	0.0000	0.0241	0.0000	-	-	-	-
9	0.0492	0.0128	0.0273	0.0244	0.0156	0.0414	0.0154	0.0154	0.1817	0.0168	0.0138	0.0221	0.0235	0.0116	0.0337	0.0083
10	0.0017	0.0006	0.0027	0.0064	0.0002	0.0013	0.0000	0.0000	0.0015	0.1244	0.0086	0.0101	0.0032	0.0027	0.0059	0.0095
11	0.0001	0.0034	0.0091	0.0002	0.0013	0.0021	0.0000	0.0000	0.0026	0.0080	0.2248	0.1880	0.0587	0.0506	0.0565	0.0013
12	0.0039	0.0048	0.0159	0.0100	0.0031	0.0065	0.0005	0.0005	0.0036	0.0138	0.0040	0.0875	0.0153	0.0108	0.0201	0.0033
13	0.0014	0.0018	0.0034	0.0001	0.0001	0.0002	0.0001	0.0001	0.0002	0.0009	0.0004	0.0004	0.1701	0.0011	0.0018	0.0004
14	0.0154	0.0274	0.0595	0.0028	0.0022	0.0091	0.0005	0.0005	0.0031	0.0038	0.0051	0.0154	0.0345	0.0836	0.0034	0.0311
15	0.0007	0.0022	0.0044	0.0004	0.0041	0.0004	0.0000	0.0000	0.0021	0.0011	0.0047	0.0045	0.0034	0.0004	0.0078	0.0002
16	0.0039	0.0157	0.0386	0.0056	0.0027	0.0058	0.0034	0.0020	0.0042	0.0170	0.0528	0.0090	0.0028	0.0016	0.0002	0.0536
17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
18	0.0001	0.0002	0.0005	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0002	0.0008	0.0001	0.0000	0.0000	0.0000	-
19	0.0000	0.0002	0.0004	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0002	0.0017	0.0001	0.0000	0.0000	0.0000	-
20	0.0003	0.0010	0.0025	0.0004	0.0002	0.0004	0.0002	0.0001	0.0003	0.0011	0.0035	0.0006	0.0002	0.0001	0.0000	-
21	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0000	0.0000	0.0000	0.0000	-
22	-	-	-	0.0011	0.0007	-	0.0026	0.0009	0.0045	0.0085	0.0044	0.0009	0.0001	0.0001	0.0002	-
23	0.0054	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	0.0001	0.0003	0.0029	0.0018	0.0007	0.0006	0.0008	0.0009	0.0009	0.0007	0.0012	0.0012	0.0002	0.0001	0.0001	0.0024
25	0.0004	0.0007	0.0016	-	-	0.0000	-	-	-	-	-	-	-	-	-	0.0004
26	0.0029	0.0009	0.0075	0.0001	0.0001	0.0002	0.0000	0.0000	0.0001	0.0002	0.0001	0.0001	0.0001	0.0000	0.0001	0.0011
27	0.0550	0.0219	0.0469	0.0514	0.0531	0.0456	0.0079	0.0079	0.0429	0.0242	0.0141	0.0372	0.0239	0.0301	0.0605	0.0363
28	0.0372	0.0306	0.0375	0.0620	0.0289	0.0431	0.0281	0.0281	0.0279	0.1218	0.0395	0.0299	0.0092	0.0101	0.0224	0.0187
29	0.0617	0.0392	0.0877	0.0552	0.0470	0.0851	0.0089	0.0089	0.0810	0.0452	0.0628	0.0595	0.0437	0.0305	0.0348	0.1101
30	0.0010	0.0016	0.0047	0.0015	0.0004	0.0040	0.0013	0.0013	0.0006	0.0007	0.0011	0.0014	0.0013	0.0003	0.0006	0.0005
31	0.0019	0.0092	0.0008	0.0016	0.0037	0.0018	0.0004	0.0004	0.0032	0.0007	0.0006	0.0006	0.0009	0.0005	0.0003	0.0020
32	0.0082	0.0074	0.0108	0.0246	0.0107	0.0162	0.0041	0.0041	0.0137	0.0079	0.0037	0.0125	0.0062	0.0041	0.0058	0.0090

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1. Continued on next page.

Table A-10 2001 Leontief monetary model direct coefficients (continued)

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0001	0.0001	0.0006	0.0010	0.0002	0.0003	0.0008	0.0002	0.0067
2	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0000	0.0000	0.0000
3	0.0000	0.0002	0.0002	0.0002	0.0002	0.0002	0.0040	0.0022	0.0020	0.0050	0.0001	0.0001	0.0002	0.0004	0.0002	0.0009
4	0.0001	0.0002	0.0002	0.0002	0.0002	0.0003	0.0020	0.0011	0.0010	0.0002	0.0102	0.0004	0.0010	0.0024	0.0012	0.0487
5	0.0001	0.0003	0.0003	0.0003	0.0003	0.0003	0.0008	0.0004	0.0004	0.0020	0.0019	0.0012	0.0007	0.0027	0.0039	0.0058
6	0.0006	0.0025	0.0023	0.0024	0.0024	0.0034	0.0115	0.0061	0.0058	0.0497	0.0423	0.0057	0.0150	0.0371	0.0096	0.0194
7	0.4934	-	-	-	-	0.0115	0.0026	0.0020	0.0011	0.0033	0.0003	0.1873	0.0000	0.0013	0.0009	0.0001
8	-	-	-	-	-	-	-	-	-	0.0017	-	0.0016	-	0.0025	-	-
9	0.0018	0.0071	0.0065	0.0068	0.0068	0.0179	0.0953	0.0508	0.0478	0.0147	0.0047	0.0057	0.0053	0.0120	0.0100	0.0140
10	0.0020	0.0081	0.0074	0.0077	0.0077	0.0002	0.0251	0.0134	0.0126	0.0848	0.0026	0.0002	0.0012	0.0018	0.0006	0.0012
11	0.0003	0.0011	0.0010	0.0011	0.0011	0.0008	0.0067	0.0036	0.0033	0.0166	0.0009	0.0004	0.0011	0.0026	0.0001	0.0005
12	0.0007	0.0029	0.0026	0.0027	0.0027	0.0044	0.0428	0.0228	0.0214	0.0492	0.0033	0.0091	0.0030	0.0044	0.0017	0.0032
13	0.0001	0.0004	0.0003	0.0004	0.0004	0.0001	0.0004	0.0002	0.0002	0.0003	0.0054	0.0217	0.0004	0.0134	0.0002	0.0008
14	0.0067	0.0266	0.0243	0.0254	0.0254	0.0031	0.0285	0.0152	0.0143	0.0560	0.0069	0.0087	0.0103	0.0118	0.0157	0.0217
15	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0005	0.0003	0.0003	0.0015	0.0015	0.0004	0.0007	0.0062	0.0014	0.0038
16	-	-	-	-	-	0.0022	0.0239	0.0187	0.0101	0.0001	0.0059	0.0020	0.0016	0.0062	0.0042	0.0030
17	0.0323	-	-	-	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	-	0.0541	-	-	-	0.0000	0.0003	0.0003	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000
19	-	-	0.0011	-	-	0.0000	0.0003	0.0002	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000
20	-	-	-	0.0015	-	0.0001	0.0016	0.0012	0.0007	0.0000	0.0004	0.0001	0.0001	0.0004	0.0003	0.0002
21	-	-	-	-	0.0015	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	-	0.4724	-	-	-	0.0393	0.0001	0.0001	0.0003	0.0000	0.0008	0.0003	0.0000	0.0004	0.0004	0.0000
23	-	-	-	-	-	-	0.0029	-	-	-	-	-	-	-	-	-
24	0.0000	0.0204	0.0001	0.0003	0.0002	0.0006	0.0005	0.0002	0.0002	0.0005	0.0006	0.0006	0.0004	0.0005	0.0012	0.0046
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0000	0.0003
26	0.0002	0.0010	0.0009	0.0009	0.0009	0.0013	0.0008	0.0004	0.0004	0.0007	0.0007	0.0014	0.0056	0.0087	0.0003	0.0020
27	0.0078	0.0310	0.0283	0.0296	0.0296	0.0217	0.0956	0.0510	0.0479	0.0527	0.0403	0.0466	0.0160	0.0160	0.0227	0.0313
28	0.0040	0.0159	0.0146	0.0152	0.0152	0.0283	0.0258	0.0137	0.0129	0.0214	0.0614	0.1179	0.0200	0.0343	0.0089	0.0164
29	0.0236	0.0940	0.0859	0.0898	0.0898	0.2433	0.2731	0.1457	0.1370	0.1084	0.2626	0.1234	0.2243	0.1605	0.0680	0.1449
30	0.0001	0.0004	0.0004	0.0004	0.0004	0.0001	0.0052	0.0028	0.0026	0.0012	0.0017	0.0076	0.0017	0.0478	0.0014	0.0007
31	0.0004	0.0017	0.0015	0.0016	0.0016	0.0013	0.0021	0.0011	0.0010	0.0004	0.0008	0.0013	0.0020	0.0032	0.0104	0.0022
32	0.0019	0.0076	0.0070	0.0073	0.0073	0.0037	0.0125	0.0067	0.0063	0.0048	0.0197	0.0091	0.0202	0.0205	0.0100	0.0470

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1.

Table A-11 2001 Leontief monetary model total coefficients

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.0989	0.0009	0.0018	0.1497	0.0440	0.0142	0.0003	0.0003	0.0062	0.0010	0.0010	0.0015	0.0009	0.0007	0.0058	0.0010
2	0.0019	1.0048	0.0123	0.0029	0.0014	0.0028	0.0011	0.0007	0.0023	0.0090	0.0388	0.0112	0.0043	0.0030	0.0032	0.2683
3	0.0009	0.0090	1.0662	0.0018	0.0004	0.0006	0.0006	0.0005	0.0015	0.0312	0.0425	0.0107	0.0037	0.0033	0.0062	0.0033
4	0.0399	0.0016	0.0034	1.1076	0.0140	0.0040	0.0009	0.0008	0.0103	0.0022	0.0018	0.0028	0.0020	0.0014	0.0030	0.0025
5	0.0033	0.0010	0.0022	0.0041	1.1020	0.0031	0.0005	0.0004	0.0037	0.0023	0.0031	0.0092	0.0027	0.0013	0.0135	0.0013
6	0.0170	0.0079	0.0173	0.0323	0.0226	1.1995	0.0048	0.0044	0.0265	0.0218	0.0134	0.0274	0.0160	0.0111	0.1133	0.0133
7	0.0529	0.0220	0.0490	0.0266	0.0122	0.0161	1.0826	0.0094	0.0184	0.0399	0.0194	0.0149	0.0065	0.0055	0.0109	0.0147
8	0.0018	0.0009	0.0020	0.0012	0.0007	0.0012	0.0196	1.0004	0.0108	0.0018	0.0320	0.0073	0.0029	0.0021	0.0027	0.0007
9	0.0734	0.0197	0.0441	0.0488	0.0282	0.0660	0.0221	0.0202	1.2282	0.0314	0.0302	0.0409	0.0410	0.0196	0.0531	0.0204
10	0.0039	0.0017	0.0063	0.0097	0.0014	0.0031	0.0003	0.0003	0.0033	1.1436	0.0146	0.0167	0.0065	0.0048	0.0089	0.0130
11	0.0049	0.0094	0.0251	0.0062	0.0048	0.0083	0.0008	0.0007	0.0074	0.0195	1.2958	0.2703	0.1011	0.0756	0.0817	0.0092
12	0.0082	0.0073	0.0228	0.0159	0.0060	0.0113	0.0014	0.0013	0.0072	0.0213	0.0096	1.1002	0.0228	0.0145	0.0255	0.0082
13	0.0043	0.0037	0.0069	0.0039	0.0021	0.0030	0.0013	0.0012	0.0023	0.0064	0.0034	0.0031	1.2063	0.0025	0.0043	0.0030
14	0.0237	0.0340	0.0770	0.0120	0.0072	0.0176	0.0021	0.0018	0.0091	0.0132	0.0179	0.0263	0.0498	1.0945	0.0099	0.0490
15	0.0014	0.0026	0.0055	0.0013	0.0051	0.0012	0.0002	0.0002	0.0031	0.0021	0.0068	0.0068	0.0051	0.0011	1.0089	0.0014
16	0.0071	0.0185	0.0472	0.0098	0.0050	0.0097	0.0044	0.0026	0.0074	0.0248	0.0762	0.0279	0.0108	0.0072	0.0075	1.0634
17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	0.0001	0.0003	0.0007	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0004	0.0011	0.0004	0.0002	0.0001	0.0001	0.0001
19	0.0001	0.0002	0.0005	0.0001	0.0001	0.0001	0.0000	0.0000	0.0001	0.0003	0.0022	0.0006	0.0002	0.0002	0.0002	0.0001
20	0.0004	0.0012	0.0030	0.0006	0.0003	0.0006	0.0003	0.0002	0.0005	0.0016	0.0048	0.0017	0.0007	0.0005	0.0005	0.0004
21	0.0000	0.0001	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0003	0.0001	0.0000	0.0000	0.0000	0.0000
22	0.0007	0.0004	0.0010	0.0019	0.0011	0.0006	0.0031	0.0011	0.0061	0.0108	0.0069	0.0029	0.0011	0.0007	0.0011	0.0004
23	0.0059	0.0000	0.0000	0.0008	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24	0.0006	0.0006	0.0036	0.0025	0.0011	0.0012	0.0010	0.0010	0.0015	0.0013	0.0022	0.0022	0.0006	0.0004	0.0006	0.0029
25	0.0004	0.0008	0.0017	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0007
26	0.0043	0.0016	0.0094	0.0018	0.0011	0.0016	0.0003	0.0003	0.0014	0.0016	0.0017	0.0014	0.0010	0.0006	0.0010	0.0028
27	0.0789	0.0318	0.0702	0.0835	0.0732	0.0711	0.0135	0.0123	0.0657	0.0482	0.0370	0.0614	0.0420	0.0413	0.0813	0.0578
28	0.0655	0.0436	0.0651	0.1016	0.0506	0.0741	0.0385	0.0351	0.0531	0.1730	0.0761	0.0663	0.0285	0.0240	0.0493	0.0465
29	0.1487	0.0831	0.1860	0.1589	0.1172	0.1880	0.0304	0.0270	0.1748	0.1368	0.1626	0.1612	0.1118	0.0761	0.1159	0.2060
30	0.0024	0.0024	0.0066	0.0035	0.0014	0.0063	0.0020	0.0018	0.0019	0.0030	0.0030	0.0032	0.0025	0.0010	0.0021	0.0021
31	0.0030	0.0098	0.0019	0.0031	0.0048	0.0031	0.0007	0.0007	0.0047	0.0018	0.0020	0.0018	0.0018	0.0010	0.0013	0.0053
32	0.0181	0.0120	0.0210	0.0381	0.0188	0.0285	0.0067	0.0061	0.0246	0.0175	0.0131	0.0231	0.0136	0.0086	0.0149	0.0194

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1. Continued on next page.

