Water availability and policies for the coal power sector

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Preface

This draft report has been produced by IEA Clean Coal Centre and is based on a survey and analysis of published literature, and on information gathered in discussions with interested organisations and individuals. Their assistance is gratefully acknowledged. It should be understood that the views expressed in this report are our own, and are not necessarily shared by those who supplied the information, nor by our member countries.

IEA Clean Coal Centre is an organisation set up under the auspices of the International Energy Agency (IEA) which was itself founded in 1974 by member countries of the Organisation for Economic Co-operation and Development (OECD). The purpose of the IEA is to explore means by which countries interested in minimising their dependence on imported oil can co-operate. In the field of Research, Development and Demonstration over fifty individual projects have been established in partnership between member countries of the IEA.

IEA Clean Coal Centre began in 1975 and has contracting parties and sponsors from: Australia, Austria, China, the European Commission, Germany, India, Italy, Japan, New Zealand, Poland, Russia, South Africa, Thailand, the UK and the USA. The Service provides information and assessments on all aspects of coal from supply and transport, through markets and end-use technologies, to environmental issues and waste utilisation.

Abstract

Global energy demand is rising primarily as a result of population and economic growth in the emerging economies. Meeting this growing demand will place increasing stress on limited fresh water resources with repercussions for other users in the agricultural, industrial and domestic sectors. Climate change could exacerbate the situation as water and climate cycles are inextricably linked. Multiple strategies are therefore required across all sectors in order to meet the increasing demand for energy, whilst managing water resources more efficiently and sustainably. This report examines the availability of fresh water for power generation, particularly for coal-fired power plants. The report begins by looking at where water stress is occurring in the world today, before discussing global water demands of the agricultural, industrial and municipal sectors. Typical withdrawal and consumption of water for power generation is then considered and compared. Four countries where there are regional concerns about water shortages (namely China, India, South Africa and the USA) are examined in more detail. These are the four top thermal coal consuming countries in the world. Each country chapter examines the availability and consumption of water within the country, and central government energy, climate and water policies and how they affect the coal-fired power generation sector. Historically, countries have developed their energy and water policies separately, without considering the implications for each other – such as the effect of energy policy on water usage and the energy requirements of the water policy. Energy planners often assume that adequate water resources will be available, whilst water planners similarly assume that energy supplies will not be a constraint. If one of these assumptions fails, then consequences could be disastrous.

Acronyms and abbreviations

CCGT	combined-cycle gas turbines
CCS	carbon capture and storage
CEA	Central Electricity Authority (India)
CSP	concentrated solar power
DOE	Department of Energy (USA)
DWA	Department of Water Affairs (South Africa)
EIA	Energy Information Administration (USA)
EPA	Environmental Protection Agency (USA)
FBC	fluidised bed combustion
FGD	flue gas desulphurisation
FY	financial year
FYP	five year plan
GDP	gross domestic product
GWh	gigawatt hours
IEA	International Energy Agency
IEP	Integrated Energy Plan
IGCC	integrated gasification combined cycle
IRP	Integrated Resource Plan for Electricity
L/kWh	litres per kilowatt hour
MEP	Ministry of Environmental Protection (China)
ML	million (10^6) litres
Mt	million (10^6) tonnes
Mtce	million tonnes of coal equivalent
Mtoe	million (10^6) tonnes of oil equivalent
MWR	Ministry of Water Resources (China)
NAPCC	National Action Plan for Climate Change
NEA	National Energy Administration (China)
NETL	National Energy Technology Laboratory (USA)
NPDES	National Pollutant Discharge Elimination System
NRDC	National Development and Reform Commission (China)
NWP	National Water Policy
NWRS2	second National Water Resource Strategy
OECD	Organisation for Economic Co-operation and Development
R	rand (South Africa)
RMB	reminbi (China)
Rs	rupee (India)
TWh	terawatt hours
UCG	underground coal gasification
US$	United States (American) dollar
USGS	United States Geological Survey
WC-WDM	water conservation and water demand management
WRI	World Resources Institute
WWAP	World Water Assessment Programme

Conversions

$1\ m^3 = 1000$ litres $\quad$ $1\ t$ water $= 1\ m^3$

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1 Introduction

Water and energy are basic necessities for human well-being and prosperity. The water industry, however, is energy intensive, requiring energy for the extraction (pumping), treatment, distribution and heating of water, and for the collection, treatment and discharge of waste water. The water system in the USA, for instance, consumes over 12% of national energy production (Hightower, 2014). Conversely, the energy industry is water intensive. Water is needed to extract, process and transport the mineral energy resource, be it coal, natural gas, oil or uranium, and for the production of biofuel (for example, for irrigation of the feedstock crops). It is used directly in hydropower generation, and is employed extensively for thermal power plant cooling, emissions control and other purposes. This interdependency of water and energy has been called the 'water-energy nexus' or 'energy-water nexus'.

Future demand for both energy and water is expected to increase as a consequence of population and economic growth, and higher living standards. The world population is growing at about 80 million people per year, and is projected to reach 9.1 billion by 2050. Consequently, agriculture will need to produce 60% more food globally by 2050, and 100% more in developing countries (WWAP, 2015). Population growth will be greatest in emerging economies, some of which are already facing water constraints. The agricultural sector is already the largest user of water, accounting for some 70% of all fresh water withdrawals globally, and over 90% in most of the world's least developed countries. It also accounts for about 30% of global energy consumption (WWAP, 2014a).

Global energy demand is projected to increase by 35% between 2010 and 2035, with the demand for electricity expanding by 70%, in the New Policies Scenario of the International Energy Agency (IEA, 2012). The Scenario takes into account existing and planned government policies. Fresh water withdrawals for energy production were about 583 billion m^3 in 2010, or some 15% of the world's total. Of this amount, consumption (the volume withdrawn and not returned to source) was 66 billion m^3 (~11%). By 2035, energy-related water withdrawals are projected to increase by about 20% to reach 691 billion m^3, whilst consumption will rise by 85% (to 120 billion m^3). This is due to changes in the power generation sector, and expansion of biofuel production.

The majority (over 90% in 2010) of energy-related water withdrawal is for power generation, which is dominated by water-intensive thermal electricity production from coal, natural gas and nuclear. Thermal power generation accounted for about 75% of the electricity generated in 2010. Its overall share is projected to fall to 68% in 2035, whereas the share of renewables (which includes some thermal electricity) more than doubles from 20% to 31%. Water withdrawals for power generation are projected to rise from 540 billion m^3 in 2010 to 560 billion m^3 in 2035 (a 3.7% increase), whilst consumption may increase by almost 40%. This is a result of a shift towards higher efficiency power plants with more advanced cooling systems, which withdraw less, but consume more, water per unit of electricity generated (IEA, 2012).

Global water demand is projected to grow by 55% between 2000 and 2050, due mainly to rising demands from manufacturing, thermal power generation and domestic use (OECD, 2012). Unless water demand and supply can be balanced, the world will face an increasingly severe shortage. A 40% water deficit by 2030 has been projected under a 'business-as-usual' scenario (2030 Water Resources Group, 2009). Ground water supplies are diminishing, with an estimated 20% of the world's aquifers being over-exploited, leading to serious consequences such as land subsidence and salt water intrusion in coastal areas (WWAP, 2015). Water quality is also deteriorating in some regions. Deterioration of wetlands worldwide is reducing the capacity of ecosystems to purify water. As fresh water supplies become depleted, other water sources are being utilised, such as brackish ground water. But this alternative water requires treatment before it can be used, and this consumes energy.

Climate change may exacerbate the situation as water and climate cycles are inextricably linked. The consequences of rising temperatures include higher surface water temperatures, greater evaporation, falling surface water flows (with the exception of glacier melt), a rise in sea levels (which will contaminate fresh water supplies), and more frequent and severe droughts, heat waves and floods. Over the past decade, the increased intensity of droughts, heat waves and local water scarcities has interrupted electricity generation, with serious economic consequences. Moreover, limitations on electricity availability have affected the delivery of water services.

The vulnerability of the energy sector to water constraints is widespread. Regions where water is scarce face obvious risks, but even regions with ample resources can face constraints due to droughts, heat waves, seasonal variations and other factors. For example, France has been forced to reduce or halt electricity generation in nuclear power plants due to elevated water temperatures threatening cooling processes during heat waves. The Parli coal-fired power plant in India had to shut-down in February 2013 because of a severe water shortage. In the USA, several nuclear and fossil fuel-fired power plants (some in regions with abundant water resources) have had to temporarily reduce power generation or shut-down due to low water flows, low reservoir levels or high water temperatures. Furthermore, the 2011 drought in Texas led to the temporary cessation of hydraulic fracturing and other natural gas extraction operations. Interruption of fuel supplies can, in turn, create issues for power generators. Recurring and prolonged droughts threaten hydropower capacity in China, Brazil and elsewhere. As well as affecting existing power plant operations, water constraints can affect the viability of proposed projects.

Regulatory restraints may impose limits on, or increase the cost of, water use by the energy sector. Water access may become difficult when it is prioritised for competing uses; households are frequently given priority under drought conditions. Environmental regulations can affect water management. Power plants are often required to limit the discharge of water heated in the cooling system to minimise adverse environmental impacts, such as harm to aquatic organisms. This has caused some plants to reduce power output or even close down at times to ensure they do not exceed the permitted discharge temperature. Stricter water pollution standards are also likely to result in increased energy consumption.

Growing demand for limited water resources is leading to increased competition between the energy sector and other water users, potentially leading to more conflicts over water allocation. Disputes between countries may arise if water abstraction from shared watersheds or trans-boundary rivers adversely affects water supply. Over 200 major river systems are shared by two or more nations.

As nations try to balance water resources with the need to support growing energy, agricultural, human health, industrial, and ecological demands in the coming decades, it is clear that water is a key factor for achieving a secure, resilient, and sustainable energy future.

This report examines the availability of fresh water for power generation, particularly for coal-fired power. The term 'water' in this report generally refers to fresh water unless otherwise stated. The report begins by looking at where water stress is occurring in the world today, before discussing global water demands of the agricultural, industrial and municipal sectors. Typical consumption of water in thermal power generation (coal, natural gas, oil, nuclear, biomass) and other power generation technologies is then considered and compared. Four countries where there are regional concerns about water shortages (namely China, India, South Africa and the USA) are examined in more detail. These are the four top thermal coal consuming countries in the world, and are also among the top ten coal producers; all have water-stressed regions. A regional analysis of water and energy issues in Europe and North America, Asia and the Pacific, the Arab region, Latin America and the Caribbean, and Africa can be found in WWAP (2014a).

Each country chapter examines the availability and consumption of water within the country, and central government energy, climate and water policies and how they affect the coal-fired power generation sector. Historically, countries have developed their energy and water policies separately, without considering the implications for each other – such as the effect of energy policy on water usage and the energy requirements of the water policy. Energy planners often assume that adequate water resources will be available, whilst water planners similarly assume that energy supplies will not be a constraint. If one of these assumptions fails, then consequences could be disastrous. The differences between the approach to water management in the various countries are examined.

Alternative (non-fresh) water sources will be covered in a future report. These are water sources external to a power plant, such as mine water, water from desalination plants, and water produced as a by-product of hydrocarbon extraction. Technologies for reducing water consumption and recovering water within a coal-fired power plant will also be covered in a later report. Low water flue gas desulphurisation technologies are described in Carpenter (2012).

2 Energy and water issues

Although 70% of the earth's surface is covered with water, most of it is salt water. Only about 2.5% of the world's water is fresh water, and of that, less than 1% is accessible via surface sources (lakes and rivers) and aquifers (subterranean water) – the remainder is locked up in glaciers and ice caps, or is deep underground (IEA, 2012). Fresh water is generally a renewable natural resource, but its availability is unevenly distributed across the planet, due to differences in climate, geography and human use. Furthermore, the quantity and quality of available water varies over the year. Surface water levels, for example, are lower and warmer during the summer than in winter. Consequently, some regions face more water constraints than others.

2.1 Global water availability

Global demand for fresh water (and energy) is expected to grow with rising population, increasing urbanisation and industrialisation, higher standards of living, and greater food demand. The majority of the growth in population will be in emerging and developing economies, some of which are already facing water scarcity, stress or some degree of vulnerability (*see* Figure 1).