Table A-11 2001 Leontief monetary model total coefficients (continued)

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	0.0003	0.0011	0.0006	0.0006	0.0006	0.0008	0.0026	0.0014	0.0013	0.0023	0.0044	0.0013	0.0015	0.0029	0.0012	0.0165
2	0.0007	0.0012	0.0004	0.0004	0.0004	0.0011	0.0084	0.0060	0.0037	0.0027	0.0024	0.0015	0.0009	0.0025	0.0015	0.0016
3	0.0005	0.0012	0.0007	0.0007	0.0007	0.0006	0.0065	0.0035	0.0032	0.0096	0.0007	0.0007	0.0006	0.0012	0.0004	0.0015
4	0.0009	0.0030	0.0016	0.0016	0.0016	0.0022	0.0068	0.0036	0.0034	0.0026	0.0145	0.0028	0.0036	0.0055	0.0028	0.0584
5	0.0005	0.0014	0.0008	0.0008	0.0008	0.0010	0.0028	0.0015	0.0014	0.0037	0.0033	0.0024	0.0016	0.0042	0.0047	0.0076
6	0.0048	0.0170	0.0082	0.0086	0.0086	0.0141	0.0339	0.0181	0.0169	0.0714	0.0635	0.0181	0.0272	0.0565	0.0165	0.0345
7	0.5535	0.0178	0.0054	0.0056	0.0056	0.0228	0.0175	0.0101	0.0085	0.0166	0.0191	0.2329	0.0076	0.0134	0.0049	0.0088
8	0.0101	0.0009	0.0004	0.0004	0.0004	0.0008	0.0021	0.0012	0.0011	0.0034	0.0008	0.0064	0.0004	0.0034	0.0003	0.0006
9	0.0144	0.0282	0.0110	0.0115	0.0115	0.0279	0.1282	0.0683	0.0641	0.0309	0.0156	0.0181	0.0122	0.0240	0.0156	0.0267
10	0.0028	0.0118	0.0092	0.0097	0.0097	0.0015	0.0320	0.0171	0.0160	0.0993	0.0048	0.0017	0.0031	0.0044	0.0014	0.0033
11	0.0018	0.0083	0.0049	0.0052	0.0052	0.0045	0.0265	0.0141	0.0132	0.0426	0.0060	0.0082	0.0050	0.0101	0.0029	0.0058
12	0.0020	0.0096	0.0045	0.0048	0.0047	0.0076	0.0523	0.0279	0.0261	0.0592	0.0076	0.0141	0.0060	0.0088	0.0033	0.0071
13	0.0011	0.0027	0.0015	0.0015	0.0015	0.0019	0.0036	0.0019	0.0018	0.0029	0.0097	0.0311	0.0019	0.0190	0.0011	0.0026
14	0.0094	0.0394	0.0295	0.0308	0.0308	0.0096	0.0429	0.0231	0.0214	0.0689	0.0162	0.0170	0.0174	0.0210	0.0201	0.0305
15	0.0003	0.0010	0.0005	0.0005	0.0005	0.0007	0.0020	0.0011	0.0010	0.0026	0.0023	0.0011	0.0012	0.0072	0.0017	0.0045
16	0.0026	0.0041	0.0013	0.0013	0.0013	0.0042	0.0311	0.0229	0.0136	0.0071	0.0089	0.0053	0.0033	0.0092	0.0055	0.0057
17	1.0333	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	0.0000	1.0573	0.0000	0.0000	0.0000	0.0001	0.0004	0.0003	0.0002	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001
19	0.0000	0.0001	1.0011	0.0000	0.0000	0.0000	0.0004	0.0003	0.0002	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001
20	0.0002	0.0003	0.0001	1.0015	0.0001	0.0003	0.0019	0.0014	0.0009	0.0004	0.0006	0.0003	0.0002	0.0006	0.0003	0.0004
21	0.0000	0.0000	0.0000	0.0000	1.0016	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	0.0017	0.5203	0.0002	0.0002	0.0002	1.0412	0.0016	0.0009	0.0010	0.0015	0.0012	0.0012	0.0002	0.0009	0.0007	0.0004
23	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0029	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
24	0.0006	0.0223	0.0003	0.0005	0.0004	0.0010	0.0014	1.0007	0.0006	0.0011	0.0012	0.0012	0.0008	0.0010	0.0014	0.0052
25	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004
26	0.0007	0.0038	0.0018	0.0018	0.0018	0.0036	0.0038	0.0020	0.0019	1.0022	0.0033	0.0032	0.0076	0.0108	0.0011	0.0037
27	0.0172	0.0613	0.0363	0.0379	0.0379	0.0359	0.1268	0.0678	0.0633	0.0762	1.0614	0.0673	0.0288	0.0337	0.0306	0.0505
28	0.0269	0.0544	0.0257	0.0268	0.0268	0.0480	0.0656	0.0352	0.0327	0.0596	0.0912	1.1556	0.0365	0.0572	0.0181	0.0386
29	0.0539	0.3401	0.1354	0.1416	0.1415	0.3575	0.4495	0.2404	0.2244	0.2107	0.3968	0.2260	1.3198	0.2618	0.1123	0.2400
30	0.0013	0.0020	0.0010	0.0011	0.0011	0.0014	0.0076	0.0041	0.0038	0.0029	0.0038	0.0103	0.0029	1.0516	0.0021	0.0020
31	0.0009	0.0036	0.0020	0.0021	0.0021	0.0024	0.0041	0.0022	0.0020	0.0015	0.0022	0.0024	0.0030	0.0044	1.0110	0.0033
32	0.0068	0.0212	0.0120	0.0125	0.0125	0.0140	0.0306	0.0164	0.0153	0.0160	0.0336	0.0199	0.0301	0.0316	0.0148	1.0591

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1.

Table A-12 2001 Ghosh monetary model direct coefficients

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.0849	0.0001	0.0001	0.2765	0.0186	0.0149	0.0000	0.0000	0.0050	0.0000	0.0001	0.0000	0.0000	0.0003	0.0011	0.0000
2	-	0.0000	-	0.0013	0.0001	0.0005	-	-	0.0007	0.0021	0.0450	0.0001	-	-	0.0000	0.1982
3	0.0013	0.0167	0.0609	0.0081	0.0001	0.0003	0.0013	0.0001	0.0054	0.0528	0.1893	0.0023	0.0003	0.0051	0.0043	0.0003
4	0.0137	0.0001	0.0001	0.0900	0.0020	0.0002	0.0000	0.0000	0.0042	0.0000	0.0001	0.0000	0.0001	0.0001	0.0001	0.0000
5	0.0036	0.0004	0.0004	0.0093	0.0919	0.0046	0.0003	0.0000	0.0069	0.0010	0.0045	0.0061	0.0018	0.0025	0.0073	0.0003
6	0.0033	0.0008	0.0008	0.0238	0.0038	0.1591	0.0011	0.0001	0.0136	0.0034	0.0033	0.0044	0.0030	0.0067	0.0206	0.0008
7	0.0410	0.0074	0.0093	0.0007	0.0001	0.0002	0.0694	0.0002	0.0114	0.0018	0.0021	0.0001	0.0000	0.0004	-	0.0007
8	-	-	-	-	-	-	0.1897	-	0.1825	0.0001	0.4846	0.0001	-	-	-	-
9	0.0295	0.0039	0.0040	0.0328	0.0050	0.0374	0.0075	0.0007	0.1817	0.0052	0.0126	0.0067	0.0104	0.0152	0.0072	0.0020
10	0.0032	0.0006	0.0013	0.0278	0.0002	0.0039	0.0000	0.0000	0.0050	0.1244	0.0253	0.0100	0.0046	0.0115	0.0041	0.0074
11	0.0000	0.0012	0.0015	0.0003	0.0005	0.0021	0.0000	0.0000	0.0028	0.0027	0.2248	0.0625	0.0283	0.0720	0.0132	0.0003
12	0.0077	0.0048	0.0076	0.0444	0.0032	0.0195	0.0008	0.0001	0.0119	0.0140	0.0121	0.0875	0.0221	0.0464	0.0141	0.0026
13	0.0019	0.0012	0.0011	0.0004	0.0000	0.0004	0.0001	0.0000	0.0004	0.0006	0.0008	0.0002	0.1701	0.0034	0.0009	0.0002
14	0.0071	0.0064	0.0067	0.0029	0.0005	0.0063	0.0002	0.0000	0.0024	0.0009	0.0036	0.0036	0.0117	0.0836	0.0006	0.0058
15	0.0019	0.0032	0.0030	0.0028	0.0062	0.0019	0.0001	0.0000	0.0099	0.0017	0.0200	0.0064	0.0070	0.0026	0.0078	0.0003
16	0.0098	0.0200	0.0234	0.0314	0.0036	0.0220	0.0068	0.0004	0.0174	0.0219	0.2006	0.0114	0.0052	0.0089	0.0002	0.0536
17	0.0101	0.0207	0.0242	0.0324	0.0038	0.0227	0.0070	0.0004	0.0180	0.0227	0.2073	0.0117	0.0054	0.0092	0.0002	-
18	0.0099	0.0202	0.0236	0.0317	0.0037	0.0222	0.0068	0.0004	0.0176	0.0221	0.2026	0.0115	0.0053	0.0090	0.0002	-
19	0.0077	0.0156	0.0183	0.0245	0.0028	0.0171	0.0053	0.0003	0.0136	0.0171	0.4436	0.0089	0.0041	0.0070	0.0001	-
20	0.0105	0.0214	0.0250	0.0335	0.0039	0.0235	0.0072	0.0004	0.0186	0.0234	0.2143	0.0121	0.0056	0.0095	0.0002	-
21	0.0111	0.0227	0.0265	0.0356	0.0041	0.0249	0.0077	0.0004	0.0198	0.0249	0.2274	0.0129	0.0059	0.0101	0.0002	-
22	-	-	-	0.0594	0.0085	-	0.0510	0.0017	0.1826	0.1058	0.1628	0.0110	0.0025	0.0058	0.0019	-
23	0.8584	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	0.0012	0.0011	0.0056	0.0323	0.0029	0.0074	0.0050	0.0005	0.0121	0.0027	0.0150	0.0051	0.0010	0.0023	0.0003	0.0076
25	0.0031	0.0032	0.0033	-	-	0.0000	-	-	-	-	-	-	-	-	-	0.0014
26	0.0016	0.0002	0.0010	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0002
27	0.0114	0.0023	0.0024	0.0240	0.0059	0.0142	0.0013	0.0001	0.0149	0.0026	0.0045	0.0039	0.0036	0.0136	0.0045	0.0030
28	0.0136	0.0057	0.0033	0.0512	0.0057	0.0238	0.0083	0.0008	0.0171	0.0231	0.0221	0.0056	0.0025	0.0081	0.0029	0.0028
29	0.0052	0.0017	0.0018	0.0105	0.0021	0.0108	0.0006	0.0001	0.0114	0.0020	0.0081	0.0025	0.0027	0.0056	0.0010	0.0037
30	0.0008	0.0006	0.0009	0.0027	0.0002	0.0048	0.0008	0.0001	0.0008	0.0003	0.0013	0.0005	0.0007	0.0005	0.0002	0.0002
31	0.0007	0.0017	0.0001	0.0013	0.0007	0.0010	0.0001	0.0000	0.0019	0.0001	0.0003	0.0001	0.0002	0.0004	0.0000	0.0003
32	0.0027	0.0012	0.0009	0.0180	0.0019	0.0079	0.0011	0.0001	0.0074	0.0013	0.0019	0.0021	0.0015	0.0029	0.0007	0.0012

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1. Continued on next page.

Table A-12 2001 Ghosh monetary model direct coefficients (continued)

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0010	0.0048	0.0006	0.0032	0.0010	0.0007	0.0208
2	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0000	0.0001	0.0000
3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0011	0.0010	0.0375	0.0023	0.0013	0.0085	0.0022	0.0018	0.0114
4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0219	0.0005	0.0052	0.0014	0.0015	0.0667
5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0070	0.0174	0.0063	0.0163	0.0065	0.0200	0.0332
6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0005	0.0005	0.0606	0.1352	0.0104	0.1179	0.0314	0.0177	0.0397
7	0.0000	-	-	-	-	0.0006	0.0000	0.0003	0.0002	0.0075	0.0018	0.6323	0.0004	0.0021	0.0031	0.0002
8	-	-	-	-	-	-	-	-	-	0.0421	-	0.0587	-	0.0421	-	-
9	0.0000	0.0000	0.0000	0.0001	0.0000	0.0004	0.0004	0.0038	0.0034	0.0162	0.0136	0.0093	0.0376	0.0092	0.0167	0.0258
10	0.0000	0.0001	0.0001	0.0004	0.0000	0.0000	0.0003	0.0032	0.0029	0.3019	0.0246	0.0009	0.0282	0.0044	0.0033	0.0072
11	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0003	0.0200	0.0027	0.0007	0.0083	0.0022	0.0003	0.0011
12	0.0000	0.0000	0.0000	0.0001	0.0000	0.0004	0.0005	0.0056	0.0050	0.1781	0.0309	0.0489	0.0693	0.0110	0.0094	0.0194
13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0007	0.0357	0.0804	0.0058	0.0233	0.0008	0.0033
14	0.0000	0.0001	0.0001	0.0003	0.0000	0.0001	0.0001	0.0009	0.0008	0.0474	0.0153	0.0109	0.0562	0.0069	0.0201	0.0308
15	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0075	0.0200	0.0029	0.0229	0.0220	0.0105	0.0325
16	-	-	-	-	-	0.0002	0.0004	0.0058	0.0030	0.0005	0.0714	0.0135	0.0463	0.0196	0.0292	0.0232
17	0.0323	-	-	-	-	0.0002	0.0004	0.0060	0.0031	0.0005	0.0737	0.0139	0.0479	0.0202	0.0302	0.0240
18	-	0.0541	-	-	-	0.0002	0.0004	0.0058	0.0030	0.0005	0.0720	0.0136	0.0468	0.0198	0.0295	0.0234
19	-	-	0.0011	-	-	0.0002	0.0003	0.0045	0.0023	0.0004	0.0557	0.0105	0.0362	0.0153	0.0228	0.0181
20	-	-	-	0.0015	-	0.0002	0.0004	0.0062	0.0032	0.0005	0.0762	0.0144	0.0495	0.0209	0.0312	0.0248
21	-	-	-	-	0.0015	0.0003	0.0004	0.0066	0.0034	0.0006	0.0809	0.0153	0.0525	0.0222	0.0331	0.0263
22	-	0.0644	-	-	-	0.0393	0.0000	0.0003	0.0008	0.0013	0.0923	0.0177	0.0009	0.0135	0.0300	0.0028
23	-	-	-	-	-	-	0.0029	-	-	-	-	-	-	-	-	-
24	0.0000	0.0009	0.0000	0.0001	0.0000	0.0002	0.0000	0.0002	0.0002	0.0072	0.0231	0.0140	0.0417	0.0055	0.0271	0.1133
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0001	0.0089
26	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0007	0.0019	0.0021	0.0362	0.0060	0.0005	0.0034
27	0.0000	0.0000	0.0000	0.0002	0.0000	0.0002	0.0001	0.0013	0.0012	0.0201	0.0403	0.0263	0.0393	0.0042	0.0131	0.0200
28	0.0000	0.0000	0.0000	0.0001	0.0000	0.0004	0.0001	0.0006	0.0006	0.0144	0.1087	0.1179	0.0873	0.0161	0.0091	0.0186
29	0.0000	0.0000	0.0000	0.0002	0.0000	0.0009	0.0001	0.0015	0.0014	0.0168	0.1067	0.0283	0.2243	0.0172	0.0160	0.0376
30	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0002	0.0018	0.0066	0.0162	0.0161	0.0478	0.0032	0.0017
31	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0014	0.0013	0.0086	0.0015	0.0104	0.0024
32	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0003	0.0002	0.0029	0.0308	0.0081	0.0778	0.0085	0.0090	0.0470

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1.

Table A-13 2001 Ghosh monetary model total coefficients

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.0989	0.0004	0.0004	0.3372	0.0237	0.0215	0.0003	0.0000	0.0103	0.0005	0.0015	0.0008	0.0007	0.0016	0.0021	0.0004
2	0.0037	1.0048	0.0059	0.0129	0.0015	0.0083	0.0018	0.0001	0.0074	0.0091	0.1159	0.0112	0.0062	0.0127	0.0022	0.2109
3	0.0038	0.0189	1.0662	0.0163	0.0009	0.0040	0.0018	0.0002	0.0104	0.0662	0.2669	0.0224	0.0113	0.0297	0.0091	0.0055
4	0.0177	0.0004	0.0004	1.1076	0.0033	0.0027	0.0003	0.0000	0.0076	0.0005	0.0012	0.0006	0.0007	0.0013	0.0005	0.0005
5	0.0061	0.0010	0.0010	0.0172	1.1020	0.0088	0.0007	0.0001	0.0116	0.0023	0.0087	0.0087	0.0036	0.0054	0.0089	0.0010
6	0.0113	0.0027	0.0028	0.0482	0.0081	1.1995	0.0026	0.0002	0.0294	0.0075	0.0135	0.0092	0.0078	0.0160	0.0268	0.0035
7	0.0655	0.0139	0.0148	0.0741	0.0081	0.0301	1.0826	0.0009	0.0381	0.0255	0.0366	0.0093	0.0059	0.0147	0.0048	0.0073
8	0.0236	0.0058	0.0064	0.0358	0.0046	0.0233	0.2083	1.0004	0.2373	0.0120	0.6426	0.0485	0.0286	0.0608	0.0127	0.0039
9	0.0439	0.0060	0.0064	0.0657	0.0091	0.0596	0.0107	0.0009	1.2282	0.0097	0.0276	0.0124	0.0181	0.0255	0.0114	0.0049
10	0.0076	0.0017	0.0030	0.0423	0.0014	0.0091	0.0005	0.0000	0.0105	1.1436	0.0432	0.0164	0.0093	0.0202	0.0061	0.0101
11	0.0032	0.0031	0.0040	0.0092	0.0017	0.0082	0.0004	0.0000	0.0081	0.0066	1.2958	0.0899	0.0488	0.1076	0.0191	0.0024
12	0.0161	0.0073	0.0109	0.0706	0.0063	0.0336	0.0023	0.0002	0.0235	0.0217	0.0287	1.1002	0.0331	0.0620	0.0179	0.0065
13	0.0058	0.0026	0.0023	0.0119	0.0015	0.0061	0.0014	0.0001	0.0052	0.0045	0.0070	0.0021	1.2063	0.0075	0.0021	0.0016
14	0.0109	0.0080	0.0086	0.0124	0.0018	0.0122	0.0008	0.0001	0.0070	0.0031	0.0126	0.0062	0.0169	1.0945	0.0016	0.0091
15	0.0039	0.0038	0.0038	0.0084	0.0076	0.0053	0.0005	0.0000	0.0145	0.0031	0.0292	0.0097	0.0106	0.0070	1.0089	0.0016
16	0.0177	0.0236	0.0286	0.0547	0.0067	0.0364	0.0089	0.0005	0.0309	0.0319	0.2897	0.0353	0.0199	0.0390	0.0067	1.0634
17	0.0179	0.0238	0.0289	0.0553	0.0068	0.0367	0.0090	0.0005	0.0312	0.0323	0.2927	0.0357	0.0201	0.0394	0.0067	0.0068
18	0.0179	0.0238	0.0289	0.0553	0.0068	0.0367	0.0090	0.0005	0.0312	0.0323	0.2927	0.0357	0.0201	0.0394	0.0067	0.0068
19	0.0140	0.0183	0.0223	0.0431	0.0055	0.0292	0.0067	0.0004	0.0251	0.0255	0.5866	0.0519	0.0287	0.0598	0.0104	0.0057
20	0.0180	0.0239	0.0289	0.0554	0.0068	0.0368	0.0090	0.0005	0.0312	0.0323	0.2933	0.0357	0.0201	0.0395	0.0067	0.0068
21	0.0191	0.0253	0.0307	0.0588	0.0072	0.0391	0.0096	0.0005	0.0331	0.0343	0.3112	0.0379	0.0213	0.0419	0.0071	0.0072
22	0.0180	0.0049	0.0057	0.1016	0.0142	0.0217	0.0611	0.0020	0.2444	0.1339	0.2549	0.0360	0.0190	0.0385	0.0098	0.0041
23	0.9461	0.0004	0.0004	0.2903	0.0204	0.0185	0.0002	0.0000	0.0089	0.0005	0.0013	0.0007	0.0006	0.0013	0.0018	0.0004
24	0.0052	0.0023	0.0071	0.0456	0.0046	0.0143	0.0063	0.0006	0.0200	0.0055	0.0274	0.0088	0.0037	0.0076	0.0018	0.0095
25	0.0035	0.0033	0.0036	0.0015	0.0001	0.0003	0.0000	0.0000	0.0003	0.0003	0.0017	0.0002	0.0001	0.0003	0.0001	0.0022
26	0.0023	0.0004	0.0012	0.0022	0.0003	0.0013	0.0001	0.0000	0.0012	0.0005	0.0014	0.0004	0.0004	0.0007	0.0002	0.0006
27	0.0163	0.0034	0.0035	0.0389	0.0082	0.0222	0.0023	0.0002	0.0227	0.0052	0.0117	0.0065	0.0064	0.0186	0.0060	0.0048
28	0.0240	0.0082	0.0058	0.0839	0.0100	0.0410	0.0114	0.0010	0.0325	0.0328	0.0426	0.0123	0.0077	0.0191	0.0065	0.0068
29	0.0125	0.0036	0.0038	0.0301	0.0053	0.0239	0.0021	0.0002	0.0246	0.0060	0.0209	0.0069	0.0069	0.0139	0.0035	0.0070
30	0.0019	0.0010	0.0013	0.0062	0.0006	0.0075	0.0013	0.0001	0.0025	0.0012	0.0036	0.0013	0.0014	0.0016	0.0006	0.0007
31	0.0011	0.0018	0.0002	0.0025	0.0009	0.0017	0.0002	0.0000	0.0028	0.0003	0.0011	0.0003	0.0005	0.0008	0.0002	0.0008
32	0.0059	0.0020	0.0017	0.0278	0.0033	0.0139	0.0017	0.0001	0.0133	0.0029	0.0065	0.0038	0.0032	0.0061	0.0017	0.0025

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1. Continued on next page.

Table A-13 2001 Ghosh monetary model total coefficients (continued)

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002	0.0042	0.0212	0.0036	0.0183	0.0037	0.0035	0.0510
2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0015	0.0009	0.0096	0.0224	0.0078	0.0217	0.0063	0.0080	0.0095
3	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0002	0.0018	0.0016	0.0722	0.0135	0.0079	0.0302	0.0061	0.0047	0.0193
4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002	0.0021	0.0312	0.0035	0.0188	0.0031	0.0035	0.0800
5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0003	0.0003	0.0127	0.0295	0.0122	0.0352	0.0099	0.0245	0.0436
6	0.0000	0.0001	0.0000	0.0001	0.0000	0.0004	0.0001	0.0015	0.0013	0.0870	0.2030	0.0327	0.2142	0.0477	0.0304	0.0705
7	0.0000	0.0001	0.0000	0.0002	0.0000	0.0012	0.0001	0.0016	0.0012	0.0379	0.1142	0.7862	0.1121	0.0212	0.0168	0.0335
8	0.0000	0.0001	0.0000	0.0001	0.0000	0.0005	0.0002	0.0019	0.0017	0.0831	0.0496	0.2306	0.0687	0.0576	0.0119	0.0240
9	0.0000	0.0001	0.0000	0.0002	0.0000	0.0007	0.0005	0.0051	0.0045	0.0341	0.0452	0.0295	0.0869	0.0183	0.0261	0.0492
10	0.0000	0.0001	0.0001	0.0005	0.0000	0.0001	0.0004	0.0041	0.0037	0.3534	0.0444	0.0089	0.0703	0.0108	0.0075	0.0197
11	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0001	0.0012	0.0010	0.0514	0.0190	0.0147	0.0392	0.0084	0.0053	0.0117
12	0.0000	0.0001	0.0001	0.0002	0.0000	0.0006	0.0006	0.0068	0.0061	0.2144	0.0724	0.0755	0.1397	0.0221	0.0181	0.0434
13	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0003	0.0003	0.0072	0.0636	0.1150	0.0298	0.0329	0.0041	0.0109
14	0.0000	0.0001	0.0001	0.0004	0.0000	0.0002	0.0001	0.0013	0.0012	0.0583	0.0360	0.0213	0.0951	0.0123	0.0258	0.0432
15	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0004	0.0003	0.0135	0.0305	0.0087	0.0413	0.0257	0.0132	0.0392
16	0.0000	0.0001	0.0000	0.0001	0.0000	0.0004	0.0005	0.0071	0.0040	0.0327	0.1074	0.0357	0.0988	0.0293	0.0383	0.0439
17	1.0333	0.0001	0.0000	0.0001	0.0000	0.0004	0.0005	0.0072	0.0040	0.0330	0.1085	0.0360	0.0999	0.0296	0.0387	0.0443
18	0.0000	1.0573	0.0000	0.0001	0.0000	0.0004	0.0005	0.0072	0.0040	0.0330	0.1085	0.0360	0.0999	0.0296	0.0387	0.0443
19	0.0000	0.0001	1.0011	0.0001	0.0000	0.0004	0.0004	0.0056	0.0033	0.0389	0.0849	0.0306	0.0843	0.0241	0.0299	0.0358
20	0.0000	0.0001	0.0000	1.0015	0.0000	0.0004	0.0005	0.0072	0.0041	0.0331	0.1087	0.0361	0.1000	0.0297	0.0388	0.0444
21	0.0000	0.0001	0.0000	0.0001	1.0016	0.0005	0.0005	0.0076	0.0043	0.0351	0.1154	0.0383	0.1062	0.0315	0.0412	0.0471
22	0.0000	0.0710	0.0000	0.0001	0.0000	1.0412	0.0002	0.0028	0.0029	0.0666	0.1392	0.0807	0.0596	0.0264	0.0448	0.0318
23	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0029	0.0001	0.0001	0.0036	0.0182	0.0031	0.0157	0.0032	0.0030	0.0439
24	0.0000	0.0010	0.0000	0.0001	0.0000	0.0003	0.0001	1.0007	0.0006	0.0160	0.0454	0.0274	0.0797	0.0106	0.0322	0.1293
25	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0004	0.0008	0.0003	0.0014	0.0002	0.0003	0.0097
26	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0001	1.0022	0.0086	0.0047	0.0490	0.0075	0.0016	0.0062
27	0.0000	0.0001	0.0000	0.0002	0.0000	0.0003	0.0002	0.0017	0.0016	0.0290	1.0614	0.0380	0.0708	0.0089	0.0177	0.0322
28	0.0000	0.0001	0.0001	0.0002	0.0000	0.0007	0.0002	0.0016	0.0014	0.0402	0.1615	1.1556	0.1589	0.0268	0.0185	0.0436
29	0.0000	0.0002	0.0001	0.0003	0.0000	0.0012	0.0002	0.0025	0.0022	0.0326	0.1613	0.0519	1.3198	0.0281	0.0264	0.0623
30	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0004	0.0042	0.0144	0.0219	0.0274	1.0516	0.0045	0.0048
31	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0010	0.0037	0.0023	0.0127	0.0020	1.0110	0.0036
32	0.0000	0.0000	0.0000	0.0001	0.0000	0.0002	0.0001	0.0007	0.0006	0.0095	0.0526	0.0175	0.1160	0.0131	0.0134	1.0591

Source: Various (see Table 1-2). Notes: Calculated from the input-output tables developed by this research, in accordance with the sectoral classification in Table A- 1.

Appendix 5 A selection of existing scenario studies for Australia

Reference	Topic	Year(s)	Scenarios	Modelling tool	Key findings	Strengths/weaknesses
ATSE (Australian Academy of Technological Sciences and Engineering (ATSE) 1999)	Water use in the economy	2020-21	3: Trend, Non-adaptive, Adaptive Management	MONASH (CGE)	Agriculture is the dominant driver for future water demand. Quantity is not a limiting factor. Efficiency improvements in the distribution and on-farm use of water can be allocated to environmental flows, but requires a custodian to 'purchase' water.	Scenarios are narrow, focusing on the economic dimension as water is viewed as an 'economic input into an expanding economy driven by market prices' (pV).
Dunlop, Foran & Poldy (2001)	Land and water use scenarios, with a focus on irrigation water	2050 to 2100	3: Commodity J curve, Urban extravaganza, climate change double whammy	ASFF + simulation model	Opportunities and challenges are present for all three scenarios and vary across regions. There are considerable water resources, but considerable adaptation would also be required. Success and rate of adaptation affected by infrastructure decisions, institutional arrangements, community expectation and global climate change.	Identifies economic, social and environmental impacts, and therefore considers wider scenario implications compared to other studies. ASFF is a dynamic physical input-output model and therefore limits the suitability for analysing carbon tax policies, etc.
Young et al. (2006)	Implications for the economy and water resources of an additional 5 million people	2032	4: No strategies other than efficiency and price changes, Urban-rural trading, Trading + desalination, Trading + desalination + wage-driven migration	TERM (CGE)	Australia can supply water to 25 million people and still enable increases to GDP. Large shadow price increases predicted for major capital cities unless trade and desalination embraced. Trade has mixed consequences for Agriculture.	Extends the monetary CGE model to include physical water use data.

Notes: CGE: Computable general equilibrium, ASFF: Australian Stocks and Flows Framework, TERM: The Enormous Regional Model, GDP: Gross Domestic Product. Continued on next page.

(continued)

Reference	Topic	Year(s)	Scenarios	Modelling tool	Key findings	Strengths/weaknesses
NIEIR et al. (2003)	Energy	2030 (10-year intervals)	4: Global Convergence, Fortress World, It's a Green World, and Muddling Through	IMP (CGE)	Primary energy demand differs between the scenarios. Coal is still a dominant fuel source, even in the Green scenario. Gas consumption will rise, whilst oil consumption will decline.	World model comprises 30 regions, with Australia disaggregated at state/territory level. Therefore external, international drivers may be captured in scenarios (eg. oil dependency and global security).
Richard, Diesendorf & Saddler (2004)	50 per cent GGE reduction by 2040	2040	4	Spreadsheet model, using forecasting (demand) and backcasting (demand + supply) techniques	Energy efficiency and technological change sufficient for meeting likely future energy demand accompanying long periods of economic growth.	Scenarios are conservative and only consider existing technologies with incremental improvements. The scenarios therefore do not model 'shocks'. Limited analysis on institutional arrangements required to achieve scenarios.
Graham et al. (2003)	To identify a set least cost electricity generation portfolios that would meet a range of GGE targets	2050	4	CSIRO Electricity Market Model	No single solution. If deep cuts required, CO_2 capture + storage suitable, if capture rate is close to 100 per cent. Otherwise, large quantities of renewables required. If moderate emissions permissible + (continue to rise at lower than BAU) + moderate demand growth, then CCGT + USC or CCGT + IGCC suitable, given adequate gas supplies.	Considers a range of existing and emerging technologies. Price is the sole determinant of which solutions are most suitable. Does not consider wider trade-offs, such as water usage.

Notes: IMP: Institute Multipurpose Model, CGE: Computable general equilibrium, CSIRO: Commonwealth Scientific and Industrial Research Organisation, BAU:Business as usual, CCGT: Combined cycle gas turbine, UCS: Ultrasupercritical, IGCC: Integrated gasification combined cycle.

Appendix 6 Percentage breakdown of direct and indirect requirements

Table A-14 Percentage breakdown of direct (D) and indirect (I) water requirements (%)

		1996										2001									
		Production sectors						Production factors				Production sectors						Production factors			
		IDW		BRW		SEW		Raw water		Instream use		IDW		BRW		SEW		Raw water		Instream use	
		D	I	D	I	D	I	D	I	D	I	D	I	D	I	D	I	D	I	D	I
1	AG	89	11		100	88	12	44	56		100	91	9	23	77	88	12	51	49	0.31	99.69
3	OMS		100	69	31	92	8	34	66		100		100	79	21	92	8	59	41	0.16	99.84
4	FBT		100	70	30		100	0.04	99.96		100		100	71	29		100	0.32	99.68		100
5	TCFL		100	83	17		100	0.06	99.94		100		100	62	38		100	0.14	99.86		100
6	WPP		100	74	26	4	96	2	98		100		100	51	49	4	96	7	93		100
9	CHEM		100	57	43		100	0.32	99.68		100		100	61	39		100	0.20	99.80		100
10	NMMP		100	52	48		100	1	99		100		100	49	51		100	1	99		100
11	BMP		100	63	37		100	0.22	99.78		100		100	54	46		100	1	99		100
12	FMP		100	54	46		100		100		100		100	57	43		100		100		100
13	TE		100	36	64		100		100		100		100	27	73		100	0.11	99.89		100
14	OME		100	37	63		100	6	94		100		100	30	70		100	0.11	99.89		100
15	MM		100	57	43		100		100		100		100	16	84		100	0.01	99.99		100
26	CONST		100	36	64		100	0.10	99.90		100		100	45	55		100	0.23	99.77		100
27	WRT		100	50	50		100	0.02	99.98		100		100	51	49		100	0.02	99.98		100
28	TS		100	56	44		100	0.04	99.96		100		100	51	49		100	0.20	99.80		100
29	FPBS		100	53	47		100	1	99		100		100	52	48		100	0.32	99.68		100
30	GAD		100	49	51		100	1	99		100		100	52	48		100	6	94		100
31	EHCS		100	73	27	27	73	3	97		100		100	84	16	27	73	8	92		100
32	OCS		100	71	29	91	9	2	98		100		100	88	12	91	9	11	89		100

Notes: Derived from the Leontief hybrid models as described in Chapter 3.