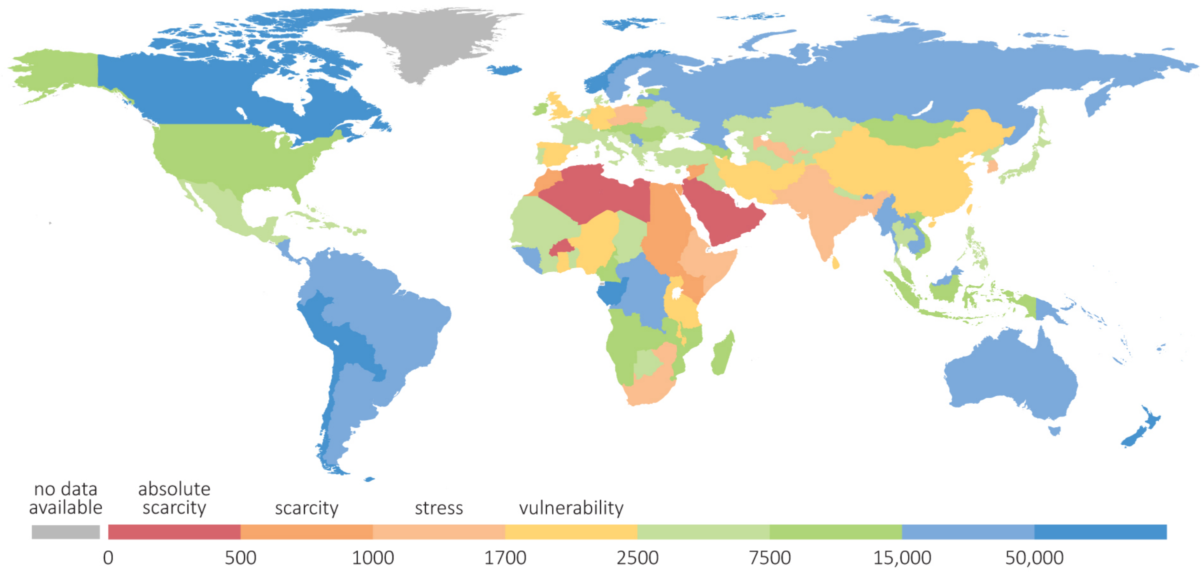


Figure 1 Total renewable water resources per capita (in m^3) in 2013 (WWAP, 2015)

It is projected that by 2025 more than 2.8 billion people in 48 countries will be facing water scarcity conditions. By 2050, the number of countries facing water scarcity is anticipated to rise to 54, with 40% of the world's population living in areas of severe water stress (World Economic Forum, 2014; WWAP, 2014a). This includes countries in North and South Africa, South and Central Asia, the Middle East, and Europe. According to the United Nations, water stress occurs when water supplies drop below 1700 m^3 per person per year and water scarcity is when there is less than 1000 m^3 per person per year.

Even countries with seemingly ample water available at a national level may face scarcity in particular regions, such as the southwest USA (*see* Figure 2). The Figure shows that significant areas of almost every continent are currently facing a high level of water stress. Here, water stress is the ratio of total withdrawals to total renewable supply in a given area. A higher number means more water users are competing for limited supplies. Large areas in India, China, Southern Africa, North Africa, the Middle East and the USA are affected. The projected increase in water withdrawals will deepen water scarcity and stress, and lead to an increasingly water-constrained future in more regions around the world. Climate change is likely to exacerbate the situation. Reduction in precipitation as a consequence of changing climate patterns in many of the mid-latitude regions is expected to reduce fresh surface water supplies by 20–40% by 2050 (Hightower, 2014).

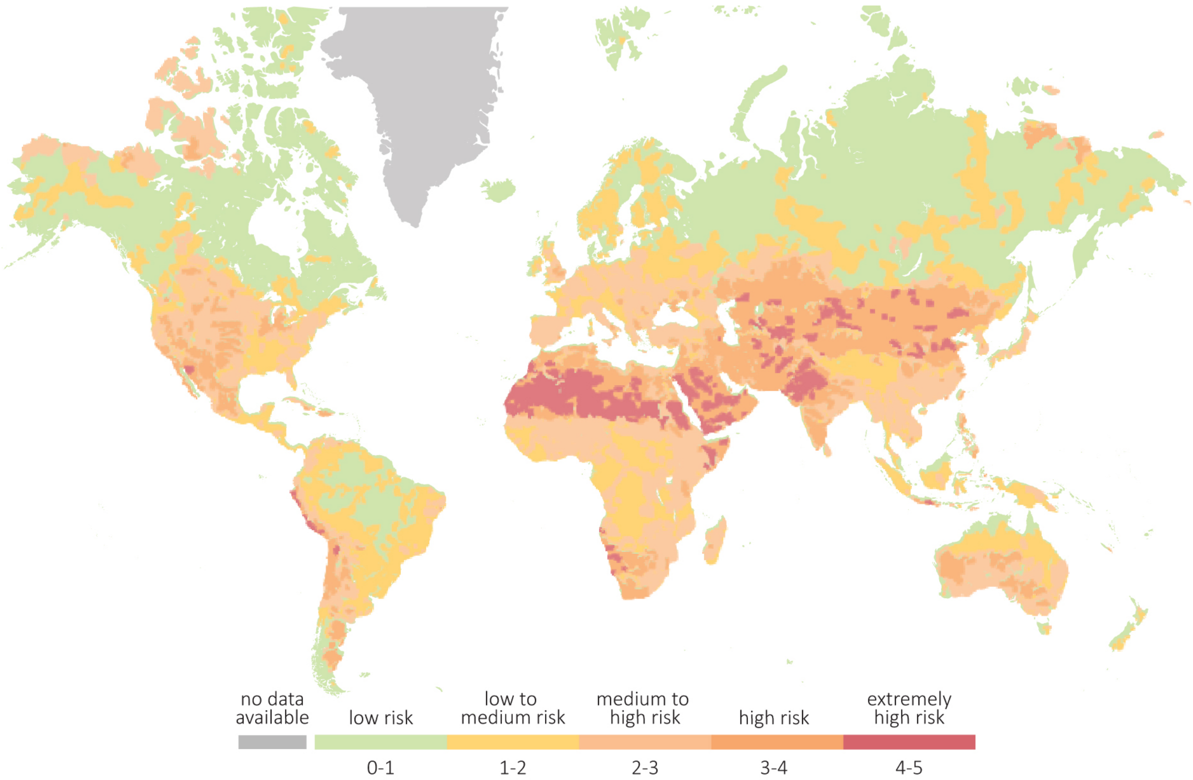


Figure 2 Water-stressed regions (WRI, 2015)

Over the last century, ground water has become a significant source of water, accounting for about 26% of total global water withdrawals. It provides drinking water to around half of the global population. As of 2010, some 1000 billion m^3/y of ground water was abstracted. Of this, about 67% was used for irrigation, 22% for domestic purposes, and 11% by industry. India was the biggest abstractor (251 billion m^3/y), followed by China and the USA, each abstracting 112 billion m^3/y (WWAP, 2012a); all three countries have water-stressed regions (*see* Figure 2). However, ground water supplies are diminishing, with an estimated 20% of the world's aquifers being over-exploited (WWAP, 2015).

Most aquifers have a considerable buffer capacity due to the relatively large volumes of water stored underground, so water can be abstracted even during long periods without rainfall. Nevertheless, uncertainty over the amount of ground water stored in aquifers and their replenishment rates pose a serious challenge to their management and, in particular, to their ability to serve as a buffer to offset periods of surface water scarcity.

Water availability may also be affected by pollution problems caused by intensive agriculture, industrial production, mining, untreated urban runoff and waste water. Pollutants cause environmental and health risks, and expensive water treatment may be necessary before polluted water can be reused.

2.2 Global water demand

Globally, agriculture is the principal user of water, accounting for about 70% of total water withdrawals, followed by industry (including mining and power generation) at 20% and the domestic sector uses the remaining 10% (WWAP, 2014a). These figures vary considerably across countries. Industry is typically responsible for a higher proportion of fresh water withdrawal in developed countries, whereas agriculture dominates in emerging and developing economies. Agriculture will need to produce 60% more food globally by 2050 in order to feed the projected population growth of about 80 million people per year, rising to 100% in developing countries (WWAP, 2015). Consequently, agricultural water consumption is expected to rise by about 19% in 2050 without improved water efficiencies (WWAP, 2012a). The OECD projects a 60% increase in water demand for livestock and a 14% decrease in irrigation water demand over the period 2000 to 2050 under their baseline scenario (*see* Figure 3). The baseline scenario reflects a combination of no new policies and continuing socioeconomic trends. But most of the increase will be in regions already suffering water scarcity.

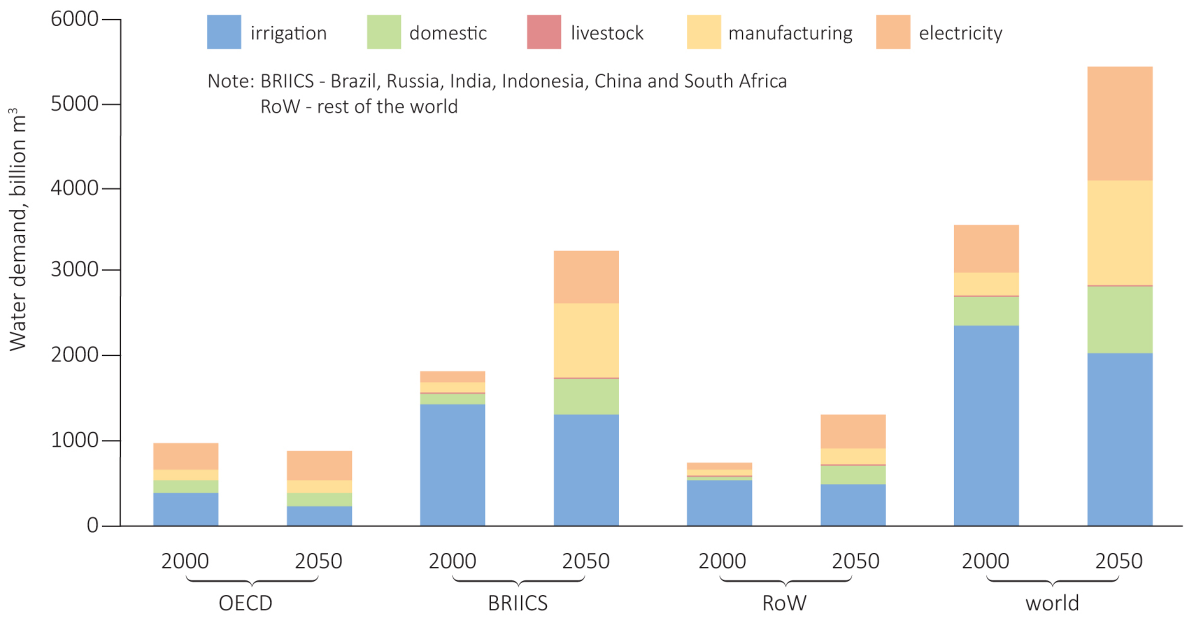


Figure 3 Global water demand (fresh water withdrawals) under the baseline scenario (OECD, 2012)

According to OECD (2012), global water demand will increase by 55% between 2000 and 2050 and, within that, domestic water use will rise by some 130% (*see* Figure 3). The increase will be most marked in countries with a growing urban population and rising affluence; per capita water consumption generally increases with affluence. Urban populations are projected to grow to 6.3 billion by 2050

(WWAP, 2012a), and to double by 2030 in Africa and Asia (WWAP, 2015). Consumption will also increase as more people presently without access to water are connected to water supplies. Around 748 million people today do not have access to an improved source of drinking water, and in 2012, some 2.5 billion people were without basic sanitation (WWAP, 2015).

Industry accounts for some 20% of global water withdrawals, but with big regional differences – 2% in South Asia and 77% in Western Europe (WWAP, 2014a). The IEA estimated that energy production (including power generation) was responsible for about 15% of global water withdrawals in 2010, or some 75% of all industrial withdrawals. In their New Policies Scenario (IEA, 2012), water withdrawals for energy production are projected to rise by 20% in 2035, with China and India accounting for over half of the growth (China increasing from 106 billion m^3 in 2010 to 145 billion m^3 in 2035, and India from 40 billion m^3 to 58 billion m^3). All IEA projections in this chapter are for the New Policies Scenario (described in Chapter 1). Water demand from the electricity generation sector is projected by the OECD (OECD, 2012) to increase by some 140% between 2000 and 2050, whilst demand from manufacturing rises by 400%, the biggest increase of all the sectors (*see* Figure 3). The bulk of the increase is expected to occur in the BRIICS countries, namely Brazil, Russia, India, Indonesia, China and South Africa. For Asia, a 65% rise in industrial water usage is forecast between 2000 and 2030 (WWAP, 2014a). Water requirements for primary energy production and power generation are discussed in more detail in Sections 2.4 and 2.5, respectively. Competing demands for water will lead to increasingly difficult decisions on water allocations and could limit the expansion of sectors essential for economic growth.