Table A-15 Percentage breakdown of direct and indirect energy requirements (%)

		1996						2001					
		Electricity		Petroleum Refining		Gas		Electricity		Petroleum Refining		Gas	
		D	I	D	I	D	I	D	I	D	I	D	I
1	AG	55	45	45	55	-	100	56	44	64	36	-	100.0
3	OMS	74	26	1	99	-	100	82	18	64	36	-	100.0
4	FBT	49	51	6	94	60	40	58	42	0.9	99.1	59	41
5	TCFL	64	36	12	88	62	38	54	46	1.0	99.0	60	40
6	WPP	63	37	5	95	-	100	61	39	0.6	99.4	-	100.0
9	CHEM	50	50	53	47	68	32	57	43	31	69	75	25
10	NMMP	65	35	9	91	82	18	69	31	7	93	79	21
11	BMP	67	33	12	88	69	31	70	30	6	94	64	36
12	FMP	20	80	7	93	21	79	32	68	1.1	98.9	30	70
13	TE	45	55	2	98	24	76	26	74	0.7	99.3	13	87
14	OME	27	73	8	92	15	85	23	77	3	97	15	85
15	MM	2	98	1.4	98.6	12	88	3	97	0.0	100.0	19	81
26	CONST	1	99	34	66	2	98	2	98	20	80	2	98
27	WRT	62	38	7	93	68	32	67	33	2	98	66	34
28	TS	36	64	84	16	15	85	38	62	83	17	22	78
29	FPBS	45	55	0.2	99.8	1.2	99	47	53	0.4	99.6	1.5	98.5
30	GAD	59	41	5	95	47	53	67	33	10	90	51	49
31	EHCS	69	31	11	89	57	43	77	23	19	81	67	33
32	OCS	53	47	0.3	99.7	9	91	53	47	0.7	99.3	9	91

Notes: Derived from the Leontief hybrid models as described in Chapter 3.

Appendix 7 Energy efficiency potential

This appendix lists the energy efficieny potential for each sector, as reported in the National Framework for Energy Efficiency (Sustainable Energy Authority Victoria (SEAV) 2003).

Sector	Low (%)	High (%)
Agriculture (AG)	20	50
Other mining & services to mining (OMS)	20	50
Food, beverages & tobacco (FBT)	25	55
Textile, clothing, footwear & leather (TCFL)	25	45
Wood, paper and printing (WPP)	20	45
Chemicals (CHEM)	25	45
Non-metallic mineral products (NMMP)	30	50
Basic metals & products (BMP)	20	42
Fabricated metal products (FMP)	20	42
Transport equipment (TE)	25	55
Other machinery & equipment (OME)	25	55
Miscellaneous manufacturing (MM)	25	50
Construction (CONST)	20	40
Wholesale & retail trade (WRT)	26	70
Transport & storage (TS)	28	74
Finance, property & business services (FPBS)	28	74
Government administration & defence (GAD)	28	74
Education, health & community services (EHCS)	29	67
Other commercial services (OCS)	29	68
Residential	34	73

Source: SEAV (2003)

Appendix 8 Detailed scenario results

Table A- 16 Estimated water consumption in the electricity sectors in 2031 (ML)

Electricity sectors	Scenario	Water production sectors					Water production factors (from Environment)		
		IDW	BRW	SEW	RECYCLE	DESAL	Raw Water	Instream Use	Seawater
CF	S1	155.55	1,963.68	574.25	161.28	11.97	11,808.34	7,448.72	3,083.85
	S2	152.72	1,925.51	433.65	60.04	30.77	11,554.48	5,828.79	3,115.51
	S3	143.80	1,811.13	674.98	254.99	-	10,872.87	7,836.99	2,823.68
	S4	242.92	1,403.92	322.14	46.21	-	8,755.67	7,278.76	2,186.79
CCGT	S1	12.64	21.10	2.15	1.45	2.00	597.32	185.04	463.22
	S2	12.39	19.36	0.92	0.53	5.10	54.48	139.52	992.30
	S3	67.86	95.72	18.05	12.68	-	5,076.05	925.68	648.44
	S4	5.42	7.23	0.31	0.18	-	22.34	63.62	327.57
COGEN	S1	1.54	1.35	0.27	0.18	0.13	5.81	15.46	0.28
	S2	1.51	1.25	0.12	0.07	0.33	5.52	11.84	0.80
	S3	1.42	1.25	0.39	0.27	-	5.31	14.61	0.03
	S4	1.31	1.00	0.09	0.05	-	4.65	8.88	0.02
HYDRO	S1	9.04	7.92	1.57	1.06	0.74	34.04	2,054,122.18	1.64
	S2	6.81	5.63	0.52	0.30	1.47	24.88	1,550,569.45	3.59
	S3	2.03	1.78	0.55	0.39	-	7.56	1,893,816.83	0.04
	S4	7.40	5.65	0.49	0.28	-	26.31	1,465,727.91	0.09

Notes: Derived from the Leontief hybrid model for 2031 as described in Chapter 3. Figures should be viewed as relative approximations for the purpose of comparison.

Continued on next page.

Table A- 16 Estimated water consumption in the electricity sectors in 2031 (ML) (continued)

Electricity sectors	Scenario	Water production sectors					Water production factors (from Environment)		
		IDW	BRW	SEW	RECYCLE	DESAL	Raw Water	Instream Use	Seawater
OR	S1	0.13	0.11	0.02	0.01	0.01	6.78	1.26	0.02
	S2	0.06	0.05	0.00	0.00	0.01	3.28	0.48	0.03
	S3	0.38	0.33	0.10	0.07		20.46	3.90	0.01
	S4	0.35	0.26	0.02	0.01		15.97	2.34	0.00
USC	S1	119.52	126.21	180.03	100.56	9.34	13,757.45	4,730.45	25.75
	S2	-	-	-	-	-	-	-	-
	S3	-	-	-	-	-	-	-	-
	S4	-	-	-	-	-	-	-	-
SC	S1	-	-	-	-	-	-	-	-
	S2	83.30	87.34	73.81	28.81	16.96	961.92	2,819.54	8,504.24
	S3	-	-	-	-	-	-	-	-
	S4	-	-	-	-	-	-	-	-
OCGT	S1	2.40	4.48	0.41	0.27	0.42	11.54	37.90	0.91
	S2	3.68	6.42	0.27	0.16	1.69	16.87	44.57	3.93
	S3	1.89	2.90	0.50	0.35	-	8.32	27.26	0.05
	S4	2.01	2.90	0.11	0.06	-	8.52	25.51	0.04
NUCLEAR	S1	-	-	-	-	-	-	-	-
	S2	160.82	161.26	25.53	16.80	42.08	623.21	1,811.64	6,589.51
	S3	-	-	-	-	-	-	-	-
	S4	-	-	-	-	-	-	-	-
WIND	S1	-	-	-	-	-	-	-	-
	S2	-	-	-	-	-	-	-	-
	S3	11.75	16.13	7.73	5.62		52.24	319.08	0.58
	S4	6.61	6.33	0.77	0.51		25.33	100.92	0.17

Notes: Derived from the Leontief hybrid model for 2031 as described in Chapter 3. Figures should be viewed as relative approximations for the purpose of comparison. Continued on next page.

Table A- 16 Estimated water consumption in the electricity sectors in 2031 (ML) (continued)

Electricity sectors	Scenario	Water production sectors					Water production factors (from Environment)		
		IDW	BRW	SEW	RECYCLE	DESAL	Raw Water	Instream Use	Seawater
GEOTHERMAL	S1	-	-	-	-	-	-	-	-
	S2	-	-	-	-	-	-	-	-
	S3	73.89	408.14	135.00	82.32		1,411.94	26,968.49	49.17
	S4	-	-	-	-	-	-	-	-
BIGCC	S1	-	-	-	-	-	-	-	-
	S2	-	-	-	-	-	-	-	-
	S3	-	-	-	-	-	-	-	-
	S4	29,328.51	52.92	38.28	15.02		77,540.70	1,044.20	1.77

Notes: Derived from the Leontief hybrid model for 2031 as described in Chapter 3. Figures should be viewed as relative approximations for the purpose of comparison.

Table A- 17 Water intensities for the electricity sectors in 2031 (ML/PJ)

Electricity sectors	Scenarios	Water production sectors										Water production factors (from Environment)					
		IDW		BRW		SEW		RECYCLE		DESAL		Raw Water		Instream Use		Seawater	
		D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T
CF	S1	-	3.10	33.60	39.17	5.33	11.46	-	3.22	-	0.24	149.69	235.57	-	148.60	57.16	61.52
	S2	-	3.12	33.78	39.33	5.35	8.86	-	1.23	-	0.63	150.50	236.01	-	119.06	57.47	63.64
	S3	-	3.10	33.47	39.03	5.31	14.55	-	5.50	-	-	149.13	234.31	-	168.89	56.94	60.85
	S4	-	6.76	33.47	39.09	5.31	8.97	-	1.29	-	-	149.13	243.81	-	202.69	56.95	60.89
CCGT	S1	-	3.18	-	5.32	-	0.54	-	0.37	-	0.50	132.58	150.49	-	46.62	112.83	116.70
	S2	-	3.20	-	4.99	-	0.24	-	0.14	-	1.31	-	14.05	-	35.99	246.78	255.97
	S3	-	3.13	-	4.41	-	0.83	-	0.58	-	-	215.35	234.01	-	42.68	29.10	29.89
	S4	-	4.14	-	5.53	-	0.24	-	0.14	-	-	-	17.09	-	48.66	244.46	250.55

Notes: D = direct, T = total (direct + indirect). Derived from the Leontief hybrid model for 2031 as described in Chapter 3. Figures should be viewed as relative approximations for the purpose of comparison. Continued on next page.

Table A- 17 Water intensities for the electricity sectors in 2031 (ML/PJ) (continued)

Electricity sectors	Scenarios	Water production sectors										Water production factors (from Environment)					
		IDW		BRW		SEW		RECYCLE		DESAL		Raw Water		Instream Use		Seawater	
		D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T
COGEN	S1	-	2.14	-	1.87	-	0.37	-	0.25	-	0.18	-	8.05	-	21.44	-	0.39
	S2	-	2.15	-	1.77	-	0.16	-	0.09	-	0.46	-	7.84	-	16.80	-	1.13
	S3	-	2.13	-	1.87	-	0.58	-	0.41	-	-	-	7.95	-	21.88	-	0.04
	S4	-	2.53	-	1.93	-	0.17	-	0.10	-	-	-	9.01	-	17.18	-	0.03
HYDRO	S1	-	2.62	-	2.30	-	0.46	-	0.31	-	0.22	-	9.86	581,789.48	595,098.74	-	0.48
	S2	-	2.63	-	2.17	-	0.20	-	0.12	-	0.57	-	9.60	585,038.18	598,495.52	-	1.38
	S3	-	0.63	-	0.56	-	0.17	-	0.12	-	-	-	2.37	579,502.19	592,686.30	-	0.01
	S4	-	2.99	-	2.28	-	0.20	-	0.12	-	-	-	10.64	579,529.61	592,728.76	-	0.03
OR	S1		0.71	-	0.62	-	0.12	-	0.08	-	0.06	35.43	38.09	-	7.08	-	0.13
	S2		0.35	-	0.29	-	0.03	-	0.02	-	0.08	17.59	18.86	-	2.74	-	0.18
	S3		2.31	-	2.02	-	0.63	-	0.44	-	-	115.68	124.29	-	23.70	-	0.04
	S4	-	2.71	-	2.07	-	0.18	-	0.10	-	-	115.68	125.32	-	18.39	-	0.03
USC	S1	-	2.90	-	3.06	-	4.37	-	2.44	-	0.23	278.82	333.65	-	114.73	-	0.62
	S2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SC	S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S2	-	2.99	-	3.14	-	2.65	-	1.04	-	0.61	-	34.55	-	101.28	280.29	305.49
	S3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Notes: D = direct, T = total (direct + indirect). Derived from the Leontief hybrid model for 2031 as described in Chapter 3. Figures should be viewed as relative approximations for the purpose of comparison. Continued on next page.

Table A- 17 Water intensities for the electricity sectors in 2031 (ML/PJ) (continued)

Electricity sectors	Scenarios	Water production sectors										Water production factors (from Environment)					
		IDW		BRW		SEW		RECYCLE		DESAL		Raw Water		Instream Use		Seawater	
		D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T
OCGT	S1	-	4.33	-	8.08	-	0.73	-	0.49	-	0.77	-	20.81	-	68.37	-	1.65
	S2	-	4.35	-	7.58	-	0.32	-	0.19	-	2.00	-	19.92	-	52.65	-	4.64
	S3	-	4.29	-	6.59	-	1.14	-	0.80	-	-	-	18.90	-	61.97	-	0.11
	S4	-	5.91	-	8.52	-	0.33	-	0.19	-	-	-	25.02	-	74.94	-	0.13
NUCLEAR	S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S2	-	10.55	-	10.58	-	1.67	-	1.10	-	2.76	-	40.88	-	118.83	424.66	432.21
	S3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WIND	S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S3	-	3.57	-	4.90	-	2.35	-	1.71	-	-	-	15.86	-	96.86	-	0.18
	S4	-	5.10	-	4.89	-	0.59	-	0.39	-	-	-	19.55	-	77.90	-	0.13
GEOTHERMAL	S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S3	-	11.44	-	63.21	-	20.91	-	12.75	-	-	38.80	218.69	-	4177.01	-	7.62
	S4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BIGCC	S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S4	-	5370.53	-	9.69	-	7.01	-	2.75	-	-	576.19	14198.98	-	191.21	-	0.32

Notes: D = direct, T = total (direct + indirect). Derived from the Leontief hybrid model for 2031 as described in Chapter 3. Figures should be viewed as relative approximations for the purpose of comparison.

Table A- 18 Estimated energy consumption in water sectors in 2031 (PJ)

Water sectors	Scenarios	Energy production sectors			Energy production factors (primary energy)				
		Electricity	Petroleum	Gas	Coal	Oil	Gas	Nuclear	Total
IDW	S1	0.02	0.01	-	0.04	0.01	-	-	0.05
	S2	0.02	0.01	-	0.03	0.01	-	0.01	0.06
	S3	0.02	0.01	0.01	0.03	0.01	0.01	-	0.05
	S4	0.02	0.01	-	0.03	0.01	-	-	0.05
BRW	S1	0.99	0.66	0.27	2.21	0.82	0.27	-	3.30
	S2	0.93	0.63	0.26	1.90	0.78	0.26	0.41	3.34
	S3	0.99	0.69	0.62	1.62	0.89	0.62	-	3.12
	S4	0.96	0.67	0.25	1.93	0.83	0.25	-	3.01
SEW	S1	0.80	0.60	0.30	1.79	0.74	0.30	-	2.83
	S2	0.82	0.62	0.31	1.68	0.77	0.31	0.36	3.13
	S3	0.71	0.56	0.52	1.18	0.72	0.52	-	2.41
	S4	0.83	0.67	0.31	1.70	0.82	0.31	-	2.84
RECYCLE	S1	0.36	0.07	0.05	0.76	0.08	0.05	-	0.90
	S2	0.27	0.05	0.04	0.52	0.06	0.04	0.12	0.74
	S3	0.45	0.09	0.23	0.69	0.13	0.23	-	1.05
	S4	0.28	0.05	0.04	0.53	0.06	0.04	-	0.62
DESAL	S1	0.78	0.01	0.01	0.02	0.01	0.01	-	0.03
	S2	1.93	0.02	0.01	0.04	0.03	0.01	0.01	0.09
	S3	-	-	-	-	-	-	-	-
	S4	-	-	-	-	-	-	-	-

Notes: Derived from the Leontief hybrid model for 2031 as described in Chapter 3. Figures should be viewed as relative approximations for the purpose of comparison.

Table A- 19 Total energy intensities for the water sectors in 2031 (MJ/ML)

Water sectors	Scenarios	Energy production sectors			Energy production factors (primary energy)				
		Electricity	Petroleum	Gas	Coal	Oil	Gas	Nuclear	Total
IDW	S1	32.05	21.73	8.50	71.37	25.87	8.48	-	105.72
	S2	31.91	21.12	8.73	65.08	26.04	8.71	14.12	113.96
	S3	32.08	21.86	19.82	52.12	28.09	19.77	-	99.99
	S4	31.00	21.21	7.92	62.50	26.16	7.90	-	96.55
BRW	S1	1,745.81	1,208.47	470.97	3,894.83	1,443.15	469.86	-	5,807.84
	S2	1,738.71	1,177.51	483.42	3,552.77	1,452.40	482.29	769.56	6,257.02
	S3	1,746.82	1,217.86	1,086.90	2,845.15	1,563.94	1,084.50	-	5,493.60
	S4	1,685.07	1,182.71	438.92	3,404.28	1,458.74	437.88	-	5,300.90
SEW	S1	1,204.62	1,027.88	452.72	2,713.66	1,127.35	1,238.73	-	5,079.74
	S2	1,200.80	917.75	461.16	2,479.35	1,133.46	1,254.39	531.41	5,398.60
	S3	1,202.33	945.68	874.36	1,984.57	1,210.05	4,331.04	-	7,525.66
	S4	1,147.48	921.59	430.26	2,346.87	1,138.22	1,068.14	-	4,553.24
RECYCLE	S1	8,437.22	2,217.98	1,241.64	17,946.75	1,911.19	1,238.73	-	21,096.67
	S2	8,061.93	1,536.07	1,257.33	15,644.53	1,893.00	1,254.39	3,570.33	22,362.26
	S3	8,663.64	1,811.40	4,340.59	13,219.84	2,552.53	4,331.04	-	20,103.41
	S4	8,339.32	1,552.27	1,070.69	15,923.69	1,910.32	1,068.14	-	18,902.15
DESAL	S1	14,391.14	204.06	93.88	282.82	242.31	93.66	-	618.79
	S2	13,604.29	159.31	91.77	262.46	223.76	91.55	37.94	615.72
	S3	-	-	-	-	-	-	-	-
	S4	-	-	-	-	-	-	-	-

Notes: Derived from the Leontief hybrid model for 2031 as described in Chapter 3. Figures should be viewed as relative approximations for the purpose of comparison.

Table A- 20 Estimated carbon emissions in the water sectors in 2031 (Gg CO2-e)

Water sectors	Scenarios	Coal	Oil	Gas	Total
IDW	S1	3.25	0.88	0.22	4.36
	S2	2.97	0.89	0.23	4.09
	S3	2.38	0.96	0.52	3.86
	S4	2.85	0.89	0.21	3.95
BRW	S1	198.64	55.24	13.80	267.68
	S2	170.52	52.32	13.33	236.17
	S3	145.08	59.86	31.84	236.78
	S4	173.56	55.82	12.85	242.23
SEW	S1	160.90	50.17	15.42	226.48
	S2	151.25	51.90	16.16	219.30
	S3	105.76	48.40	26.77	180.93
	S4	152.72	55.59	16.08	224.39
RECYCLE	S1	68.59	5.48	2.73	76.80
	S2	46.45	4.22	2.14	52.81
	S3	61.80	8.96	11.66	82.42
	S4	47.28	4.26	1.83	53.36
DESAL	S1	1.38	0.89	0.26	2.53
	S2	3.35	2.14	0.67	6.17
	S3	-	-	-	-
	S4	-	-	-	-

Notes: Derived from the Leontief hybrid model for 2031 as described in Chapter 3. Figures should be viewed as relative approximations for the purpose of comparison.

Table A- 21 Total carbon intensities for the water sectors in 2031 (kg CO2-e/ML)

Water sectors	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Direct	Total	Direct	Total	Direct	Total	Direct	Total
IDW	0.06	8.59	0.06	8.05	0.06	7.60	0.06	7.78
BRW	3.19	471.32	3.19	441.87	3.19	416.97	3.19	426.66
SEW	2.13	343.02	2.13	322.83	2.13	304.88	2.13	309.66
RECYCLE	-	1,804.47	-	1,597.32	-	1,583.10	-	1,613.93
DESAL	-	46.57	-	43.38	-	-	-	-
Weighted average	**2.62**	**565.89**	**2.39**	**420.55**	**2.71**	**586.09**	**2.99**	**495.96**

Notes: Derived from the Leontief hybrid model for 2031 as described in Chapter 3. Figures should be viewed as relative approximations for the purpose of comparison.

References

Abercrombie, N. et al. 2006, *The Penguin dictionary of sociology*, 5th edn, Penguin, London.

ABS 2004, Australian Bureau of Statistics (ABS), *Water account Australia 2000-01*, Report Number 4610.0, Canberra.

ABS 2006a, Australian Bureau of Statistics (ABS), *2006 Year book of Australia*, Commonwealth of Australia, Canberra.

ABS 2006b, Australian Bureau of Statistics (ABS), *5220.0 Australian national accounts: State accounts*, Canberra, viewed 15 August 2007, <http://www.abs.gov.au/AUSSTATS/abs@.nsf/second+level+view?ReadForm&prodno=5220.0&viewtitle=Australian%20National%20Accounts:%20State%20Accounts~2006-07~Latest~16/11/2007&&tabname=Past%20Future%20Issues&prodno=5220.0&issue=2006-07&num=&view=&>.

ABS 2006c, Australian Bureau of Statistics (ABS), *8221.1 – Manufacturing industry, New South Wales and Australian Capital Territory, 1999-2000*, Canberra, viewed 20 July 2008, <http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/8221.1Main+Features11999-2000?OpenDocument>.

ABS 2006d, Australian Bureau of Statistics (ABS), *Water account Australia 2004-05*, Report Number 4610.0, Canberra.

ABS 2007, Australian Bureau of Statistics (ABS), *2007 Year book of Australia*, Commonwealth of Australia, Canberra.

ABS 2008, Australian Bureau of Statistics (ABS), *3101.0 Australian demographic statistics March 2008*, viewed 10 October 2008, <http://www.abs.gov.au/AUSSTATS/abs@.nsf/second+level+view?ReadForm&prodno=5220.0&viewtitle=Australian%20National%20Accounts:%20State%20Accounts~2006-07~Latest~16/11/2007&&tabname=Past%20Future%20Issues&prodno=5220.0&issue=2006-07&num=&view=&>.

ACIL Tasman 2006, *The contribution of the minerals industry to the NSW economy: An economic assessment of the opportunities for the NSW minerals industry to 2020*, Prepared for Minerals Ministerial Advisory Council.

ACIL Tasman 2007, *Fuel resource, new entry and generation costs in the NEM, Report 2 – Data and documentation*, Draft prepared for NEMMCO.

Adham, S. & Gagliardo, P. 1998, *Membrane bioreactors for water repurification phase, final technical report*, Report Number Desalination Research and development Program Report No. 34, Bureau of Reclamation, Denver, CO.

Aird, W.V. 1961, *The water supply, sewerage and drainage of Sydney*, Halstead Press, Sydney.

Allen, R.I.G. & Gossling, W.F. (eds) 1975, *Estimating and projecting input-output coefficients*, Input-outputpPublishing company, London.

American Wind Energy Association (AWEA) 2008, *Wind energy FAQ – How much water do wind turbines use compared with conventional power plants?*, American Wind Energy Association, viewed 23 March 2008 <http://www.awea.org/faq/water.html>.

Anon. 2007a, *Delta's water crisis*, viewed 25 February 2008 <http://lithgow.yourguide.com.au/printerFriendlyPage.asp?story_id=583231>.

Anon. 2007b, 'Sydney desalination plant to double in size', *ABC News*, 25 June 2007.

Antipova, E. et al. 2002, 'Optimization of Syr Darya water and energy uses', *Water International*, vol. 27, no. 4, pp. 504-516.

Aristotle (attributed), viewed 24 November 2008, cited at <hnn.us/articles/1328.html>.

Australian Academy of Technological Sciences and Engineering (ATSE) 1999, *Water and the Australian economy*, Australian Academy of Technological Sciences and Engineering and the Institute of Engineers, Parkville, Victoria.

Australian Business Council for Sustainable Energy 2005, *Waste to energy, a guide for local authorities*, Carlton, Victoria.

Australian Business Council for Sustainable Energy (BCSE) 2007, *Discussion paper: Wind serious power ready now*, Australian Business Council for Sustainable Energy, Melbourne.

Australian Government 2007a, *Asia-Pacific partnership on clean development and climate*, viewed 11 April 2007 <http://www.ap6.gov.au/>.

Australian Government 2007b, *'Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Energy (Stationary Sources)'*, viewed 26 July 2008 <http://www.climatechange.gov.au/inventory/methodology/index.html>.

Australian Government 2007c, *National Greenhouse and Energy Reporting Act 2007 Fact Sheet*, Department of the Environment and Water Resources

Australian Greenhouse Office, viewed 30 January 2008 <http://www.climatechange.gov.au/reporting/publications/pubs/nger-fs.pdf>.

Australian Government 2007d, *'A National plan for water security'*, Department of the Prime Minister and Cabinet, <www.pm.gov.au/docs/national_plan_water_security.pdf>.

Australian Government 2007e, *'National Water Initiative'*, viewed 11 April 2007 <http://www.nwc.gov.au/nwi/index.cfm#overview>.

Australian Government 2007f, *The snowy mountains scheme*, viewed 14 March 2007 <http://www.cultureandrecreation.gov.au/articles/snowyscheme/>.

Australian National University 2003, *Hot Rock Energy*, viewed 10 November 2006 <http://hotrock.anu.edu.au/index.htm>.

Australian Petroleum Production & Exploration Association (APPEA) 2007, *Submission to the Owen Inquiry into electricity supply in New South Wales*, Australian Petroleum Production & Exploration Association Limited.

Babcock & Brown Power (BBP) 2007, *Owen inquiry into electricity supply in NSW*, Babcock & Brown Power, Sydney.

Balderstone, S. 1995, *Kakadu: A heritage for the future*, Lansdowne Publishing Pty Ltd, Sydney.

Ball, J. & Keane, P. 2006, *Western Sydney recycled water initiative replacement flows project environmental assessment*, Sydney Water Corporation, Sydney.

Beal, C. et al. 2008, 'Energy and water metabolism of a sustainable subdivision in South East QLD: the little toe of the urban ecological footprint?' *Enviro 08*, Melbourne.

Beasley, M. 1988, *The sweat of their brows: 100 years of the Sydney Water Board 1888-1988*, The Board, Sydney.

Beck, D. 2005, *The Remarkable Evolution of Spiral Dynamics* National Values Center/ The Spiral Dynamics Group, viewed 8 August 2005 <http://spiraldynamics.net/evolution.shtml>.

Beder, S. 1990, 'Early environmentalists and the battle against sewers in Sydney', *Royal Australian Historical Society Journal*, vol. 76, no. 1, pp. 27-44.

Beder, S. 1992, 'Getting into deep water: Sydney's extended ocean sewage outfalls', in P. Scott (ed.), *A herd of white elephants? : some big technology projects in Australia*, Hale & Iremonger, Sydney, p. 159.

Ben Aim, R. 2004, 'Recent developments in MBR', *in Recent advances on water and wastewater treatment using membranes*, Singapore.

Bennett, R. 1990, *Australian society and government*, 4th edn, M.M. & B. Book Company, Sydney.

Bharadwaj, K.R. 1966, 'A note of structural interdependence and the concept of a key sector', *Kyklos*, vol. 19, pp. 315-319.

Bildstien, C. 2007, 'Power price rise alarms industry', *The Advertiser*, 14 May 2007, viewed 26 February 2008 <http://www.euaa.com.au/files/2007/Power%20price%20rise%20alarms%20industry.pdf>.

Billington, R. & ebrary Inc. 1997, *Understanding eastern philosophy*, Routledge, London, UK.

Blackburn, S. 1996, *The Oxford dictionary of philosophy*, Oxford University Press, Oxford.

Blainey, G. 1976, *Triumph of the nomads: A history of ancient Australia*, Sun Books, Melbourne.

Blakers, A. et al. 2006, 'Solar electricity', paper presented to the *ABARE Outlook 2006*, 28 February 2006.

Booth, A.L. & Jacobs, H.M. 1990, 'Ties that bind: Native American beliefs as a foundation for environmental consciousness', *Environmental Ethics*, vol. 12, no. Spring, pp. 27 – 43.

Booth, R.R. 2003, *Warring tribes: The story of power development in Australia*, Rev. edn, Bardak Group, Doonan, Queensland.

Boyle, G. 2004, *Renewable energy*, 2nd edn, Oxford University Press in association with the Open University, Oxford, UK.

Brady, V. 1999, 'Towards an ecology of Australia: Land and spirit', *Worldviews: Environment, Culture and Religion*, vol. 3, no. 2, pp. 139-155.

Broughton, W.C. 1999, *A century of water resources development in Australia*, The Institution of Engineers, Australia.

Bryman, A. 2004, *Social research methods*, 2nd edn, Oxford University Press, Oxford.

Bullard, C.W. & Herendeen, R.A. 1975, 'The energy cost of goods and services', *Energy Policy*, vol. 3, no. 4, pp. 268-278.

Bureau of Meteorology (BOM) 2008, *Annual Australian climate statement 2007* Bureau of Meteorology, viewed 10 February 2008 <http://www.bom.gov.au/announcements/media_releases/climate/change/20080103.shtml>.

Burger, D. 2004, *Electrical and electronic & telecommunications milestones in Australia*, IEEE NSW Section, viewed 27 April 2005 <www.ewh.ieee.org/r10/nsw/>.

Burley, L. 2008, 'Plan for recycled water expected to be quashed', *The Chronicle*, 26 November, viewed 3 December 2008 <http://www.thechronicle.com.au/story/2008/11/26/plan-for-recycled-water-expected-to-be-quashed/>.

Callicott, J.B. 1994, *Earth's insights: A multicultural survey of ecological ethics from the Mediterranean Basin to the Australian Outback*, University of California Press, Berkeley.

Campbell, B. 2008, 'at the 11th International Riversymposium', personal communication, 3 September 2008, Brisbane.

Carson, R. 1962, *Silent spring*, Houghton Mifflin, Boston, MA.

Cherryholmes, C.H. 1992, 'Notes on pragmatism and scientific realism', *Educational Researcher*, vol. August-September, pp. 13-17.

Cichocki, K. & Wojciechowski, W. 1988, 'Investment coefficient matrix in dynamic input-output models: An analysis and prognosis', in M. Ciaschini (ed.), *Input-output analysis: current developments*, Chapman and Hall Ltd, London.

Clarke, F.G. 2002, *The history of Australia*, Greenwood Press, Westport, CT.

Cohen, R. et al. 2004, *Energy down the drain, the hidden costs of California's water supply*, NRDC and Pacific Institute, Oakland, CA.

Collis, B. 1990, *Snowy: The making of modern Australia*, Hodder & Stoughton, Sydney.

Commonwealth of Australia 2003a, *The Australian Constitution*, viewed 15 August 2003 <http://www.aph.gov.au/senate/general/constitution/>.