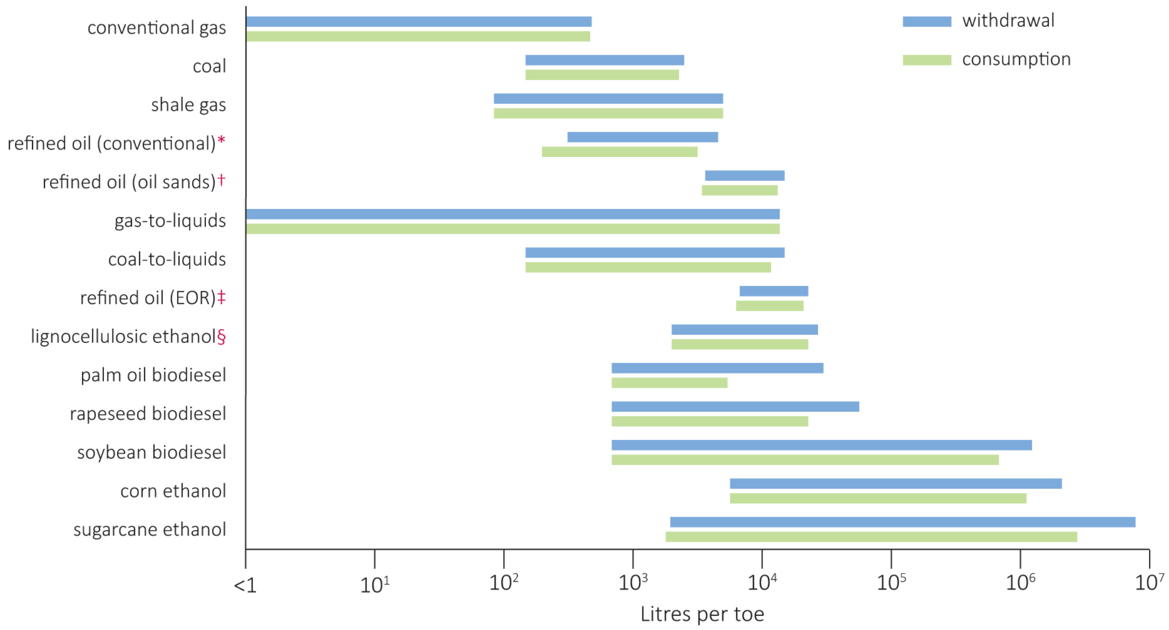
2.3 Energy requirements for water provision

Energy is required for the extraction, transport and treatment of water. Around 7–8% of global energy is used to raise ground water to the surface and pump it through pipes, and to treat both ground water and waste water. This figure rises to around 40% in developed countries (WWAP, 2012a). Water for agriculture generally requires little or no treatment, and so energy requirements are mainly for pumping (WWAP, 2014a). The amount of energy needed for water and waste water treatment depends on the quality of the source water, the nature of any contamination, the treatment process and other factors.

As fresh water supplies become strained, water sources once considered to be unusable, such as brackish ground water and sea water, will increasingly be employed. In addition, more waste water will need to be reused. All these water sources require treatment before they can be utilised. Treatment of brackish water, sea water and other saline water entails desalination, the most energy intensive water treatment process. Desalination capacity has increased significantly over the last 20 years as countries try to augment fresh water supplies, and is expected to continue to grow as technology developments lower energy consumption and costs. At least 75.2 TWh/y is consumed in water desalination, or about 0.4% of global electricity consumption. Although desalination may be appropriate for supplementing water supplies for some domestic and industrial users in middle- and high-income regions near the coast, it is currently not an affordable alternative for the poorest countries, for large water consuming sectors such as agriculture, or for consumption at a distance from the plant due to transportation costs (WWAP, 2014a).

2.4 Water requirements for primary energy production

Water is needed for the production of nearly all forms of energy. For primary fuels, water is used for irrigating biofuel feedstock crops, and in the extraction, refining, processing and transport of fuels. The water requirements for the various processes vary widely (*see* Figure 4).



* the minimum is for primary recovery; the maximum is for secondary recovery
† the minimum is for in situ production; the maximum is for surface mining
‡ includes CO_2 injection, steam injection and alkaline injection and in situ combustion
§ excludes water use for crop residues allocated to food production

Notes: Ranges shown are for source-to-carrier primary enegy production, which includes withdrawals and consumption for extraction, processing and transport. Water use for biofuel production varies considerably because of differences in irrigation needs among regions and crops; the minimum for each crop represents non-irrigated crops whose only water requirements are for processing into fuels. EOR: enhanced oil recovery; toe: tonnes of oil equivalent. For numeric ranges see: www.worldenergyoutlook.org

Figure 4 Water use for primary energy production (IEA, 2012)

Figure 4 shows that conventional natural gas production is generally less water intensive than producing other fossil fuels or biofuel. The amount of water required for conventional gas and oil extraction is determined mainly by the recovery technology, the geology of the deposit and the production history. Secondary oil recovery techniques that use water flooding to support reservoir pressure can use about ten times more water than primary recovery (IEA, 2012). If insufficient water is available, then an oil or gas reservoir that requires water flooding to support production will see a fall in output. High volumes of produced water (water that comes out of the well with the gas and oil) are generated. After treatment, this water can be reinjected to enhance oil recovery. It could also provide an alternative water source for a nearby power plant. After extraction, natural gas and oil must be processed, transported and stored. The amount of water required for refining crude oil into end products varies widely according to the technologies employed (such as the cooling system) and process configuration. Typical volumes of water needed for extraction through refining into petroleum-based fuels are 7–15 L water/L fuel (WWAP, 2014a).

Global demand for natural gas and oil is expected to continue to grow (and consequently the associated water requirements), with most of the growth in emerging economies. More than 40% of the gas required to meet the projected demand to 2040 is expected to come from conventional sources, with the rest from unconventional sources (primarily shale gas). Overall, the share of unconventional gas in total gas output is projected to rise from 17% to 31% between 2012 and 2040 (IEA, 2014d).

Unconventional gas (shale gas) and oil (oil sands) production is generally more water intensive than conventional gas and oil production (*see* Figure 4), due mainly to the additional water required for hydraulic fracturing (fracking). Water requirements vary from well to well depending on the gas recovery rate, number of hydraulic fracturing treatments needed, and the use of water recycling (IEA, 2012). Based on experience in the USA, drilling a single well needs 0.2–2.5 million L of water, and hydraulic fracturing a well requires 7–23 million L (Reig and others, 2014). Drilling and fracturing several wells, multiple times, in the same area, can rapidly escalate local water consumption. There is also a risk of contaminating ground water. Innovations in hydraulic fracturing may reduce water requirements in the future. Reusing more water recovered from wells, or saline water rather than fresh, may lessen some of the effects of hydraulic fracturing on both water quantity and quality. The amount of produced water that comes to the surface with the gas or oil varies widely between wells, depending on the formation geology.

There is a considerable potential for the development of shale resources gas. Known shale gas deposits worldwide have added 47% to global technically recoverable natural gas resources, and tight oil deposits some 11% to the world's technically recoverable oil. Shale resources are already being actively exploited in the USA, Canada and elsewhere. A lack of fresh water availability could curtail shale development in many places around the world. Some 38% of global shale resources are in areas that are either arid or under a high level of water stress. These include areas in China, Mexico and South Africa, which have some of the largest technically recoverable shale gas and tight oil resources (Reig and others, 2014). Public concerns over ground water contamination and possible earthquakes may also limit shale resource development.

Water is used in coal mining for cutting coal, suppressing dust and other activities. The amount needed depends on the characteristics of the mine (surface or underground), and processing and transport requirements. Underground mining typically uses more water than surface mining (WWAP, 2012a). Many surface and underground mines are situated at least partially below the water table, and so water must be pumped from the working area. This water could be captured, treated (if necessary) and reused (if it is not already).

Washing coal improves its quality, but requires water. The amount used depends on the design of the plant, number of washing stages and other factors. Dry technologies, which will be needed in water-stressed areas, are available and more efficient processes are being developed. Washing is mostly carried out for export quality grades of coal, and is likely to become more widespread in countries such as India, where coal quality is poor (*see* Chapter 4). Burning higher quality coal in power plants improves combustion efficiency, and hence lowers water consumption, as well as reducing sulphur dioxide and particulate emissions.

The key water quality concerns arising from coal production are runoff from mine operations and tailings that can pollute surface and ground water. Underground mining may disrupt and contaminate aquifers, affecting other water users relying on the aquifer for their water supply. Coal-to-liquids technologies, which generate transport fuels as an alternative to crude oil, are also water-intensive.

Coal production is projected by the IEA to increase in non-OECD countries by 20% between 2012 and 2040 (IEA, 2014d). India and Indonesia together account for 60% of this growth, with production projected to increase from 372 Mtce in 2012 to 664 Mtce in 2040 in India. China is expected to remain the largest coal producer, with production growing from 2695 Mtce to 2779 Mtce over this timeframe. Many of the planned new mines in China and India are in water-stressed regions. It is anticipated that coal production will continue to decline in OECD countries to 2040, with the exception of Australia (currently the world's second largest coal exporter).

Virtually all nuclear power plants use uranium. Mining and processing uranium requires some 0.086 m^3 of water per GJ (WWAP, 2012a). Demand for uranium is projected by the IEA to grow from 56,000 t in 2012 to 106,000 t in 2040 (IEA, 2014d).

The production of biofuel (irrigation and fuel conversion) generally requires more water per unit of energy then fossil fuel production (*see* Figure 4), mainly because of the water demand for irrigation. Irrigation requirements vary widely depending on the crop, the region where it is grown, and the water efficiency of the irrigation technology used. Growing feedstock crops which require minimal water or their cultivation in areas with ample rainfall can greatly reduce or eliminate irrigation water demand (IEA, 2012). Growing crops for energy will compete with food crops for scarce land and water resources, already a major constraint on agricultural production in many parts of the world. China and India have both initiated programmes for boosting biofuel production, but they are already facing severe water limitations in agricultural production (WWAP, 2014a).

Biofuel production is expected to increase significantly in Brazil, China, India, the European Union and USA in order to meet rising global demand. Global demand for bioenergy (which includes biomass, biofuel and biogas) is projected by the IEA to rise from 1344 Mtoe to 2000 Mtoe between 2012 and 2040 (IEA, 2014d). Bioenergy consumption in the power generation and transport sectors is expected to more than triple over this period, whilst industry use rises by 80%. Consequently, water withdrawals for biofuel production and power generation are projected to rise from 25 billion m^3 to 110 billion m^3 over 2010 to 2035, and consumption to increase from 12 billion m^3 to almost 50 billion m^3 (IEA, 2012). This is mainly due to the irrigation of feedstock crops for ethanol and biodiesel (principally sugarcane, corn and soybean) in the major producing countries. The growth in the use of bioenergy (wood, agricultural residues, municipal waste and biogas) for power generation is being driven by a combination of government policies, technological advances and higher prices for fossil fuels.

2.5 Water requirements for power generation

Power generation accounted for over 90% of global water withdrawals for energy production in 2010 (IEA, 2012). Thermal power plants (which are responsible for about 80% of global electricity generation) are the largest users of water. Water is heated to convert it to steam to power turbines. The heat is generated from a range of fuels including coal, natural gas, oil, nuclear, biomass, solar thermal energy (also known as concentrated solar power), and geothermal energy.

Several factors determine how much water is required by thermal power plants, including the fuel type, plant efficiency, cooling system, and prevailing meteorological conditions. Water is primarily used at thermal power plants for cooling. The ambient temperature of the cooling water largely dictates the efficiency of the power plant as warmer water is less effective in removing heat. Generally, the more efficient the power plant, the less heat has to be dissipated, and consequently less cooling is needed. Older power plants tend to be less efficient than newer ones, and thus consume more water (using the same cooling system under similar meteorological conditions). Climate change is likely to increase water requirements due to the resultant higher ambient air and water temperatures. Water is also needed at fossil fuel power plants for boiler feedwater, pollution control systems, handling ash in coal-fired power plants, and for other uses around the plant. Wet flue gas desulphurisation (FGD) systems consume some 250 L/MWh of make-up water in subcritical coal-fired power plants and around 220 L/MWh in supercritical plants; semi-dry FGD technologies consume approximately 60% less water (Carpenter, 2012).

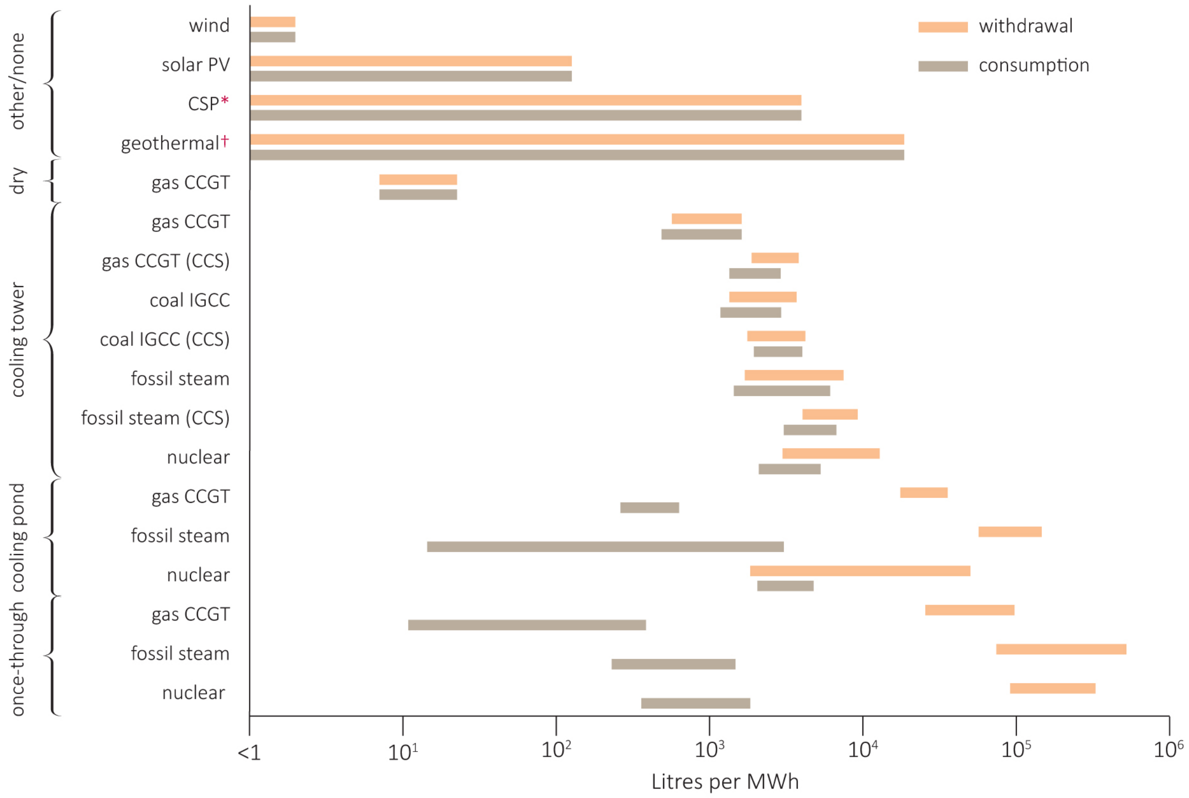
The cooling system used largely determines how much water is required at thermal power plants. There are two broad categories of cooling systems: open-loop and closed-loop, which is further subdivided into wet, dry and hybrid systems. Each of these systems involves trade-offs in terms of water use, impacts on water quality, plant efficiency and cost (IEA, 2012), as follows:

- Open-loop or once-through systems withdraw large amounts of water (fresh or saline), use it once to condense steam exiting the turbine, before returning most of it to the source; only a small fraction is consumed through evaporation. The water is discharged at a higher temperature, which can be detrimental to aquatic life and ecosystems. Therefore the discharge temperature is usually regulated. Nevertheless, fresh water (when used) is available for use by downstream users. The capital costs of open-loop systems are the lowest, but water withdrawal requirements are the highest. Power plants with fresh water cooling systems are more exposed to fluctuations in water availability due to their high water withdrawal needs;
- Wet closed-loop (or wet closed-cycle or wet recirculating) systems withdraw less water than open-loop systems as the heated water is cooled through the use of a wet tower or pond and reused. Most of the withdrawn water is lost through evaporation. The lower water withdrawal rate reduces exposure to risks posed by constrained water resources, as well as environmental impacts (but periodic discharges are needed to prevent the accumulation of minerals and dissolved solids in the

system). However, water consumption and capital costs are higher than open-loop systems, and more land is required. Plant efficiency is also lower;

- Dry cooling systems use air instead of water as the cooling medium in the cooling tower. Water requirements are minimal compared with the other cooling systems, and therefore they are better suited to drier regions. But they are the least attractive economically, costing about 3–4 times more to build than wet tower or pond systems. They typically have a larger footprint and higher capital costs than open-loop facilities of comparable capacity. Dry cooling lowers overall plant efficiency by about 2 to7 percentage points (more on hot days) since air is a less efficient cooling medium than water. Spraying water within a dry-cooled tower can increase the efficiency of the system but increases water consumption;
- Hybrid systems combine air cooling in tandem with a wet tower. These offer the flexibility of operating during warm and cool periods, but are expensive, and suffer from the same shortcomings as dry cooling when water resources are unavailable. Water consumption will be between those for air cooling and wet closed-loop systems. They are not widely used.

Water withdrawals per unit of electricity generated are highest for fossil fuel-fired (steam cycle) and nuclear power plants with open-loop cooling (*see* Figure 5). Nuclear power plants tend to operate with lower thermal efficiencies than typical coal and gas plants because they operate at lower temperatures; hence their water withdrawals are the highest. Combined-cycle gas turbines (CCGT) generate less waste heat per unit of electricity produced due to higher thermal efficiency (and less need for emission control), and therefore require less cooling. The water withdrawal and consumption rates of CCGT plants are the lowest among the thermal power plants (with similar types of cooling system).



* includes trough, tower and Fresnel technologies using tower, dry and hybrid cooling, and Stirling technology
† includes binary, flash and enhanced geothermal system technologies using tower, dry and hybrid cooling

Notes: Ranges shown are for the operational phase of electricity generation, which includes cleaning, cooling and other process related needs; water used for the production of input fuels is excluded. Fossil steam includes coal-, gas- and oil-fired power plants operating on a steam cycle. Reported data from power plant operations are used for fossil steam once-through cooling; other ranges are from the literature and IEA analysis. Solar PV: solar photovoltaic; CSP: concentrating solar power; CCGT: combined-cycle gas turbine; IGCC: integrated gasification combined cycle; CCS: carbon capture and storage.
For numeric ranges see www.worldenergy outlook.org

Figure 5 Water use for electricity generation by cooling technology (IEA, 2012)

Fitting fossil fuel power plants with CCS systems increases water requirements. As well as the water needs of the CO_2 capture process, additional water is required to meet the higher cooling needs associated with reduced power plant efficiencies and consequently, greater heat generation. Adding a CCS system to power plants with a wet cooling tower is estimated by the US Department of Energy to increase water withdrawals by between 60% for coal-fired integrated gasification combined cycle (IGCC) power plants and 95% for gas-fired CCGT plants; consumption rises by similar amounts (IEA, 2012). Waste heat integration may lower fresh water withdrawal and usage. Any waste water produced in the capture process could, after treatment, help meet the increased water requirements. Less water- and energy intensive technologies are being developed.

Renewable technologies that use a cooling system (biomass, concentrated solar power (CSP) and geothermal) withdraw and consume similar, or even higher, amounts of water than fossil fuel and nuclear power plants with the same type of cooling system. Their water requirements vary widely depending on the particular technology and cooling system employed. Dry cooling systems are being installed at some CSP plants to reduce water use, although this increases cost and lowers plant efficiency.

Most of the growth in power generation from thermal power plants will occur in water-constrained countries. Natural gas for electricity (and heat) generation is projected by the IEA to increase at an annual rate of 1.5% between 2012 and 2040; its overall share in the energy generation mix increases from 22% to 24% in 2040. Some 80% of the growth occurs in non-OECD countries, particularly in water-stressed China and the Middle East (*see* Figure 2), where gas-fired capacity is expected to more than double to 1440 GW by 2040. Global coal-fired power generation is projected to grow by 40% over the same time frame, although its share of the energy mix falls from 41% to 31%. Most of the growth occurs in China, India, Southeast Asia and Africa, whilst coal-fired power generation declines in OECD countries. Oil-fired power generation is likely to diminish, partly due to more competition for oil by the transportation sector. Nuclear power capacity is projected to increase from 392 GW to 624 GW, with China, India, Korea and Russia seeing the most significant increases. Geothermal electricity generation is projected to grow from 70 TWh to almost 380 TWh in 2040, with the largest amounts installed in Africa, the USA, Japan and Southeast Asia. The largest increase is from CSP, which is projected to grow at an annual rate of 16.7%, to reach around 360 TWh in 2040 (from 5 TWh in 2012). The additions occur primarily in the USA, although China, the Middle East and Africa, all with water-constrained regions, lead additions after 2020 (IEA, 2014d).

Based on energy projections in the 2012 World Energy Outlook New Policies Scenario, water withdrawals for power generation could reach 560 billion m^3 in 2035, compared to 540 billion m^3 in 2010 (IEA, 2012). The slowly rising requirement is due to two counteracting forces at play. A reduction in generation from subcritical coal-fired plants that use open-loop cooling systems, particularly in the USA, China and European Union, cuts global water withdrawals by almost 10%. But the growth in new nuclear power plants that use open-loop cooling increases water withdrawals by a third. Water consumption is projected to increase by almost 40%, boosted by the increased use of wet tower cooling. The rising share of gas-fired and renewable generation plays a significant role in constraining additional water use as global electricity demand grows by 70% over 2010–35, much more that the projected water withdrawals (3.7%) and water consumption (40%).

Non-thermal renewables, such as wind and solar photovoltaic, generally use minimal amounts of water. Water is needed for maintenance, such as washing solar photovoltaic panels. This makes them well-suited to water-constrained regions. Furthermore, they have little impact on water quality compared to thermal power plants that discharge large volumes of heated cooling water or contaminants into the environment. In addition, renewable technologies will not require water for CCS systems since they do not emit CO_2. Electricity generation from wind and solar photovoltaic is one of the fastest growing sectors in the world, with declining production costs and more countries, such as India, introducing policies to support their growth. The IEA projects that wind power capacity will increase by 1003 GW and solar photovoltaic by 794 GW between 2013 and 2040 (IEA, 2014d). However, increasing air temperatures could reduce the generation efficiency of solar photovoltaic cells due to constraints on the semiconductor materials. A rise of 1°C decreases output from a crystalline silicon cell by 0.65% (Li and others, 2014a). In addition, the intermittent service provided by wind and solar photovoltaic has to be compensated for by other sources of power, mostly thermal power plants that require large amounts of water. Developments in energy storage could reduce this need.

Although hydropower is a major water user, most of the water is returned to the river downstream of the plant after it has passed through the turbines or when the reservoir has been filled. Water is consumed via seepage and evaporation from the reservoir, which are difficult to quantify. Consumption is highly site-specific and variable, depending on the climate, reservoir demand and water allocations for other uses. It is difficult to attribute the share of evaporation specific to power generation because of the multipurpose nature of most reservoirs. Estimates for hydropower plants in the USA range from 40 L to 209,000 L/MWh (Sanders, 2015). 'Run-of-river' hydropower plants consume minimal water as they store little water, and thus evaporation losses are near zero. Currently, they are too small in scale to supply large amounts of energy and are therefore, best suited for small community projects (WWAP, 2014a). Hydropower plants do not pollute water and so the water can be used by downstream users. However, large-scale hydropower plants have been criticised for the damage they cause to the environment and biodiversity, for loss of cultural and historical sites, and social disruption. In addition, there may be times when the reservoir and water levels drop to near or below the water intake structures, thereby curtailing or halting electricity generation.

Hydropower is currently the largest renewable source for power generation in the world. Its share in the global electricity mix is projected by the IEA to remain at 16% over the period 2012 to 2040. Hydropower generation capacity, though, grows by 70% over this time period, the second largest increase in renewable-based generation after wind (IEA, 2014d). Consequently, water consumption from hydropower generation will rise. The majority of hydropower additions are expected in Latin America, Asia (particularly, China and India), and Africa.

3 China

China is the world's most populous country, with almost 20% of the world's population. It is the second largest user of water, responsible for 14% of global withdrawals (Reig and others, 2014), and is the third driest country, holding only 6% of global fresh water resources. Water scarcity has emerged as one of the most significant challenges to China's economic and social development.

3.1 Water resources, demand and use

Water resources are unevenly distributed across China. In general, the southern region is water-rich, whilst the northern and central regions are experiencing shortages. Unfortunately, the population and economic activity are concentrated disproportionately in the arid North China Plain. Although water demand is growing, supply is becoming increasingly limited. Already seven provinces and autonomous regions (Beijing, Hebei, Henan, Jiangsu, Ningxia, Shanghai and Tianjin) are running water deficits where water withdrawals exceed their renewable resources (Tan and other, 2015). Drought, shrinking snow caps and retreating glaciers are all reducing water supplies and river flows across China. Climate change will only worsen the situation, with northwestern China projected to experience a 27% decline in glacier areas (WWAP, 2012a). Ground water accounts for ~20% of China's total water consumption, but as much as 50–80% in the north and northwest (Lehane, 2014). Some 112 billion m^3/y of ground water were extracted in 2010 (WWAP, 2012a). Over-extraction has led to raised salinity in the aquifers, land degradation and a loss of agricultural productivity in the North China Plain. Furthermore, the over-exploitation has caused the water table to drop, with the depth of water wells increasing in response.