Commonwealth of Australia 2003b, *Mandatory Renewable Energy Target Review*, Commonwealth of Australia, viewed 21 April 2008 <http://www.mretreview.gov.au/about.html>.

Commonwealth of Australia 2006, *Uranium mining, processing and nuclear energy – opportunities for Australia?*, Report to the Prime Minister by the Uranium Mining, Processing and Nuclear Energy Review Taskforce, December 2006, Canberra.

Commonwealth of Australia 2008a, *Carbon pollution reduction scheme green paper summary*, Department of Climate Change, viewed 10 August 2008 <http://www.climatechange.gov.au/>.

Commonwealth of Australia 2008b, *Energy in Australia 2008*, in Department of Resources, Energy and Tourism (ed.), Australian Bureau of Agricultural & Resources Economics (ABARE).

Commonwealth of Australia 2008c, *Garnaut climate change review draft report*, viewed 5 August 2008 <http://www.garnautreview.org.au/domino/Web_Notes/Garnaut/garnautweb.nsf>.

Commonwealth of Australia 2008d, *Renewable Energy Target*, Commonwealth of Australia, Department of Climate Change, viewed 21 April 2008 <http://www.greenhouse.gov.au/renewabletarget/index.html>.

Commonwealth of Australia 2008e, *Water for the Future*, Department of the Environment, Water, Heritage and the Arts, viewed 8 August 2008 <www.environment.gov.au/water>.

Cooper, B. 2008, personal communication, 14 February 2008, Sydney.

Council of Australian Governments (COAG) 2001, *Communique 8 June 2001 – Energy Policy*, Council of Australian Governments, Canberra.

Council of Australian Governments (COAG) 2003, *Communique 29 August 2003*, Council of Australian Governments, Canberra.

Cousins, S. 2005, *The lucky country*, National Centre for Australian Studies, Monash University, viewed 10 April 2007 <http://www.radioaustralia.net.au/australia/pdf/lucky_country.pdf>.

Cowan, J. 2007, *Water shortages worry power stations*, ABC PM Program, Thursday 10 May 2007, Canberra.

Cruz, L.M.G. 2002, 'Energy policy and modelling in Portugal: The assessment of energy-economy-environment interactions in an input-output framework', PhD thesis, Keele University, Keele, UK.

Cuevas-Cubria, C. & Riwoe, D. 2006, *Australian energy: national and state projections to 2029-30*, Australian Bureau of Agricultural and Resource Economics (ABARE) Research Report 06.26.

Davies, P. 2006, *Lake Margaret power scheme, conservation management plan*, Paul Davies Pty Ltd.

Davis, H.C. & Salkin, E.L. 1984, 'Alternative approaches to the estimation of economic impacts resulting from supply constraints', *Annals of Regional Science*, vol. 18, no. 2, pp. 25-34.

de Miera, G.S. 2000, 'A hybrid input-output model of water', paper presented to the *13th International Conference on Input Output Techniques*, University of Macerata, Italy, August 21-25.

Degremont 2008, *Prospect Water Filtration Plant Fast Facts*, viewed 20 July 2008 <http://www.australianwaterservices.com.au/WaterFacts.htm>.

deMonsabert, S. & Liner, B.L. 1998, 'Integrated energy and water conservation modeling', *Journal of Energy Engineering – ASCE*, vol. 124, no. 1, pp. 1-19.

Department of Primary Industries and Resources of South Australia (PIRSA) 2008, *Australian geothermal licence holders (alphabetical order)*, viewed 21 July 2008 <http://www.pir.sa.gov.au/__data/assets/word_doc/0014/25070/Australian_Geothermal_Licence_Holders.doc>.

Department of Resources and Energy 1983, *Water 2000: A perspective on Australia's water resources to the year 2000*, Australian Government Publishing Service, Canberra.

Department of Water and Energy (DWE) 2008, *Transitional arrangements for the NSW Greenhouse Gas Reduction Scheme – Consultation paper*, in NSW Department of Water and Energy (ed.), viewed 21 April 2008

<http://www.dwe.nsw.gov.au/energy/pdf/sustain_greenhouse_gas_consultation_paper_nsw_ggas_reduction_scheme.pdf>.

Diesendorf, M. 2007, *Greenhouse solutions with sustainable energy*, University of New South Wales Press, Sydney.

Dovers, S. 1994, *Australian environmental history: Essays and cases*, Oxford University Press, Melbourne.

Doyle, T. 2000, *Green power: The environment movement in Australia*, University of New South Wales Press Ltd, Sydney.

Drengson, A. 2006, *Deep Ecology Movement*, viewed 15 December 2006 <http://www.deepecology.org/movement.htm>.

Duarte, R. et al. 2002, 'Water use in the Spanish economy: An input-output approach', *Ecological Economics*, vol. 43, no. 1, pp. 71-85.

Duchin, F. 1988a, 'Analysing structural change in the economy', in M. Ciaschini (ed.), *Input-output analysis: Current developments*, Chapman and Hall Ltd, London.

Duchin, F. 1988b, 'Analysing technological change: An engineering data base for input-output models of the economy', *Engineering with Computers*, vol. 4, pp. 99-105.

Duchin, F. 2005, personal communication, 9 February 2005, (email correspondence).

Dunlop, M. et al. 2001, *Report IV: Scenarios of Future Water Use*, Land & Water Australia, CSIRO Sustainable Ecosystems, Canberra.

Eames, M. & Skea, J. 2002, 'The development and use of UK environmental futures scenarios', *GMI*, vol. 37, no. Spring, pp. 53-70.

Ebensperger, U. & Isley, P. 2005, 'Review of the current state of desalination water policy working paper 2005-2008', unpublished, Wangnick Consulting GMBH.

ECOTECT 1998, *The economic impact of renewable energy*, Report Number ETSU K/PL/00121/REP.

Egan, C. & Dowling, J. 2007, 'Water drain: $160m 'lost' in secret deal', *Sunday Age*, 4 November 2007, p. 1.

Einstein, A. (attributed), viewed 24 November 2008, cited at <thinkexist.com>.

Electric Power Research Institute (EPRI) 2002, *Comparison of alternate cooling technologies for California power plants: Economic, environmental and other tradeoffs*, California Energy Comission, Sacramento, CA.

Electricity Commission of New South Wales 1991, *New & alternative technologies for electricity generation*, 2nd edn, The Commission, Sydney.

Electricity Supply Association Australia (ESAA) 1973, *The electricity supply industry in Australia year 1971-72*, Electricity Supply Association of Australia, Melbourne.

Electricity Supply Association of Australia (ESAA) 2003, *Electricity Australia 2002*, Electricity Supply Association of Australia, Melbourne.

Energy Australia 2006, personal communication, Sydney.

Energy Supply Association of Australia 2006, *Electricity Gas Australia*, Energy Supply Association of Australia, Melbourne.

Energy Task Force 2004, *Securing Australia's energy future*, Commonwealth of Australia, Canberra.

EnergyAustralia 2007, *Response to Owen Inquiry into electricity supply in NSW*, viewed 24 July 2007 <http://www.nsw.gov.au/energy/index.aspx?id=65898d52-4840-4d0c-b81b-2a1a0cd1ec7b>.

Environment Agency 2001, *Water resources for the future: a strategy for England and Wales*, UK Government, Rotherham, UK.

Eraring Energy 2007, *Submission to the Owen Inquiry*, viewed 24 July 2007 <http://www.nsw.gov.au/energy/index.aspx?id=65898d52-4840-4d0c-b81b-2a1a0cd1ec7b>.

Esbjorn-Hargens, S. 2005, *Integral ecology: The what, who and how of environmental phenomena*, vol. 61, no 1, Taylor and Francis, pp. 5-49<http://www.informaworld.com/10.1080/02604020590902344 >.

Faber, A. et al. 2007, 'Exploring techno-economic scenarios in an input-output model', *Futures*, vol. 39, pp. 16-37.

Fane, S. & Mitchell, C. 2006, 'Appropriate cost analysis for decentralised water systems', *Enviro 06 Conference and Exhibition, 9-11 May 2006*, Australian Water Association (AWA), Melbourne.

Fathollahzadeh, R. 2005, 'Electricity industry reform in Australia: Reasons, impacts, challenges', *UTS: Engineering Research Showcase*, Sydney.

Foley, J. et al. 2008, 'Fugitive Greenhouse Gas Emissions from Wastewater Systems', *Water* vol. 35, no. 2.

Foran, B. et al. 2005, *Balancing act: A triple bottom line analysis of the Australian economy*, Commonwealth of Australia, CSIRO, Dickson, ACT.

Friedlander, J. 2007, 'Cool solutions to hot showers', *The Sydney Morning Herald*, 22 March 2007, p. 31.

Gaard, G. 2001, 'Women, water, energy – An ecofeminist approach', *Organization & Environment*, vol. 14, no. 2, pp. 157-172.

Gaard, G.C. 1993, *Ecofeminism: Women, animals, nature*, Temple University Press, Philadelphia, NJ.

Gandhi, M. (attributed), viewed 24 November 2008, cited at <thinkexist.com>.

Geodynamics Limited 2007, *Industry fact sheet*, viewed 15 October 2007 <http://www.geodynamics.com.au/IRM/content/home.html>.

Ghosh, A. 1958, 'Input-output approach in an allocation system', *Economica*, vol. 25, no. 97, pp. 58-64.

Godden Mackay 1995, *Industrial heritage of power generation: A framework for heritage management*, Report Number Vol 2, Report prepared for the Electricity Supply Association of Australia, Redfern, NSW.

Golder, H. 2001, *A short electoral history of the Sydney city council 1842-1992*, viewed 9 February 2007 <http://www.cityofsydney.nsw.gov.au/boundaries/>.

Gordon, J. 2007, 'Hydro call to end restrictions', *The Sydney Morning Herald*, 30 March 2007, p. 4.

Gordon, J. & Kleinman, R. 2007, 'Power and water bills set to soar', *The Age, 12 April 2007*, 12 April 2007.

Gore, A. et al. 2006, *An inconvenient truth*, videorecording /, Paramount,, Hollywood, Calif.

Graham, P. et al. 2005, *Options for electricity generation in Australia*, Technology assessment report 44, Cooperative Research Centre for Coal in Sustainable Development, Pullenvale, Queensland.

Graham, P. et al. 2003, *Options for electricity generation in Australia*, Technology Assessment Report 31, Cooperative Research Centre for Coal in Sustainable Development, Pullenvale, Queensland.

Gravetter, F.J. & Wallnau, L.B. 2004, *Statistics for the behavioural sciences*, 6th edn, Wadsworth, Belmont.

Grix, J. 2004, *The foundations of research*, Palgrave Macmillan, New York, NY.

Gujarati, D.N. 2006, *Essentials of econometrics*, 3rd edn, McGraw-Hill/Irwin, Boston, MA.

Hagebro, C. & Cederwell, K. 2003, 'Workshop 7 (synthesis): Integrating the water and energy sectors', *Water Science and Technology*, vol. 47, no. 6, pp. 189-191.

Haisman, B. 2005, 'Impacts of water rights reform in Australia', in B.R. Bruns, C. Ringler & R. Meinzen-Dick (eds), *Water rights reform: lessons for institutional design*, International Food Policy Research Institute, Washington, DC.

Hallows, P.J. et al. 1995, *The history of irrigation in Australia*, ANCID, First Mildura Irrigation Trust, Mildura, Victoria.

Han, S.-Y. et al. 2004, 'The role of the four electric power sectors in the Korean national economy: An input-output analysis', *Energy Policy*, vol. 32, no. 13, pp. 1531-1543.

Hansen, L.G. 1996, 'Water and energy price impacts on residential water demand in Copenhagen', *Land Economics*, vol. 72, no. 1, pp. 66-79.

Hazari, B.R. 1970, 'Empirical identification of key sectors in the Indian economy', *Review of Economics & Statistics*, vol. 52, no. 3, p. 301.

Heads of Agreement 2000, *The agreed outcome from the snowy water Inquiry*, viewed 5 November 2006 <http://www.parliament.nsw.gov.au/prod/parlment/hansart.nsf/V3Key/LC20001206039>.

High Level Steering Group on Water 1999, *Progress in implementation of the COAG water reform framework*, Report Number Occasional Paper No. 1, Canberra.

Hirschman, A.O. 1958, 'Interdependence and industrialization', in, *The strategy of economic development*, Yale University Press, New Haven, CT.

Hodge, A. 2005, 'Water scheme not worth its salt', *The Australian, 9 September 2005*, 9 September 2005, p. 5.

Holt, P. & James, E. 2006, *Wastewater reuse in the urban environment: Selection of technologies*, Landcom, Sydney.

Hondo, H. 2001, *Evaluation of nuclear power generation technologies based on life cycle CO_2 emissions*, Report Number Y01006, Central Research Institute Electric Power Industry, Tokyo (in Japanese).

Hondo, H. et al. 2000, *Evaluation of power generation technologies based on life cycle CO_2 emissions*, Report Number Y99009, Central Research Institute Electric Power Industry, Tokyo (in Japanese).

Hooker, R. 2006, *The European enlightenment glossary*, viewed 8 December 2006 <http://www.wsu.edu/~dee/GLOSSARY/CLASSMEC.HTM>.

Horvath, A. 2005, *Life-cycle energy assessment of alternative water supply systems in California*, Report Number CEC-500-2005-101, California Energy Commission, PIER Energy-Related Environmental Research.

Houghton, J.T. et al. (eds) 2001, *Climate change 2001: The scientific basis. Contribution of working group I to the third assessment report of the intergovernmental panel on climate change*, Cambridge University Press, Cambridge and New York, NY

Hunwick, R. 2008, personal communication, 26 June 2008, Sydney.

Hutton, D. & Connors, L. 1999, *A history of the Australian environment movement*, Cambridge University Press, Cambridge.

IEEE 2007, *A brief history of the electrical utilities in NSW*, IEEE, viewed 1 March 2007 <http://www.ewh.ieee.org/r10/nsw/subpages/history/history_electricity_syd_county_council.pdf>.

Industry Commission 1995, *Implementing the national competition policy: Access and prices regulation*, AGPS, Canberra.

Institut national de la statistique et des études économiques (INSEE) 2007, *2004 Tableau des entrées-sorties niveau 118*, viewed 4 December 2007 <http://www.insee.fr/fr/indicateurs/cnat_annu/base_2000/tableaux/xls/tes_118_2004.xls#TEI!A1>.

Integrated Sustainability Analysis (ISA) 2006, *Life-cycle energy balance and greenhouse gas emissions of nuclear energy in Australia*, The University of Sydney, Sydney.

Intergovernmental Panel on Climate Change (IPCC) 2004, *Intergovernmental Panel on Climate Change, 16 Years of Scientific Assessment in Support of the Climate Convention*, IPCC, viewed 11 April 2007 <http://www.ipcc.ch/about/anniversarybrochure.pdf>.

James, D.E. 1980, 'A system of energy accounts for Australia', *The Economic Record*, vol. 56, no. 153, pp. 171-181.

James, K. et al. 2002, *Watergy: Taking advantage of untapped energy and water efficiency opportunities in municipal water systems*, Alliance to Save Energy, Copenhagen.

Jensen, R.C. & West, G.R. 1986, *Input-output for practitioners: Theory and applications*, vol. 1, AGPS, Canberra.

Jobson, S. 2004, *Power for the people: A history of electricity in Sydney*, viewed 27 April 2005 <http://www.onlineopinion.com.au/print.asp?article=2485>.

Johnson, M. & Rix, S. 1993, *Water in Australia: Managing Economic, Environmental and Community Reform*, Pluto Press and the Public Sector Research Centre, University of New South Wales, Sydney.

Johnston, D. 2006, *A brief history of philosophy from Socrates to Derrida*, Continuum, London.

Johnston, S. et al. 1999, *Engineering and society: An Australian perspective*, Addison Wesley Longman, South Melbourne.

Kalland, A. 2003, 'Environmentalism and images of the other', in H. Selin (ed.), *Nature across cultures: Views of nature and the environment in non-western cultures*, Kluwer Academic Publishers, Dordrecht.

Karunaratne, N.D. 1981, 'An input-output analysis of Australian energy planning issues', *Energy Economics*, vol. 3, no. 3, pp. 159-168.

Kennedy, D. et al. 2003, 'Low pressure, high tension: The energy-water nexus and regional co-operation in the CIS-7 countries', *Conference of the CIS-7 Initiative, 20-22 January 2003*, Lucerne, Switzerland.

Kenway, S. 2008, 'At the 11th International RiverSymposium', personal communication, 2 September, Brisbane.

Kim, H.B. et al. 2001, 'Impact analysis of a water quality enhancing policy: a simple input-output approach', *Regional Studies*, vol. 35, no. 2, pp. 103-111.

Kleinman, R. & Houston, C. 2007, 'Drought puts pressure on state's power supply', *The Age*, 10 May 2007, p. 1.

Koestler, A. 1967, *The ghost in the machine*, Hutchinson, London.

Kumar, M.D. 2003, 'Impact of electricity prices and volumetric water allocation on energy and groundwater demand management: Analysis from Western India', *Energy Policy*, vol. In Press, Corrected Proof.

Kutscher, C.F. 2000, 'The status and future of geothermal electric power', paper presented to the *American Solar Energy Society Conference*, Madison, Wisconsin, 16-21 June 2001.

LaHaye, L. 2006, *Mercantalism*, viewed 23 October 2006 <http://www.econlib.org/library/Enc/Mercantilism.html>.

Lahr, M.L. & Dietzenbacher, E. 2001, *Input-output analysis: Frontiers and extensions*, Palgrave, Basingstoke, UK.

Leavesley, G.H. et al. 1996, 'The modular modeling system (MMS) – The physical process modeling component of a database-centered decision support system for water and power management', *Water Air and Soil Pollution*, vol. 90, no. 1-2, pp. 303-311.

Lei, M. 2000, 'Integrated input-output accounting for natural resources-energy-economy-environment', *13th International Conference on Input-ouput Techniques*, 21-25 August, Macerata, Italy.

Lenzen, M. 1998, 'Primary energy and greenhouse gases embodied in Australian final consumption: an input-output analysis', *Energy Policy*, vol. 26, no. 6, pp. 495-506.

Lenzen, M. 1999, 'Total requirements of energy and greenhouse gases for Australian transport', *Transportation Research Part D*, vol. 4, pp. 265-290.

Lenzen, M. 2003, 'Environmentally important paths, linkages and key sectors in the Australian economy', *Structural Change and Economic Dynamics*, vol. 14, pp. 1-34.

Lenzen, M. & Foran, B. 2001, 'An input-output analysis of Australian water usage', *Water Policy*, vol. 3, pp. 321-340.

Leontief, W. 1941, *The structure of the American economy, 1919-1939: an empirical application of equilibrium analysis*, Oxford University Press, New York.

Leslie, G. 2007, *'Submission: Review of prices for Sydney's water, sewage, stormwater and recycled water services from 1 July 2008'*, viewed 16 January 2008 <http://www.ipart.nsw.gov.au/files/Submission%20-%20SWC%20Price%20Review%20effective%2001%20July%202008%20-%20School%20of%20Chemical%20Science%20and%20Engineering%20University%20of%20NSW%20-%20Greg%20Leslie%20-%2012%20October%202007%20-%20WEBSITE%20DOCUMENT.PDF>.

Lloyd, C.J. 1988, *Either drought or plenty: Water development and management in New South Wales*, Department of Water Resources NSW, Parramatta, NSW.

Locke, J. 1690, *Second treatise of government*, viewed 20 February 2007 <http://oregonstate.edu/instruct/phl302/texts/locke/locke2/locke2nd-a.html>.

Lofman, D. et al. 2002, 'Water, energy and environment Nexus: The California experience', *International Journal of Water Resources Development*, vol. 18, no. 1, pp. 73-85.

Lougheed, A.L. 1988, *Australia and the world economy*, McPhee Gribble/Penguin, Fitzroy, Victoria.

Lowe AO, I. 2005, *Is nuclear power part of Australia's global warming solutions?*, Australian Conservation Foundation, Canberra.

Ludlow, M. & Wisenthal, S. 2007, 'Drought drains Beattie's coffers', *Australian Financial Review*, 22 March 2007, p. 7.

Lugari, P. (attributed), viewed 2 December 2008, cited at <http://www.panda.org/about_wwf/what_we_do/freshwater/our_solutions/policy_practice/international_law/index.cfm>.

Lundie, S. et al. 2004, 'Life cycle assessment for sustainable metropolitan water systems planning', *Journal of Environmental Science and Technology*, vol. 38, pp. 3465-3473.

Macquarie Generation 2007, *'Submission to the Owen Inquiry into Electricity Supply in New South Wales'*, viewed 24 July 2007 <http://www.nsw.gov.au/energy/index.aspx?id=65898d52-4840-4d0c-b81b-2a1a0cd1ec7b>.

Maiden, S. & Kerr, J. 2006, 'N-power for desalination', *The Australian*, 3 June 2006, p. 1.

Malik, R.P.S. 2002, 'Water-energy nexus in resource-poor economies: The Indian experience', *International Journal of Water Resources Development*, vol. 18, no. 1, pp. 47-58.

Marriott, J. 2007, 'An electricity-focused economic input-output model: Life-cycle assesssment and policy implications of future electricity generation scenarios', Carnegie Mellon University, Pittsburgh, PA.

McColl, G.D. 1976, *The economics of electricity supply in Australia*, Melbourne University Press, Carlton, Victoria.

McLachlan, R. et al. 2002, *Australia's service sector: A study in diversity*, Productivity Commission Staff Research Paper, AusInfo, Canberra.

McLennan Magasamik Associates (MMA) 2006, *Renewable Energy – A Contribution to Australia's Environmental and Economic Sustainability*, Renewable Energy Generators of Australia, Melbourne.

McNeil, I. & NetLibrary Inc. 2002, *An encyclopaedia of the history of technology*, Routledge, viewed 1 November 2008 <http://www.lib.uts.edu.au/cgi/goto.cgi?url=http://www.netLibrary.com/urlapi.asp?action=summary&v=1&bookid=69794 >.

McNeill, J.R. 2000, *Something new under the sun: An environmental history of the twentieth-century world*, WW Norton & Company, Inc, New York, NY.

MDBC 2007, *The Murray-Darling Basin Agreement*, Murray Darling Basin Commission, viewed 4 April 2007 <http://www.mdbc.gov.au/about/the_mdbc_agreement>.

Meadows, D.H. & Club of Rome. 1972, *The limits to growth: A report for the Club of Rome's project on the predicament of mankind*, Earth Island, London.

Melbourne Water 2002, *'Using the Power of Water'*, The Source, no. 21, <http://thesource.melbournewater.com.au/content/issue/august2002/using_power.htm>.

Merchant, C. 1989, *The death of nature: Women, ecology, and the scientific revolution*, Harper & Row, New York, NY.

Mies, M. & Shiva, V. 1993, *Ecofeminism*, Spinifex Press, North Melbourne.

Miller, R.E. & Blair, P.D. 1985, *Input-output analysis: Foundations and extensions*, Prentice-Hall

Inc., New Jersey, NJ.

Moore, G. 2008, 'At the 11th International RiverSymposium', personal communication, 2 September 2008, Brisbane.

Muir, J. 1911, *My first summer in the Sierra*, Houghton Mifflin, Boston.

Murthy, N.S. et al. 1997, 'Economic development, poverty reduction and carbon emissions in India', *Energy Economics*, vol. 19, pp. 327-354.

Nakicenovic, N. & Swart, R. (eds) 2000, *IPCC special report on emissions scenarios*, Cambridge University Press, The Hague.

National Competition Council (NCC) 2007, *Water: NCP water reforms – Research papers*, National Competition Council, viewed 6 April 2007 <http://www.ncc.gov.au/actInSector.asp?actID=41&sectorID=8&page=>.

National Heritage Trust 2005, *Water Resources in Australia: A summary of the National Land and Water Resources Audit's Australian Water Resources Assessment 2000*, viewed 27 July 2005 <www.nlwra.gov.au/atlas>.

National Institute of Economic and Industry Research (NIEIR) 2007, *The economic outlook for the NEM states to 2016-17*, A report for the National Electricity Market Management Company, Clifton Hill, Victoria.

National Institute of Economic and Industry Research (NIEIR) et al. 2003, *Living in a turbulent world: Autsralia at the dawn of the 21st century*, Strategic Energy Supply and Security Working Group, Clifton Hill, Victoria.

New South Wales Government 2004, *Energy Directions Green Paper*.

New South Wales Government 2007, *Owen Inquiry, Background Paper 1 – Future of electricity generation in NSW*.

Nowak, O. 2003, 'Benchmarks for the energy demand of nutrient removal plants', *Water Science and Technology*, vol. 47, no. 12, pp. 125-132.

NSW Department of Energy 1998, *Analysis of energy use in the New South Wales manufacturing sector*, Sydney.

NSW Department of Planning 2005, *New South Wales state and regional population projections 2001-2051*, Transport and Population Data Centre, Sydney.

NSW Department of Water Resources 1988, *Review of reforms in the water industry – 1988 report to the Minister for Natural Resources*, NSW Department of Water Resources, Sydney.

NSW Government 1986, *Uranium mining and nuclear facilities (Prohibitions) Act*, <http://www.austlii.edu.au/au/legis/nsw/consol_act/umanfa1986479/index.html#longtitle>.

NSW Government 2004, *NSW water reforms: A secure and sustainable future*, Department of Infrastructure Planning and Natural Resources, viewed 15 September 2008 <http://www.naturalresources.nsw.gov.au/water/legislation.shtml>.

NSW Government 2006, *2006 metropolitan water plan*, NSW Government, Sydney.

NSW Government 2007, *Welcome reef dam proposal*, NSW Parliament Hansard, 26 September 2007, viewed 20 September 2008 <http://www.parliament.nsw.gov.au/prod/parlment/hansart.nsf/86ca1d5c167e46c8ca2571ca000080c8/2ae482cc48ff2902ca25736e00095859!OpenDocument>.

NSW Government 2008a, *Agency detail: Electricity advisory committee*, Department of Commerce, State Records Authority of New South Wales, viewed 1 December 2008 <http://investigator.records.nsw.gov.au/Entity.aspx?Path=\Agency\490>.

NSW Government 2008b, *Agency detail: Electricity authority of New South Wales*, Department of Commerce, State Records Authority of New South Wales, viewed 1 December 2008 <http://investigator.records.nsw.gov.au/Entity.aspx?Path=\Agency\492>.

NSW Government 2008c, *Agency detail: Energy authority*, Department of Commerce, State Records Authority of New South Wales, viewed 1 December 2008 <http://investigator.records.nsw.gov.au/Entity.aspx?Path=\Agency\493>.

NSW Government 2008d, *State plan – A new direction for NSW*, viewed 20 November 2008 <http://www.nsw.gov.au/stateplan/>.

NSW Water Resources Commission (NSWRC) 1984, *The role of water in the development of New South Wales*, New South Wales Water Resources Commission, North Sydney.

Nunn, J. et al. 2002, *A lifecycle assessment of the NSW electricity grid*, Report Number 25, Cooperative Research Centre for Coal in Sustainable Development, Pullenvale, Queensland.

Oak Ridge National Laboratory 2002, 'Water & energy security', *ORNL Review*, vol. 35, no. 2, p. 2.

Ochrepoint 2008, *Murray-Darling Basin*, River Murray Urban Users Committee, viewed 23 August 2008 <http://www.murrayusers.sa.gov.au/maps.php>.

Oosterhaven, J. 1988, 'On the plausibility of the supply-driven input-output model', *Journal of Regional Science,*, vol. 28, no. 2, pp. 203-217.

Orchison, K. 2007, 'No backing down on coal as the future fuel', *The Australian*, 24 March 2007.

Orchison, K. 2008, 'Water enters coal-fired power station debate', *The Australian*, 1 March 2008, p. 18.

Organisation for Economic Co-operation and Development (OECD) 2005, *Projected costs of generating electricity 2005 update*, Nuclear Energy Agency,

International Energy Agency, Paris.

Owen, A.D. 2007, *Inquiry Into electricity supply in NSW; Key findings and recommendations*, New South Wales Government, Sydney.

PA Government Services Inc. 2006, *Water energy nexus project: Project concept*, viewed 9 November 2006 <http://www.waterenergynexus.com/wenexa2/downloads/water_energy_nexus_project_concept_note.pdf>.

Pachauri, S. & Spreng, D. 2002, 'Direct and indirect energy requirements of households in India', *Energy policy*, vol. 30, no. 6, pp. 511-523.

Pacific Hydro 2006, *The Drop Hydro*, viewed 25 October 2006 <http://www.pacifichydro.com.au/OurEnergy/HydroPower/TheDropHydro/tabid/125/Default.aspx>.

Padmanaban, S. 2001, 'Energy and water: The critical link', *The Bulletin on Energy efficiency*, vol. 2, no. 1.

Pan, H. 2006, 'Dynamic and endogenous change of input-output structure with specific layers of technology', *Structural Change and Economic Dynamics*, vol. 17, pp. 200-223.

Pandit, B. 2001, *The Hindu mind: Fundamentals of Hindu religion and philosophy for all ages*, New Age Books, New Delhi.

Peet, J. 1993, 'Input-output methods of energy analysis', *International journal of global energy Issues, Special Issue on energy analysis*, vol. 5, no. 1, pp. 10-18.

Performance and Innovation Unit (PIU) 2001a, 'Working paper on energy scenarios to 2020', unpublished, UK Cabinet Office.

Performance and Innovation Unit (PIU) 2001b, 'Working paper on energy systems in 2050', unpublished, UK Cabinet Office.

Petre, J. 2005, 'Energy manager, Sydney Water', personal communication, 20 October 2005, Sydney.

Phillips, W.A. 1994, 'Rejuvinating Allen's arc with the geometric mean', *Journal of Economic Education*, vol. Fall, pp. 309-323.

Porter, G. 2005, *Industrial revolution*, Microsoft Corporation, viewed 5 April 2005 <http://inventors.about.com/gi/dynamic/offsite.htm?site=http%3A%2F%2Fencarta.msn.com%2Fencyclopedia_761577952%2FIndustrial_Revolution.html>.

Powell, J.M. 2002, 'Environment and insitutions: Three episodes in Australian water management, 1880-2000', *Journal of Historical Geography*, vol. 28, no. 1, pp. 100 – 114.

Powell, R. 1991, *Understanding and applying input-output methods*, Commonwealth Government Printer, Canberra.

Powell, R. 2005, personal communication, 15 March, Sydney.

Productivity Commission 1999, *Microeconomic reforms and Australian productivity: Exploring the links*, AusInfo, Canberra.

Productivity Commission 2002, *Financial performance of government trading enterprises, 1996-1997 to 2000-01, performance monitoring*, AusInfo, Canberra.

Productivity Commission 2003, *Trends in Australian manufacturing*, Commission Research Paper, Ausinfo, Canberra.

Proops, J.L.R. 1977, 'Input-output analysis and energy intensities: A comparison of some methodologies', *Applications of mathematical modelling*, vol. 1, pp. 181-186.

Proops, J.L.R. et al. 1992, *Reducing CO_2 emissions: A comparative input-output study for Germany and the UK*, Springer-Verlag, Berlin.

Proust, K. 2008, 'Salinity in colonial irrigation: British India and south-eastern Australia', *Australian Geographer*, vol. 39, no. 2, pp. 131-147.

Queensland Government 2006, *Projetc overview*, viewed 7 November 2006 <http://www.westerncorridor.com.au/sitedocument.aspx?docId=2>.

Radcliff, J. 2004, *Water recycling in Australia*, Australian Academy of Technological Sciences and Engineering, Parkville, Victoria.

Rann, A. 1998, *Background paper 21 1997-1998, Electricity industry restructuring – A chronology*, viewed 20 July 2005 <http://www.aph.gov.au/library/pubs/bp/1997-98/98bp21.htm>.