The annual renewable water resources (surface and ground water) for the whole country are an estimated 2840 billion m^3, and precipitation is about 6192 billion m^3/y (*see* www.fao.org/nr/water/aquastat/countries_regions/chn/index.stm). Average water resources are just 1730 m^3 per person per year, barely above the United Nation's water stress marker (7000 m^3 per person per year). Eight provinces have less than 500 m^3 per person per year of total available surface water (Luo and others, 2014). Moreover, the Ministry of Water Resources (MWR) in 2013 stated that the number of rivers had halved over the last 50 years (Lehane, 2014). Water pollution is exacerbating water shortages. About 30% of river water is considered to be unfit for agricultural and even industrial use (Faeth and others, 2014). Over 57% of ground water is polluted (Lehane, 2014), but this number increases to nearly 70% in the North China Plain (Tan, 2014). Agriculture is the largest water polluter.

The economic boom in China is contributing to water shortages with its demand for energy and water. The annual average gross domestic product (GDP) growth rate was about 10% between 2000 and 2011, but has now slowed to ~7.7% per year. This growth has led to China becoming the largest energy consumer in the world, with coal playing a crucial role in meeting its energy needs – in 2011 about 70% of primary energy consumption was from coal. Oil was the second largest source, accounting for 18% of the country's total energy consumption, followed by hydropower (6%), natural gas (4%), nuclear power (nearly 1%), and other renewables (1%) (EIA, 2014a). Primary energy production more than doubled between 2000 and 2010. Energy demand is projected to increase from 2909 to 4185 Mtoe (44%) over the period 2012–40 in the IEA's New Policies Scenario (IEA, 2014d). This scenario is based on the continuation of existing policies, and implementation of policies already announced. Consequently, there will be more competition for limited water resources.

Agriculture is by far the largest consumer of water, followed by the power sector, which, in 2012, used ~10% of China's water (Tan and others, 2015). The MWR estimated that annual water use will increase from 591 billion m^3 in 2010 to as much as 630 billion m^3 in 2020. The largest share of the increase (15 billion m^3/y) is due to the increase in coal mining and processing, and coal-fired power generation (Schneider, 2011). But a water deficit of some 200 billion m^3 in 2030 has been projected by the 2030 Water Resources Group (2009) in their base case scenario; demand is projected to reach 818 billion m^3 in 2030, whilst current supplies are just over 618 billion m^3. According to Chinese government statistics, water usage in 2013 has already reached 618 billion m^3 (Tan and others, 2015).

3.2 Coal and power generation sector

China is by far the largest producer and consumer of coal in the world, accounting for just over half of 2013 global coal consumption. Preliminary data for this year shows that China produced 3560.7 Mt of coal and consumed 3880.6 Mt (IEA, 2014a). According to BP (BP, 2014) there were 114.5 Gt of proved reserves at the end of 2013, whilst the Bundesanstalt für Geowissenschaften und Rohstoffe state that overall coal reserves were 191.6 Gt in 2012 (Andruleit and others, 2013). Despite the ample reserves (third largest proven reserves after the USA and Russia), China is currently the world's biggest coal importer, with some 327.2 Mt imported in 2013 (IEA, 2014a). The amount of imported coal reflects the rising energy demand and the bottlenecks in transporting domestic coal to the end user. Over half of China's coal reserves are in the provinces of Shanxi, Shaanxi and Inner Mongolia in northern China, whereas the major consumers are in the East. These three provinces account for over half of China's coal production and 16% of thermal power generation, but are only endowed with 3% of water resources (Zhang and Anadon, 2013). Overall, 86% of coal reserves are in the North, which has only 25% of China's total renewable water resources (Tan and others, 2015).

Just over half of the coal is consumed in power and heat generation – China is the world's largest power generator. In 2012, China's total installed power generation capacity was 1144.9 GW, of which 758 GW (66.2%) was from coal-fired power plants. Hydropower contributed 248.9 GW (21.7%), natural gas 38.27 GW (3.3%), nuclear 12.57 GW (1.1%), wind 60.83 GW (5.3%), solar 3.28 GW (0.3%) and other sources <2% (Huang, 2013). However, the contribution of coal to electricity and heat generation was a larger percentage than its share of installed capacity. Some 3784.93 TWh and 3139.26 PJ were generated from coal in 2012, 78.5% of the total electricity generation (IEA, 2014a). Nearly 70% of the coal-fired power capacity and the majority of coal mines are in medium to extremely high baseline water stress provinces (*see* Figure 6). Medium stress areas are where 20–40% of the available renewable water supply is withdrawn every year, high stress areas are where 40–80% is withdrawn, and in extremely high water stress areas the number goes above 80%.

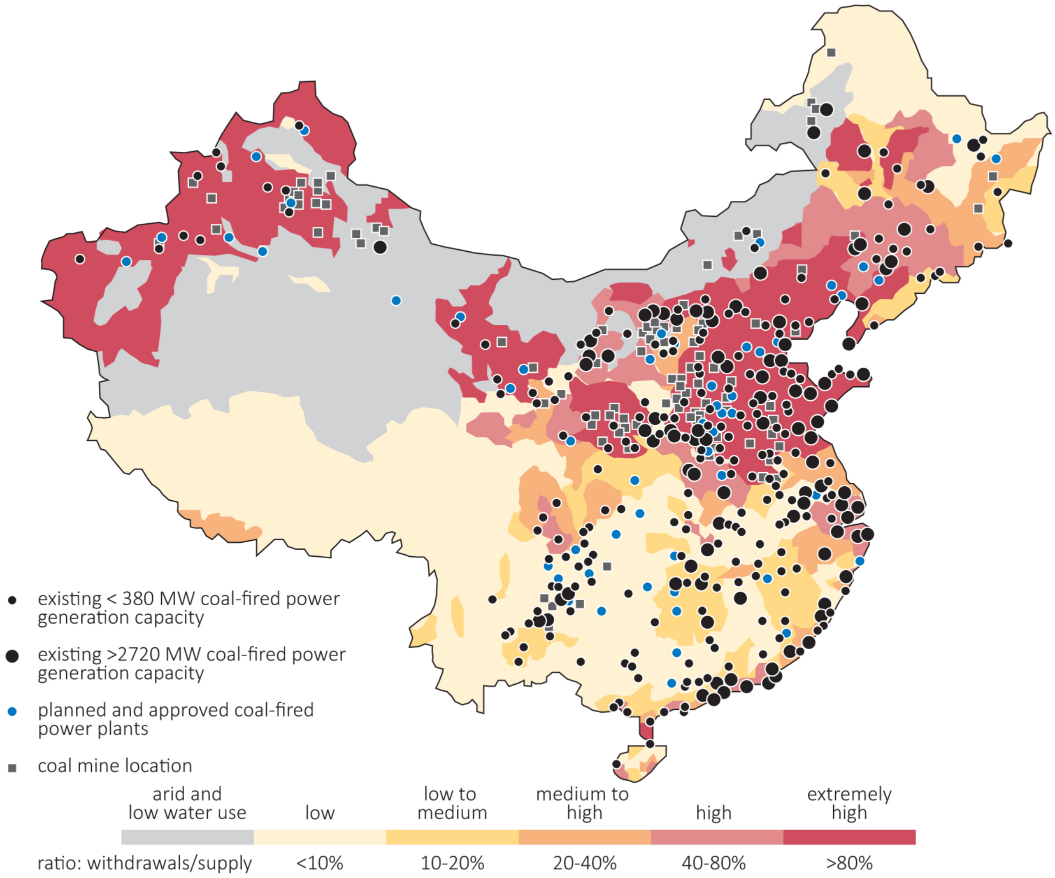


Figure 6 Location of coal mines, coal-fired power plants and water stress areas (Luo and others, 2013b)

Power generation from coal is expected to continue to grow because of China's large coal reserves and concerns over energy security, even as other cleaner fuels increase market share. The IEA projects a doubling of electricity generation over 2012–40, with coal and non-hydro renewables each accounting for around 30% of the growth (IEA, 2014d). Tan and others (2015) report that there are plans to add 650 GW of coal and gas, 325 GW of nuclear, 220 GW of hydro, and 808 GW of solar and wind over the period 2013 to 2050.

A World Resources Institute (WRI) report found that over half of the 363 planned coal-fired power plants (as of July 2012) are in high or extremely high baseline water stress provinces. More than 60% of the proposed generating capacity of 557.9 GW is concentrated in six northern provinces (Inner Mongolia, Shaanxi, Gansu, Ningxia, Shanxi and Hebei), which contain only about 5% of the country's total water resources. If built, the new plants could potentially threaten water security for other water users (Luo and others, 2013a). Two reasons for building the power plants in water scarce regions are that they are near the coal mines, which reduces coal transportation costs, and will bring power where it is needed, particularly to areas where industry is rapidly developing. It is not clear how many of the plants will eventually be built.

The IEA's New Policies Scenario projects a 37% increase in water withdrawals for energy production (including power generation) over the period 2010–35, from 106 billion m^3 to 145 billion m^3

(*see* Figure 7); consumption, though, increases by almost 90%, from 16 to 30 billion m³ (IEA, 2012). Water withdrawals by coal-fired power plants rise by 12%, despite their electricity output increasing by about 65%. This is due to the deployment of more efficient power plants and the use of wet cooling towers (which pushes up consumption). Water withdrawals by the coal mining sector are projected to rise by 18% for an equivalent percentage increase in coal production. Much of this increase is expected to come from the coal reserves in the dry north and west parts of the country. Water requirements per tonne of coal produced will rise as coal mining operations move deeper underground and the need for washing becomes more widespread.

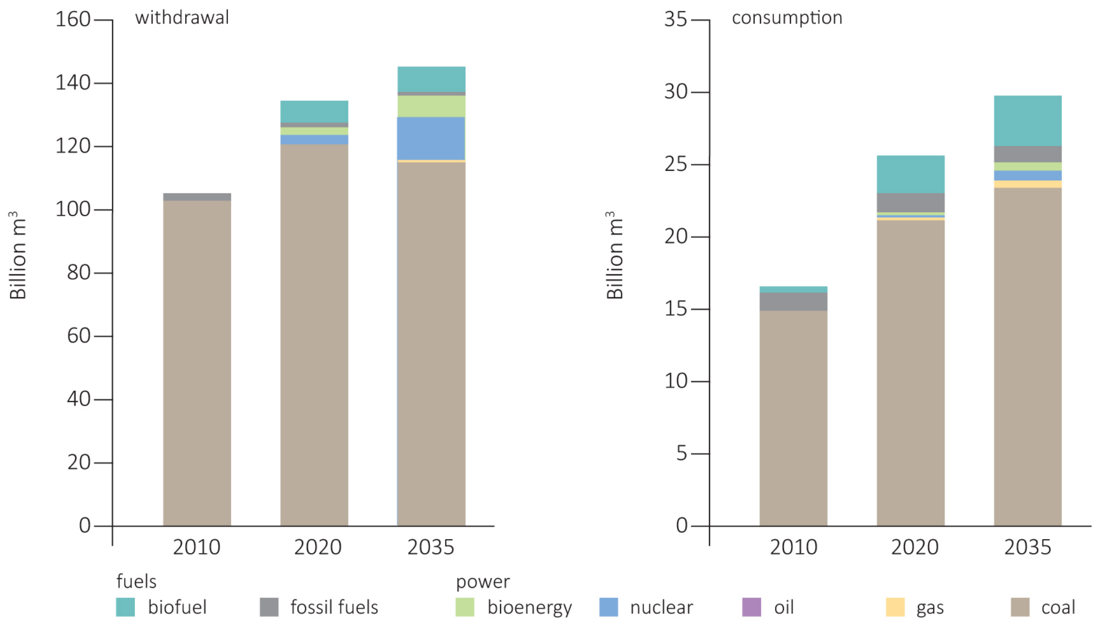


Figure 7 Water use for energy production (IEA, 2012)

Bloomberg New Energy Finance found that coal mining and coal-fired power generation together withdrew 98 billion m³ in 2010 or 15% of total fresh water withdrawals (Bullard, 2013). They project that water withdrawals by the power sector will grow from 102 to 124 billion m³ over 2010–40, driven by a tripling of water-intensive thermal power generation (Bloomberg New Energy Finance, 2013). According to the MWR, coal mining, processing and power generation consumed over 112 billion m³ of water in 2010, nearly 20% of national water consumption (Schneider, 2011). The term consumption as used here probably means withdrawal. The increase in water use will strain China's limited water resources.

China's high and rising energy demand, underpinned by fossil fuels, has resulted in the country becoming the world's largest emitter of CO_2, although in cumulative and per capita terms the USA is the larger emitter. In 2012, some 8.3 $GtCO_2$ were emitted from fuel combustion, of which 6.8 $GtCO_2$ came from coal. Electricity and heat production accounted for 4.1 $GtCO_2$ (IEA, 2014c). Installing CCS systems on power plants to control CO_2 emissions is likely to increase water consumption (*see* Section 2.5).

3.3 Energy policy implications for water

The Chinese government has some complex decisions to make on water policy since water, energy, food production, economic growth and social stability are inextricably linked. Energy policy goals may conflict with the need to manage water resources more efficiently. This section examines China's energy policy and its implications for water.

3.3.1 12th FYP for National Economic and Social Development

China operates on the basis of a five year planning cycle. The central government's ***Five-Year Plan (FYP) for National Economic and Social Development*** sets out the country's economic, social and environmental development, and provides guidelines, policy frameworks and targets to be met. The need to cut water consumption and pollution has again been recognised by the Chinese government in its current 12th FYP (covering 2011–15). The Plan sets new limits on water and energy consumption, and provides targets for reducing pollution. These include:

- Water consumption per unit of value-added industrial output to be cut by 30% from 2010 levels;
- Water efficiency coefficient in agricultural irrigation to increase to 0.53;
- Energy consumption per unit of GDP to be cut by 16% from 2010 levels;
- Non-fossil fuel use to account for 11.4% of primary energy consumption, with a target of 15% for 2020;
- CO_2 emissions per unit of GDP to be reduced by 17% from 2010 levels; and
- Chemical oxygen demand, and SO_2 and NOx emissions to be cut by 8%, 8% and 10%, respectively, from 2010 levels.

These targets are all binding. The CO_2 emission target is in line with an earlier pledge to cut CO_2 emissions per unit of gross GDP by 40–45% from 2005 levels by 2020. The Plan also states the need to enhance conservation of water resources and protect the environment, including setting up a polluter-pays system (Delegation of the European Union in China, 2011). Seven strategic emerging industries were listed that would be promoted. These include energy saving and environmental protection technologies, the development of which could help make thermal power plants cleaner and more energy efficient.

The energy intensity and carbon emission reduction targets have significant implications for water use. Circle of Blue has calculated that if these two targets are to be met then for each new dollar of economic growth, water use must decline by nearly a fifth (Schneider and Ivanova, 2011). Water use is expected to rise to 670 billion m^3 by the end of 2020. Economic growth is to be restrained to 7% a year under the 12th FYP, down from 10% in the previous four years.

3.3.2 12th FYP for Energy Development

The 12th FYP for Energy Development (*see* www.gov.cn/zwgk/2013-01/23/content_2318554.htm), released in January 2013 by the State Council (national government), clarifies the targets, key tasks and policy measures, in line with the national targets outlined in the 12th FYP for National Economic and

Social Development. It also encompasses previously released sub-sector industry energy plans, such as those for the coal industry, for coal, wind and solar power, and for emissions reduction and energy saving. Some of the main targets of the Energy Development Plan are given in Table 1; a number of these will impact water resources. The increase in primary energy consumption has been capped at 4 Gt of standard coal. Standard coal is a Chinese coal equivalent unit where 1 kg of standard coal has a heating value of 7000 kcal (29.3 MJ). Total electricity consumption has been capped at 6150 TWh. However, neither of these caps is legally binding. As well as raising the proportion of non-fossil primary energy consumption to 11.4% by 2015, the proportion of natural gas increases to 7.5%. China is trying to ease its dependence on coal and reduce pollution, and plans to lower coal use to 65% by the end of 2015. Eventually, the government plans to cut the contribution from coal to 43% by 2050 (Hu, 2014). However, the demand for coal will continue to grow in absolute terms due to the large growth in total energy consumption. More recent policies curbing coal consumption are discussed in Section 3.4.

Table 1 Some of the main objectives of the Energy Development Plan (State Council, 2013)

	2010	2015	Target
Primary energy consumption and energy efficiency			
Total primary energy consumption, Gt standard coal	3.25	4	Forecast
Proportion of non-fossil energy consumption, %	8.6	11.4	Binding
Total electricity consumption, TWh	4200	6150	Forecast
Energy consumption per unit of GDP, Mt standard coal	0.81	0.68	Binding
Thermal power standard coal consumption, g/kWh	333	323	Forecast
Energy production and supply			
Domestic primary energy production capacity, Gt standard coal	2.97	3.66	Forecast
Coal production capacity, Gt	3.24	4.1	Forecast
Crude oil production capacity, Mt	200	200	Forecast
Natural gas production capacity (including conventional gas, coalbed methane and shale gas), billion m^3	94.8	156.5	Forecast
Non-fossil energy production capacity, Mt standard coal	280	470	Forecast
Electric power development			
Power capacity, GW	970	1490	Forecast
Coal	660	960	Forecast
Hydro	220	290	Forecast
Nuclear	10.82	40	Forecast
Natural gas	26.42	56	Forecast
Wind	31	100	Forecast
Solar	0.86	21	Forecast
Environmental protection			
CO_2 emissions per GDP unit	–	–17% from 2010 levels	Forecast
Coal SO_2 emission factor, g/kWh	2.9	1.5	Forecast
Coal NOx emission factor, g/kWh	3.4	1.5	Forecast

Primary energy supply capacity will reach 4.3 Gt of standard coal, of which domestic supply is 3.66 Gt. Coal production capacity is to be expanded by 4.8%/y, from 3.24 to 4.1 Gt, and production controlled to 3.9 Gt by the end of 2015. This is a lower growth rate than in previous years as the government tries to restrain production growth. A number of new mines are planned, many of which will be in water-constrained provinces. China currently has approximately 14,000 coal mines. Some 70% of these mines are located in the water-scarce regions, with about 40% experiencing severe water shortage problems. During coal mining, ~0.5 t (~0.5 m^3) of water is consumed to produce 1–2 t of coal, and on average 4 t of mine water is drained. Coal mining is already contributing to the depletion of ground water reserves. In Shanxi Province, for example, 1.07 t of underground water reserves are used to produce 1 t of coal. Cumulatively, coal mining generates ~3–6 Gt/y of waste water (Li and others, 2014b). Recycling the currently discharged waste water for other purposes would save a large volume of water – a mine water utilisation rate of 75% is one of the targets of the Energy Development Plan. There is also a focus in the Plan on consolidating the coal supply industry. Some 2000 small coal mines will be closed by the end of 2015 (Tan and others, 2015).

Although oil production is projected to remain the same over the Plan period, oil processing capability is being expanded to 620 Mt, and processed oil production to 330 Mt. Water consumption, though, is to be reduced to 0.5 t/t oil. The planned growth in natural gas production capacity to 156.5 billion m^3 and production to over 130 million m^3 at the end of 2015 will increase industrial water use. The role of coalbed methane and shale gas is being raised, with their exploitable volumes increased to 20 billion m^3 and 6.5 billion m^3, respectively. Most of these two gases will be used for power generation, with a power capacity target of 2.85 GW for coalbed methane. China (which holds the largest technically recoverable global reserves of shale gas) plans to reach 400 billion m^3/y of shale gas and natural gas production by 2030. The extraction process will require at least 15 billion m^3/y of water (Li, 2014). The Energy Development Plan promotes the rational use of water resources in gas exploitation.

It is planned to raise power generating capacity to 1490 GW by the end of 2015, a cumulative increase of ~9%/y, with biomass capacity reaching 13 GW. Water availability was a key factor in the planned restructuring of China's energy mix. The proportion of non-fossil power generation installed capacity under the 12th Plan is to increase to 30% by the end of 2015. This will also help China meet its CO_2 emission target. The new 13th FYP on Energy Development (2016–20), currently under discussion, plans to raise the renewable energy targets, especially wind and solar power. China is the world's largest investor in renewable energy. It is also the largest global generator of both hydropower and wind power, and the largest manufacturer and exporter of photovoltaic cells (Hu and Cheng, 2013). According to the National Energy Administration (NEA), China's total wind power installed capacity in the 13th Plan would reach 200 GW, doubling the 12th FYP capacity. Solar power capacity will increase by over five times to more than 100 GW, and ~53 GW of nuclear power capacity will be in operation by 2020. Currently, all nuclear power plants are sited on the coast and so use sea water for cooling. However, some of the new plants will be built inland and will require fresh water for cooling, adding to the pressure on water resources. Renewable energy subsidies are to be capped in the future. National energy consumption is projected to grow to 4.8 Gt of standard coal by the end of the timeframe (http://english.peopledaily.com.cn/business/n/2014/1009/c90778-8792100.html). However, coal will remain the dominant energy source for some time, with the keystone for energy security being clean and efficient utilisation of coal. An ***Action Plan for Clean and Efficient Utilisation of Coal (2015–20)***, was released by the NEA in April 2015 (*see* http://zfxxgk.nea.gov.cn/auto85/201505/t20150505_1917.htm).

Although coal-fired power generation capacity is projected to increase to 960 GW in the 12th Plan, some 20 GW of old coal-fired power plants are being retired. Water overuse and pollution are recognised as major challenges for the coal power sector. Consequently, efficient water-saving and other advanced technologies are mandated. The majority of the new coal power plants will be either 600 or 1000 MWe supercritical or ultra-supercritical units. These plants use 15–20% less water than subcritical plants (Schneider and others, 2011). In 2010, the average water consumption of thermal power plants was 2.45 kg/kWh – most of these were coal-fired plants. In 2008, coal-fired power plants used 7.86 billion m^3 of water to generate 2759 TWh of electricity (Li and others, 2014b).

Replacing open-loop water cooling systems with closed-cycle or dry cooling systems can save substantial amounts of water (*see* Section 2.5). Bloomberg New Energy Finance estimated that retrofitting 100 GW of coal-fired power plants with closed-cycle cooling systems would not only cost some US$20 billion, but would reduce the total system capacity by 10 GW due to lower efficiencies (Bullard, 2013).

Since 2004, the Chinese government has issued a number of policies to promote dry cooling as a way of relieving pressure on water resources. In some water-stressed regions, the local government has set compulsory requirements for new coal-fired power plants to install these systems. For example, the 1000 MW supercritical, dry-cooled unit at the Lingwu Power Plant in the Ningdong Energy Base, Ningxia, will use 9000 m^3 of water a day for industrial operations and cooling. A similarly sized conventional water-cooled plant would use nearly five times (44,660 m^3/d) as much water (Ivanova, 2011). Zhang and others (2014) estimated that 832–942 million m^3 of consumptive water use was saved by the deployment of dry cooling in 2012; at this time dry-cooled coal-fired power plant capacity was 112.4 GW. This is about 60% of Beijing's total annual water use. The two provinces with the largest fleet of dry-cooled units, by far, were Shanxi (33.4 GW or 67% of its total thermal power capacity) and Inner Mongolia (32.3 GW or 54% of its total installed capacity). Retrofitting water-cooled plants with dry cooling systems would therefore save a substantial amount of water. Power generators also save money by avoiding high industrial water tariffs, and minimising power disruptions during droughts.

However, dry cooling lowers thermal efficiency (*see* Section 2.5), thereby requiring more coal per unit of energy produced and increasing operational costs. Consequently, in 2012 an additional 24.3–31.9 Mt of CO_2 were emitted. In 2013, the capacity of installed thermal power units with dry cooling had risen to 150 GW, which was 17% of the country's total thermal power installed capacity (Li and others, 2014b). So greater water efficiency would come at the expense of higher emissions and a net loss in power output for every unit installed.

The efficient and clean use of coal is being actively promoted by the national government. It is planned to decrease the thermal power standard coal consumption to 323 g/kWh by 2015; the increased efficiency will help lower water consumption of thermal power plants. The amount of washed coal used in power plants is growing as this improves combustion efficiency, and hence lowers their water consumption, and reduces sulphur and particulate emissions. But washing coal consumes water. Wet washing is the main method utilised in China with 94% of cleaned coal prepared by this method. On average, 2.5 t (2.5 m^3) of water is used to prepare 1 t of coal: 0.15 t is removed with the by-products, 0.05 t is consumed in the process and for maintenance purposes, and the remainder is recycled in a closed loop. Coal producers in water stressed areas will need to balance the enhanced value of their washed coal against the added cost of using water, and potential savings from waste water recycling. Water is either unavailable or too expensive for many producers. Hence the low wash rate – just 56% of coal and 35% of steam coal were washed in 2012 (Li and others, 2014b).

Water consumption at power plants could increase due to the legally binding CO_2 target and coal SO_2 and NOx emission factors in the 12th FYP (*see* Table 1 on page 30). The amount is dependent on the technology installed to control the emissions. Some CO_2 capture processes, such as those using amine solvents, and wet FGD technologies are water-intensive (*see* Section 2.5). Dry FGD systems, described by Carpenter (2012), could lower SO_2 emissions without increasing water consumption.