Rasmussen, P.N. 1956, *Studies in inter-sectoral relations*, North-Holland Publishing Co., Amsterdam.

Rawlinson 2007, *Rawlinson's Australian construction handbook*, Rawlhouse Publishing, Perth, Western Australia.

Rayan, M.A. & Khaled, I. 2002, 'Seawater desalination by reverse osmosis', *Desalination*, vol. 153, pp. 245 – 251.

Richard, D. et al. 2004, *A clean energy future for Australia*, Clean Energy Future Group, Sydney.

Riedy, C. & University of Technology Sydney – Institute for Sustainable Futures 2005, 'The eye of the storm: An integral perspective on sustainable development and climate change response', PhD thesis, University of Technology, Sydney.

Roberts, G. 2006, 'Scarce drinking water wasted for excess electricity', *The Australian*, 20 November 2006.

Roberts, G. 2007a, 'Big bills to pump water for power – NSW decides', *The Australian*, 15 March 2007, p. 4.

Roberts, G. 2007b, 'Blackouts on way as power plants dry up', *The Australian*, 9 March 2007, p. 5.

Roberts, G. 2007c, 'Cheap power a drain on water supply', *The Australian*, 7 March 2007, p. 5.

Robins, B. 2007, 'Desal to run even as dams fill', *The Sydney Morning Herald*, 8 December 2207, p. 2.

Rogner, H.-H. et al. 2008, 'Nuclear power versus fossil-fuel power with CO2 capture and storage: a comparative analysis', *International Journal of Energy Sector Management*, vol. 2, no. 2, pp. 181-196.

Rose, A. & Allison, T. 1989, 'On the plausibility of the supply-driven input-output model: Empirical evidence on joint stability', *Journal of Regional Science,*, vol. 29, no. 3.

Rosenthal, S. & Russ, P. 1988, *The politics of power: Inside Australia's electric utilities*, Melbourne University Press, Melbourne.

Ross, W.D. & ebrary Inc. 1995, *Aristotle*, Routledge, <Electronic version http://www.lib.uts.edu.au/sso/goto.php?url=http://site.ebrary.com/lib/utslibrary/Doc?id=2003152 >.

Rudd, K. 2007, *Ratifying the Kyoto protocol*, viewed 10 February 2008 <http://www.pm.gov.au/media/Release/2007/media_release_0003.cfm>.

Scholz 2006a, *History of electricity from its beginning* viewed 20 December 2006 <http://www.scholzelectrical.com.au/history/history1.html#electrochemistry>.

Scholz 2006b, *The incandescent light – From 1879* viewed 20 December 2006 <http://www.scholzelectrical.com.au/history/history1.html#light>.

Schuck, E.C. & Green, G.P. 2002, 'Supply-based water pricing in a conjunctive use system: Implications for resource and energy use', *Resource and Energy Economics*, vol. 24, no. 3, pp. 175-192.

Shadwick, M. 2002, *A viable and sustainable water industry*, Ausinfo, Canberra.

Sharma, D. 2003, 'The multidimensionality of electricity reform – An Australian perspective', *Energy Policy*, vol. 31, pp. 1093-1102.

Sharma, D. & Bartels, R. 1998, 'Distributed electricity generation in competitive energy markets: A case study in Australia', *The Energy Jounal*, vol. DR Special Issue, pp. 17-39.

Shaw, A.G.L. 1966, *Growth and development in australia: An introduction to Australian history*, Angus & Robertson, Sydney.

Sheehan, P. 2007, 'Power cuts, bigger bills on the way', *The Sydney Morning Herald*, 19 May 2007, p. 1.

Shergold, C. & Allen, M. 2003, *Sydney city and suburban sewage and health board*, Government of New South Wales, viewed 16 April 2007 <http://www.records.nsw.gov.au/cguide/sy/sc&ss&hb.htm>.

Skolimowski, H. 1981, *Eco-philosophy: Designing new tactics for living*, Marion Boyars, London.

Skolimowski, H. 1993, *A sacred place to dwell: Living with reverence upon the Earth*, Element Books, Rockport, MA.

Smith, D.I. 1998, *Water in Australia – Resources and management*, Oxford University Press, Melbourne.

Smith, D.W. 2003, *Phenomenology*, viewed 23 February 2007 <http://plato.stanford.edu/entries/phenomenology/>.

Smith, S. 2005, *Desalination, waste water and the Sydney metropolitan water plan*, Report Number 10/05, NSW Parliamentary Library Research Service, Sydney.

Snowy Hydro Limited 2007, *Snowy scheme water storages update 11 May 2007*, viewed 10 January 2008 <http://www.snowyhydro.com.au/sysfiles/media//SnowyHydro_MR_143.pdf>.

Spoehr, J. 2003, *Power politics – The electricity crisis and you*, Wakefield Press, Kent Town, South Australia.

State of NSW 2008, *Drought maps and declarations*, NSW Department of Primary Industries, viewed 20 April 2008 <http://www.dpi.nsw.gov.au/agriculture/emergency/drought/situation/drought-maps/drought-maps?155500_result_page=1>.

Stilwell, F. 2002, *Political economy: The contest of economic ideas*, Oxford University Press, Melbourne.

Stucley, C.R. & Rural Industries Research and Development Corporation (RIRDC) 2004, *Biomass energy production in Australia: Status, costs and opportunities for major technologies*, Rural Industries Research and Development Corporation, Canberra.

Sustainable Energy Authority Victoria (SEAV) 2003, *National framework for energy efficiency: Preliminary assessment of demand-side energy efficiency improvement potential and costs*, Sustainable Energy Authority Victoria, Melbourne.

Sustainable Energy Development Authority (SEDA) 2001, *Demand side management: Evaluating market potential in NSW*, Sustainable Energy Development Authority, Sydney.

Sveiby, K.E. & Skuthorpe, T. 2006, *Treading lightly: The hidden wisdom of the world's oldest people*, Allen & Unwin, Crows Nest, NSW.

Sydney Catchment Authority 2003, *Mini-hydro to generate electricity from Sydney's dams*, viewed 25 October 2006 <http://www.sca.nsw.gov.au/news/media/52.html>.

Sydney Catchment Authority (SCA) 2007, *Warragamba hydro electricity plant*, Sydney Catchment Authority, viewed 2 April 2007 <http://www.sca.nsw.gov.au/dams/hydro.html>.

Sydney Gas Limited 2008, *Operations – Camden gas project*, viewed 21 July 2008 < http://www.sydneygas.com/content.php/3.html#mod144>.

Sydney Olympic Park 2008, *Urban water reuse and integrated water management*, viewed 20 July 2008 <http://www.sydneyolympicpark.com.au/education_and_learning/environment/water/wrams>.

Sydney Water 1999, *Sydney Water's annual environment and public health report: Social impacts*, viewed 4 April 2007 <http://www.sydneywater.com.au/Publications/Reports/AnnualEnvironmentAndPublicHealthReport1999Part3of4.pdf>.

Sydney Water 2004a, *Busby's Bore: Sydney's second water supply*, viewed 9 February 2007 <http://www.sydneywater.com.au/Publications/Factsheets/BusbysBore.pdf#Page=1>.

Sydney Water 2004b, *Tank stream: Sydney's first water supply*, viewed 9 February 2007 <http://www.sydneywater.com.au/Publications/Factsheets/Tank_Stream_1.pdf#Page=1>.

Sydney Water 2007a, *Description of the project: Western Sydney recycled water initiative replacement flows project environmental assessment*, viewed January 30 2008 <http://www.sydneywater.com.au/MajorProjects/ReplacementFlowsProject/pdf/chapter3.pdf#Page=1>.

Sydney Water 2007b, *Media Release 19 July 2007: Sydney Water to be carbon neutral by 2020* Sydney Water, viewed 29 April 2008 <http://www.sydneywater.com.au/WhoWeAre/MediaCentre/MediaView.cfm?ID=388>.

Sydney Water 2007c, *'Submission to the independent pricing and regulatory tribunal review of prices for Sydney Water corporation'*, viewed 14 September <http://www.ipart.nsw.gov.au/files/Submission%20-%20SWC%20Price%20Review%20effective%2001%20July%202008%20-%20Sydney%20Water%20Corporation%20-%20Dr%20Kerry%20Schott%20-%2014%20September%202007%20-%20WEBSITE%20DOCUMENT.PDF>.

Sydney Water 2007d, *Sydney's desalination project, volume 4: Operate and maintain contract*, Sydney Water, Sydney.

Sydney Water 2007e, *Sydney's desalination project: Project report*, Sydney Water, Sydney.

Sydney Water 2008a, *Rouse Hill recycled water scheme*, viewed 20 July 2008 <http://www.sydneywater.com.au/SavingWater/RecyclingandReuse/RecyclingAndReuseInAction/RouseHill.cfm>.

Sydney Water 2008b, *Saving water*, viewed 1 March 2008 <http://www.sydneywater.com.au/SavingWater/>.

Sydney Water 2008c, *Water restrictions*, viewed 1 March 2008 <http://www.sydneywater.com.au/SavingWater/WaterRestrictions/>.

Sydney Water 2008d, *When were water restrictions introduced?*, viewed 8 September 2008 <http://www.sydneywater.com.au/Savingwater/WaterRestrictions/WhenWereWaterRestrictionsIntroduced.cfm>.

Tan, P.-L. 2002, 'Legal Issues Relating to Water Use', in, *Property: Rights and Responsibilities, Current Australian Thinking*, Land and Water Australia, Canberra.

Teilhard de Chardin, P. (attributed), viewed 24 November 2008, cited at <wisdomquotes.com/003647.html>.

The Wilderness Society 2007, *History of the Franklin river campaign 1976-83*, viewed 4 April 2007 <http://www.wilderness.org.au/campaigns/wildrivers/franklin/franklin>.

Transgrid 2007, *New South Wales annual planning report*, TransGrid, Sydney.

Tremolet, S. & Neale, J. 2002, *Emerging lessons in private provision of ifrastructure services in rural areas: Water and electricity services in Gabon*, Report Number 8524, Environmental Resources Management for, London.

Twidell, J. & Weir, A.D. 2002, *Renewable energy resources*, New edn, E. & F. N. Spon, London.

Tze, L. 1963, *The way of Lao Tzu (Tao-te ching)*, trans. Wing-tsit Chan, Prentice Hall, New Jersey.

United Nations Framework Convention on Climate Change (UNFCCC) 2007, *Essential background*, viewed 11 April 2007 <http://unfccc.int/essential_background/items/2877.php>.

US Government 2008, *International energy outlook 2008*, Department of Energy, Energy Information Administration, <http://www.eia.doe.gov/oiaf/ieo/index.html>.

USAID 2003, *Transboundary water and energy management: An overview of USAID activities in central Asia*, viewed 6 January <http://www.usaid.gov/regions/europe_eurasia/car/index.html/briefers/transboundary_water.html>.

USAID 2006, *Policy activities to reduce groundwater and energy use in irrigated agriculture in Andhra Pradesh*, viewed 9 November 2006 <http://www.waterenergynexus.com/wenexa2/downloads/policy_activity_reduce_groundwater_energy_use_andhra.pdf>.

USAID Global Environment Centre 2001, *The water-energy nexus: Opportunities for integrated environmental management*, viewed 6 January 2004 <www.usaid.gov/our_work/environment/water/enviro.notes/enviro.notes,water-energy.pdf>.

Veblen, T. (attributed), viewed 24 November 2008, cited at <http://www.quotationspage.com/quote/32057.html>.

Veziroglu, T.N. 2004, *Quarter century of hydrogen movement 1974-2000*, International Association for Hydrogen Energy, viewed 10 October 2006 <http://www.iahe.org/history.asp>.

Vickers, J. & Yarrow, G. 1988, *Privatization: An economic analysis*, Massachusetts Institute of Technology, Cambridge, MA.

Vink, S. 2008, 'At the 11th International RiverSymposium', personal communication, 2 September 2008, Brisbane.

Voutchkov, N. 2007, 'Estimating Desalination Plant Costs', *DBOOT Desalination: An Intensive Class on Desalination Technologies*, Australian Water Association, Sydney.

Wahlquist, A. & Mitchell, S. 2006, 'Farmers 'denied water' – Snowy hydro diverts supplies to cities', *The Australian*, 18 November 2006, p. 9.

Walker, K.J. 1994, *The political economy of environmental policy: An Australian introduction*, University of New South Wales Press, Kensington, NSW.

Walliman, N.S.R. & Baiche, B. 2001, *Your research project: A step-by-step guide for the first-time researcher*, Sage Publications, London.

Warren, M. 2007, 'Drought to force up bills for power – Climate Change', *The Australian*, 5 May 2007, p. 4.

Wei, Y.-M. et al. 2006, 'A scenario analysis of energy requirements and energy intensity for China's rapidly developing society in the year 2020', *Technological forecasting and social change*, vol. 73, pp. 405-421.

Wibberley, L. 2001, *Coal in a sustainable society*, Report Number C9058, Australian Coal Association Research Program.

Wibberley, L. et al. 2006, *Techno-economic assessment of power generation options for Australia*, Cooperative Research Centre for Coal in Sustainable Development, Pullenvale, Queensland.

Wilber, K. 2000a, *A brief history of everything*, 2nd edn, Shambala Publications Inc., Boston, MA.

Wilber, K. 2000b, *Sex, ecology and spirituality: A spirit of evolution*, 2nd edn, Shambala Publications Inc., Boston, MA.

Wilber, K. 2000c, *A theory of everything: An integral vision for business, politics, science, and spirituality*, Shambhala, Boston, MA.

Wilber, K. 2005a, *'Excerpt B: The many ways we touch '*, viewed 27 July 2005 <http://wilber.shambhala.com/html/books/kosmos/excerptB/part2.cfm>.

Wilber, K. 2005b, *'Introduction to excerpts, from volume 2 of the kosmos trilogy'*, viewed 27 July 2005 <http://wilber.shambhala.com/html/books/kosmos/>.

Wilkenfeld, G. & Spearritt, P. 2004, *Electrifying Sydney: 100 years of Energy Australia*, Energy Australia, Sydney.

Wilkinson, M. & Clennell, A. 2007, 'Grim news for city-dwellers', *The Sydney Morning Herald*, 22 September 2007, p. 25.

Wilkinson, M. & Smith, A. 2007, 'Drought will force power costs up: Ministers', *The Sydney Morning Herald*, 26 May 2007, p. 3.

Wilting, H.C. et al. 2004, 'Exploring technology scenarios with an input-output model', *International conference on input-output and general equilibrium: data, modelling and policy analysis*, 2-4 September 2004, Brussels, Belgium.

Woods, G. 2006, *Water requirements of nuclear power stations*, Department of Parliamentary Services, Commonwealth of Australia, Canberra.

Working Group 1 IPCC 2007, *Climate change 2007: The physical science basis – Summary for policymakers*, Intergovernmental Panel on Climate Change (IPCC), viewed 6 February 2007 <http://ipcc-wg1.ucar.edu/wg1/docs/WG1AR4_SPM_Approved_05Feb.pdf>.

World Commission on Environment and Development 1987, *Our common future*, Oxford University Press, Oxford.

Xinhua 2005, *South-north diversion, a dream to be realised*, viewed 24 October 2006 <http://www.mwr.gov.cn/english1/20050928/58800.asp>.

Yoo, S.-H. & Yang, C.-Y. 1999, 'Role of Water Utility in the Korean National Economy', *Water Resources Development*, vol. 15, no. 4, pp. 527-541.

Young, M.D. & McColl, J.C. 2003, 'Robust reform: The case for a new water entitlement system for Australia', *The Australian Economic Review*, vol. 36, no. 2.

Young, M.D. et al. 2006, *Without water: the economics of supplying water to 5 million more Australians*, CSIRO and Monash University, Melbourne.

Zakkour, P.D. et al. 2002, 'Developing a sustainable energy strategy for a water utility. Part I: A review of the UK legislative framework', *Journal of Environmental Management*, vol. 66, no. 2, pp. 105-114.