Coal bases

The national government is promoting large-scale 'coal bases' that bring power plants and other large coal-related facilities (such as coal-to-chemical plants) near to coal mines. Fourteen large-scale coal production bases are planned in the ***12th FYP for Coal Industry Development (2011–15)*** (*see* http://www.china.com.cn/policy/txt/2012-03/22/content_24961312_11.htm). According to a study commissioned by Greenpeace (Greenpeace, 2012), the coal from the 14 mining bases will fuel 16 power generating bases with an installed capacity of over 600 GW. Table 2 gives the estimated water demand for coal mining, coal-fired power generation and coal chemical production for each of the 14 planned coal bases.

Table 2 Planned coal bases (Greenpeace, 2012)				
Coal base	**Coal mining capacity, Mt** **Water demand, billion m^3**	**Coal-fired power plant capacity, MW** **Water demand, billion m^3**	**Coal chemical capacity (model projects)** **Water demand, billion m^3**	**Total water demand, billion m^3**
Shendong (Shaanxi and Inner Mongolia)	5.2 1.768	48,000 0.303	50.9 billion m^3 coal gas, 0.8 Mt dimethyl ether, 0.5 Mt coal tar hydrogenation 0.224	2.295
Mengdong (eastern Inner Mongolia)	5.2 1.768	83,170 0.525	0.4 Mt glycol, 10 billion m^3 coal gas, 1.2 Mt methanol, 0.46 Mt propylene 0.105	2.398
Jinbei, Jinzhong, Jindong (Shanxi)	7.35 0.684	80,000 0.505	3 Mt methanol, 0.6 Mt olefin, 0.3 Mt dimethyl ether, 0.16 Mt coal oil, 0.1 Mt maleic anhydride 0.066	1.255
Yungui (Yunnan and Guizhou)	2.6 0.312	– –	200 million m^3 coal-derived natural gas, 0.5 Mt methanol, 0.6 Mt polyolefin 0.054	0.366
Henan	2.15 0.366	– –	0.75 Mt methanol, 0.4 Mt ethylene glycol, 1.8 Mt olefin 0.055	0.421
Luxi (western Shandong)	1.4 0.069	– –	0.4 Mt hydroxyl acetate synthesis 0.0022	0.071
Lianghuai (Anhui)	1.5 0.21	– –	1.7 Mt methanol, 0.6 Mt olefin 0.039	0.249
Huanglong (Huating) (Shaanxi, Gansu)	1.45 0.261	50,000 0.315	0.8 Mt methanol 0.012	0.588
Jizhong (Hebei)	0.8 0.32	– –	– –	0.32
Ningdong (Ningxia)	0.9 0.153	30,000 0.189	4 Mt indirect coal liquefaction 0.044	0.386
Shaanbei (northern Shaanxi)	3 0.54	52,500 0.331	1 Mt indirect coal liquefaction, 7 Mt olefin, 0.4 Mt methanol 0.171	1.042
Xinjiang	4 0.196	7960 0.05	46.4 billion m^3 coal-derived natural gas, 0.8 Mt dimethyl ether, 0.5 Mt coal tar hydrogenation 0.338	0.584
Total	35.55 6.647	351,630 2.218	– 1.110	9.975

By 2015, total water demand will reach almost 10 billion m^3/y, which is more than one-quarter of the water available for withdrawal every year from the Yellow River. The Yellow River basin is the primary water supply for the northern and western provinces. Coal mining accounts for 66.6%, the coal-fired sector for 22.2% and the coal chemical industry for 11.13% of the total water demand. Just the 351.63 GW of power capacity would require 2.2 billion m^3 of water. Furthermore, the annual water demand of the coal power bases in Inner Mongolia, Shaanxi, Shanxi and Ningxia will either challenge or exceed the respective areas' total industrial water supply capacity (*see* Figure 8). Moreover, Ningxia and Henan are already running water deficits where withdrawals exceed their renewable water resources

(Tan and others, 2015). The development of coal-related industries in these areas will therefore consume significant amounts of water that are currently allocated to non-industrial uses, such as farming and drinking water, and may cause pollution and ecological damage. This could lead to conflict between the various water users if the coal bases are constructed. However, the water demand figures, in particular for coal mining, have been questioned as over estimations. According to MWR estimates, total water demand for the energy bases in Shanxi, Shaanxi, Inner Mongolia, Ningxia and Gansu will not exceed 3 billion m^3, and can be met by agricultural water savings and inter-basin transfer (Jia, 2015). The need to use advanced water-saving technologies at all coal bases was acknowledged in the 12th FYP for Energy Development.

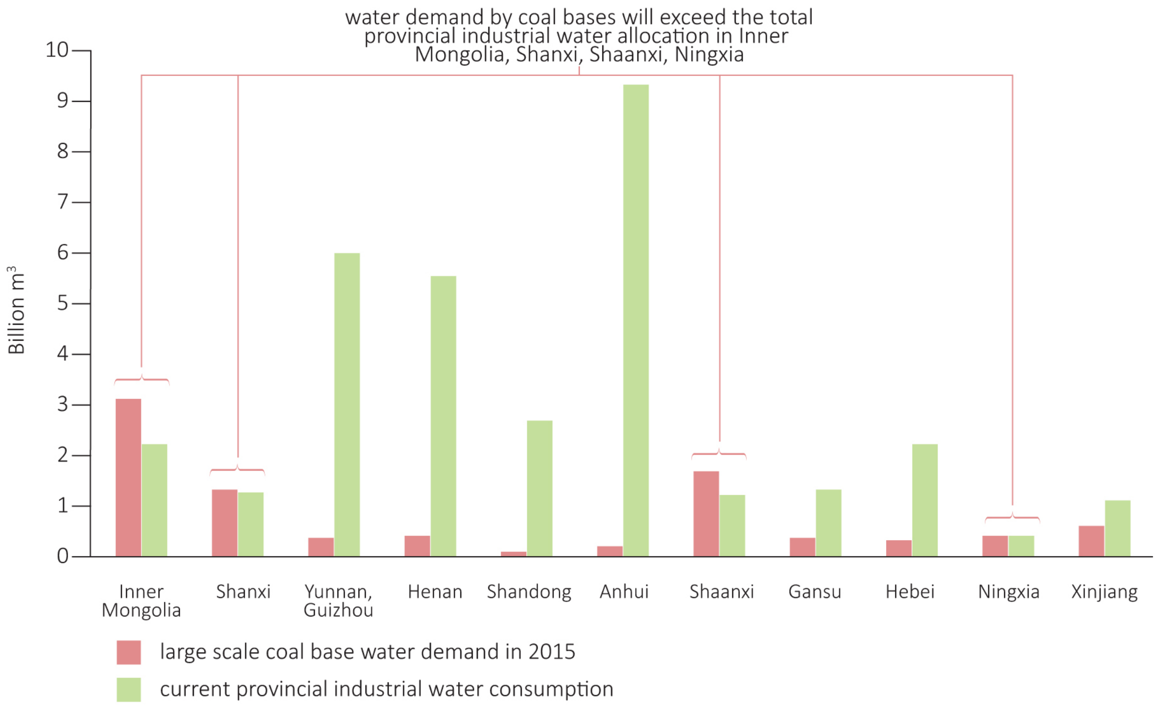


Figure 8 Comparison of current industrial and proposed coal bases water demand in 2015 (Kahya, 2014)

A Water Allocation Plan for the Development of Coal Bases, published by the MWR in December 2013, states that future development of large coal bases of China must take into account regional water availability. It lists several requirements for the management and future development of these coal bases (*see* Section 3.5.4). Furthermore, water quotas have now been applied to all provinces, and stricter water pollution limits are being implemented.

The ***Energy Development Strategy Action Plan (2014–20),*** written in June 2014 and released by the State Council in November 2014, stated that the coal bases will account for 95% of coal production and 9 GWh of power generation (*see* www.gov.cn/zhengce/content/2014-11/19/content_9222.htm). Discussions in September 2014 for the ***13th FYP for Social and Economic Development (2016–20)*** and ***13th FYP for Energy Development (2016–20)*** indicate that China will focus on developing nine coal power bases in the fourteen main coal producing areas, with priorities given to three coal producing bases, namely eastern Inner Mongolia, Huanglong and northern Shaanxi. The development of the

Ningdong and Shendong coal bases, as well as the three bases in Shanxi province (*see* Table 2), will be encouraged. But the development of the coal bases in central Hebei, western Shandong, and in Henan and Anhui provinces (none of which include new power plants) are to be restricted. The Xinjiang coal base will be optimised and developed as a reserve base (Wu, 2014).

There are a number of other policies that affect the development of the coal bases. For instance, the Ministry of Environmental Protection (MEP) published a notice in July 2014 to further improve the environmental assessment stage during the planning phase of the coal bases (*see* www.mep.gov.cn/gkml/hbb/bgt/201407/t20140725_280531.htm). It requires the capacity of water resources to be evaluated based on resources demand and allocation among all the main industries in the coal bases.

3.4 Environmental policy implications for water

A number of measures are being introduced by the government to curb coal consumption as part of its strategy to tackle air pollution. This could also lower water usage depending on the technology that replaces coal in the power generation sector.

3.4.1 Air Pollution Prevention and Control Action Plan

In September 2013, the State Council released the Airborne Pollution Prevention and Control Action Plan (*see* http://english.mep.gov.cn/News_service/infocus/201309/t20130924_260707.htm) covering 2013–17, in which the government recognised that tackling the air pollution crisis will require significant reductions in coal consumption. Coal use is capped to below 65% by 2017, and total consumption must be reduced in three key regions (Patel, 2014). The approval of new conventional (subcritical) coal-fired power plants is also banned in these key regions. The plan was accompanied by specific coal consumption targets in provincial action plans. These cover some of the main population centres, such as Beijing-Tianjin-Hebei, Shangdong (the largest coal consumer among the provinces), and the Pearl River and Yangtze River Deltas. It is estimated that coal consumption could decrease by 355 Mt by the end of 2017, compared to 2012 consumption levels, in the 12 provinces that have pledged to cap their consumption. A further 17 provinces have announced that they will also cap or reduce coal consumption (Shao and Myllyvirta, 2014). Curbing consumption could help reduce pressure on scarce water resources in coal production regions, as well as lowering CO_2 emissions.

The Plan also intends to accelerate the construction of desulphurisation, denitrification and dust removal projects in key sectors. This could increase water consumption if the pollution control system uses water.

3.4.2 Energy Saving and Low-Carbon Development Action Plan

The pressure to lower China's coal demand is likely to continue, particularly with the rising public concern over air pollution and water availability. On 26 May 2014, the State Council released the 2014–15 Energy Saving and Low-Carbon Development Action Plan (*see* http://politics.people.com.cn/n/2014/0526/c1001-25065061.html). It was drawn up to help meet the energy reduction and emission targets (including CO_2) set out in the 12th FYP, that are falling behind schedule. It reiterates the need to curb coal consumption in certain provinces, restrict the sale of coal with more than 16% ash and 1% sulphur, accelerate the construction of denitrification and desulphurisation units at coal-fired power plants, promote clean coal technology, strengthen water pollution control, and strictly implement environmental impact assessments, among other measures. Some 0.2 Mt of small coal-fired boilers will be closed. Consequently, power costs are likely to rise.

3.4.3 Air Pollution Prevention and Control Law

In September 2014, China published a draft amending the Air Pollution Prevention and Control Law for public comments (*see* www.chinalaw.gov.cn/article/cazjgg/201409/20140900396925.shtml and http://climateobserver.org/china-considers-a-cap-on-coal-use-under-new-air-pollution-law/). It includes a prohibition on the production, import, sale and combustion of coal that does not meet quality standards. The draft did not say what the quality standards would be. However, an announcement a few days later on 15 September 2014 by the government set three new quality thresholds that essentially ban the use of coal with more than 16% ash and 1% sulphur content in key population centres.

The government has now banned the sale, transport and imports of coal with ash and sulphur contents exceeding 40% and 3%, respectively, from January 2015 (a lower requirement than for key population centres). A lower ash content (20%) is proposed for coal transported over 600 km from the production site or importing port. Lignite containing more than 30% ash and over 1.5% sulphur is also prohibited (Acid News, 2014). The quality restrictions mean that more domestic coal will need to be washed, with consequent impact on water resources. Moreover, coal is likely to become more expensive.

3.5 Water policy

Water security has emerged as one of the most significant challenges to China's economic and social development. In the 2011 No. 1 Document, which reflects the government's top priorities each year, the Chinese government announced plans to improve the water conservancy situation. This was the first time that water topped the political agenda. Nevertheless, water has been a major issue in the last three FYPs for Social and Economic Development. China has enacted and enforced water efficiency and conservation measures since the mid-1990s, such as the 2002 Water Law. Policies on water usage, quality, pricing and protection have been implemented to address scarcity and environmental concerns. Surface and ground water are the property of the government. This section examines some of the more recent water policies which affect the coal power industry. Improving industrial water efficiency is important since coal and coal-related industries account for over 50% of industrial water use (Tan, 2013a). A list of key water policies issued in 2011 to February 2013 and 2013–14 can be found at http://chinawaterrisk.org/resources/analysis-reviews/2011-2013-water-policies-review/ and http://chinawaterrisk.org/resources/analysis-reviews/2013-2014-key-water-policies-review/, respectively. These plans reflect the strong commitment of the Chinese government to address the nation's water problems.

3.5.1 Three Red Lines

In 2010, the government announced the establishment of the Three Red Lines covering water usage, efficiency and quality. The policy, which was clarified by the State Council in early 2012 (Moore, 2014; Tan, 2012), aims to:

- Control water demand by capping annual maximum water use to 635 billion m^3 by 2015, 670 billion m^3 by 2020, and 700 billion m^3 by 2030;
- Raise water use efficiency to around the levels of developed nations by 2030; and
- Protect water quality. For instance, 95% of tested water must meet national water quality guidelines by 2030.

The government announced a plan to establish some 14,000 monitoring stations throughout the country to continuously monitor water quality and quantity to ensure that the targets are being met at local levels (Moore, 2014). National targets have not always been met – those for cleaning water and air for 2011 were missed (Tan, 2012).

Tan (2013a) reports that an analysis by HSBC shows that the water caps are unlikely to be met unless water-saving strategies are adopted. The bulk of the water savings in the coal sector by 2030 are expected to come from:

- Coal production, with water use in coal mining falling to 1.15 m^3/t and coal washing to 1.17 m^3/t;
- Coal-fired power generation with water withdrawals declining from 28.5 to 12 m^3/MWh.

3.5.2 Water Resources Development Plan

The five year Water Resources Development Plan (2011–15), published in June 2012, set a number of targets to be met by 2015. These include (EU SME Centre, 2013):

- Increase the percentage of rural population connected to a centralised water supply from 64% to 80%, and ensure water safety for the 300 million rural residents;
- Control national water use to within 635 billion m^3 by 2015, one of the goals of the 'Three Red Lines';
- Reduce industrial water use by 30% per unit of GDP compared with 2010;
- 85% of total waste water generated in urban areas should be treated, and 20% of the treated waste water should be reused;
- Improve grade I–III water quality for major rivers and lakes by 60%; and
- Reduce ground water over-extraction.

Thus power plants will need to reduce their water consumption to help meet the national cap and to decrease ground water extraction to avoid over-extraction. Water withdrawals for power plant cooling currently exceed 100 billion m^3 annually, nearly 16% of the 2015 target (Bloomberg New Energy Finance, 2013). Furthermore, water treatment at power plants may be required, if it is not already in place, in order to improve water quality.

3.5.3 Most Stringent Water Management System Methods

Water usage, efficiency ratios for industry and agriculture, and quality measurements for each province (including the autonomous regions and municipalities) are set out in the Most Stringent Water Management System Methods (*see* www.gov.cn/zwgk/2013-01/06/content_2305762.htm), announced by the State Council in January 2013. The quotas are to allow China to meet the targets in the Three Red Lines policy. Five of the provinces, namely Jiangsu, Anhui, Xinjiang, Shanghai and Guangdong, have to reduce their current total water consumption by 2015. Large-scale coal bases (*see* Table 2 on page 34) are planned for two of these provinces, Anhui and Xinjiang, which are both water stressed. Overall, Xinjiang has to lower water usage from 53.5 billion m^3 in 2010 (Tan, 2013b) to 51.6 billion m^3 in 2015 and 52.7 billion m^3 by 2030. The quotas may hamper, or even halt, its planned coal base developments and coal-to-chemicals industry. The government is already planning to restrict the development of coal bases in Anhui (*see* Section 3.3.2). Effectively capping water consumption will have repercussions for coal-fired power plants in other water-stressed provinces.

3.5.4 Water Allocation Plan for the Development of Coal Bases

The policy specific to the coal industry is the Water Allocation Plan for the Development of Coal Bases (*see* www.mwr.gov.cn/zwzc/tzgg/tzgs/201312/t20131217_520799.html and http://chinawaterrisk.org/notices/mwr-announces-for-coal-plan/), issued by the MWR in December 2013. The Plan is part of the Most Stringent Water Management System Methods. It states that total water allocation for coal bases is to be 'taken seriously' and that usage must be within provincial quotas. Coal power plants, mines and other projects should co-ordinate water utilisation. The need to use non-fresh water sources is acknowledged with coal-fired power plants constructed in the north given priority access to mine drainage and recycled water. The use of surface water is to be strictly controlled for the coal bases, and ground water use is prohibited, except that originating from mine drainage. The Plan requires large coal bases to reach a mine water reuse rate (Thieriot, 2015) of:

- 100% in water scarce regions;
- 90% in less water stressed areas; and
- 80% in water rich areas.

However, the more recent NEA's ***Action Plan for Clean and Efficient Utilisation of Coal (2015–20)***, released in April 2015 (*see* http://zfxxgk.nea.gov.cn/auto85/201505/t20150505_1917.htm), sets lower targets for mine water reuse, namely, 95% in water scarce regions, 80% in less water stress areas, and 75% in water rich areas (Thieriot, 2015).

Water efficiency measures for coal-fired power plants are specified with a 'first save and then use' policy in the Water Allocation Plan. Dry cooling and dry ash technologies are being promoted to save water (*see* Section 3.3.2), especially in plants in water-scarce regions. Annual water consumption of installed capacity will be reduced to 2.52 million m^3 or 0.1 m^3/s per GW. Water pollution from coal bases has to be controlled to meet current water quality standards. Water pollution is a serious problem in some areas, with over 70% of deep and shallow ground water polluted in the North China Plain (Hu, 2014). The transfer of water use rights is restricted, and all new large-scale coal mines must submit a water resources planning study. In addition, future coal base development plans should not be made independently, but carried out in conjunction with relevant bodies responsible for water administration in the relevant province. In short, the aim of the Water Allocation Plan is to protect China's water resources by managing water in the future development of coal, and implies that water security is more important than energy security. The Plan indicates that regional water availability will dictate coal development plans in the future.

3.5.5 Environmental Protection Law

With public concern over pollution, this topic has moved up the political agenda with Premier Li Keqiang declaring 'war on pollution' (air, water and land pollution) at the 18th National People's Congress in March 2014. Consequently, environmental protection standards are being strengthened and higher fines introduced, along with more stringent regulations and monitoring efforts. A total of RMB3.7 trillion (~US$592 billion) was set aside to tackle air and water pollution in 2014, of which RMB2 trillion (~US$320 billion) is dedicated to water pollution (Tan, 2014). Agriculture is the largest polluter in China.

The amended Environmental Protection Law (*see* www.chinadialogue.net/Environmental-Protection-Law-2014-eversion.pdf) was published in April 2014 and came into force in January 2015. It shows a fundamental shift by the Chinese government in that it states that environmental protection is a basic national policy and should be coordinated with economic and social development. The powers of MEP to deal with polluters were strengthened. Currently, polluters have little incentive to adopt safe practices and invest in waste treatment as costs exceed the fines received for discharging waste into the environment. MEP can now levy unlimited and daily fines on pollution violators as long as the violations continue.

Other pollution-related laws may be revised now that the fundamental Environmental Protection Law has been changed. Several water pollution plans are already in force, such as the ***National Ground Water Pollution Prevention and Control Plan 2011–20*** (*see* www.mep.gov.cn/gkml/hbb/bwj/201111/W020111109376922920938.pdf), and various discharge standards. In April 2015, the State Council released the ***Water Pollution Prevention and Control Action Plan***, which includes measures to reduce ground water over extraction, tough controls on pollution of rivers and ground water, and measures to conserve water, such as the use of sea water for power plant cooling (*see* www.gov.cn/zhengce/content/2015-04/16/content_9613.htm and http://chinawaterrisk.org/notices/new-water-ten-plan-to-safeguard-chinas-waters/).

Water prices and waste water fees (*see* www.sdpc.gov.cn/gzdt/201409/t20140905_624993.html) for industry are also rising in order to conserve water resources by encouraging more efficient use (including the use of water-saving technologies) and to deter water pollution. A progressive pricing scheme is being promoted with higher rates for water-intensive industries. The cost of ground water has risen – it costs more to use ground water than surface water. Consequently, thermal power plants that rely on ground water have seen their costs rise. However, the implementation of water tariffs has been problematic in the past due to poor collection rates, unclear responsibilities and other factors.

Companies are going to be assessed and assigned an environmental rating based on their pollution level under the Enterprise Environmental Credit Evaluation scheme. These ratings will be used by banks and financial institutions in China to either limit access to capital, or provide preferential lending rates, depending on performance (Tan, 2014). Consequently, access to finance could become more expensive for power generators and coal companies unless they take active measures to improve their environmental rating. A trial system started on 1 March 2014.

3.5.6 Water access right transfer

The government has set up a 'water access right transfer' programme, where industrial users can invest in building water-saving irrigation infrastructure for farmers. In return, companies can themselves benefit by increasing water supply reliability for their operations, especially during times of water shortages and droughts. A water rights trading programme was started in Ningxia in 2003 requiring new industries to invest in lining and repairing irrigation canals in exchange for the right to use Yellow River water. The first three projects under the programme remodeled more than 60 km of centuries-old canals and about 170 km of substreams, along with rebuilding more than 2,500 ancillary buildings in Ningxia. This freed up 50 million m^3/y of water for coal-fired power plants at the Ningdong Energy Base and elsewhere. Other projects include the Shuidonggou Power Plant, which has traded 4.2 million m^3/y of water at an investment cost of US$1.4 million (Ivanova, 2011). A similar programme has been operating in Inner Mongolia. A water rights trading market is now being actively promoted by MWR (Tan and others, 2015). Allowing the trading of water use and waste water discharge permits can help the government control total water use and waste water discharge within an industry.

3.6 Water transfer projects

The geographic disparity of water resources between the north and south has lead to a number of large-scale transfer projects in an attempt to balance demand with access. However, the movement of water on such a large scale has caused significant ecological degradation, water quality deterioration, and the displacement of millions of people. The most ambitious project is the South-North Water Transfer Project, due to be completed in 2050.

This project (*see* www.nsbd.gov.cn/) will divert some 45 billion m^3 of water a year from the Yangtze River basin to the Yellow River basin through three canal routes (the Eastern, Central and Western routes). A number of dams are being built for storage purposes as part of the project. The first stage of the Eastern route began supplying water to Jiangsu, Anhui and Shandong in 2013, using the Grand Canal as the link between the Yangtze River and the northern routes (Lehane, 2014). The Eastern and Central routes are expected to cost RMB65 billion and RMB117 billion (2000 RMB year), respectively. Costs include the building of water treatment plants needed to clean the polluted water. Construction is yet to start on the Western Route, which is the only one to link directly with the Yellow River basin. This basin is the primary water supply for the energy-rich northern and western provinces. Hence it may not be finished in time to help solve any water shortage problems at the planned coal bases in Xinjiang, Inner Mongolia, Shanxi, and Ningxia. This route is the most controversial as it will affect India's water supply.

Water flows in the Yangtze River have seen a significant reduction over the past decade, with the basin experiencing its worst drought in 50 years in 2011 (Lehane, 2014). Moreover, rainfall has declined, leading to questions over the prudence of transferring a large proportion of water from the south to the north. There are also concerns over whether the water transferred will be clean enough to use when it reaches its destination despite passing through water treatment plants. Power consumption, and hence power demand, will increase due to pumping station and other equipment power demands. Consequently, the need for more electricity could increase water demand. Barriers to the project are discussed in more detail by Schneider and others (2011). Similar smaller-scale water transfer projects are planned at the provincial level in several provinces.

3.7 Comments

Increasing population and economic growth continue to drive China's demand for energy and water resources. But water resources are unevenly distributed across the country and there is limited availability in many coal-rich regions. A water deficit of some 200 billion m^3 in 2030 has been projected (2030 Water Resources Group, 2009). Water withdrawals for just energy production (including power generation) are projected to increase nearly 37% from 106 billion m^3 in 2010 to 145 billion m^3 in 2035, whilst consumption rises by almost 90%, from 16 to 30 billion m^3 (IEA, 2012). This is under the IEA's New Policies Scenario, which is based on the continuation of existing policies and implementation of policies already announced. Consequently, the Chinese government has some complex decisions to make on its energy and water policies.

Water security has become one of the government's top priorities. Water availability was a key factor in the planned restructuring of the country's energy mix. The proportion of renewable energy has been increased in the 13th FYP for Energy Development, with wind capacity rising from 31 GW in 2010 to 200 GW in 2020; solar power capacity increases from 0.86 to over 100 GW. Water savings will depend on the solar power technology employed. China is the world's largest investor in renewables. However, coal will remain the dominant energy source for some time. The need to conserve water resources has been recognised. Hence the coal industry must use efficient water-saving and other advanced technologies. The majority of new coal power plants will be supercritical or ultra-supercritical units, which use 15–20% less water than subcritical plants. The Water Allocation Plan for the Development of Coal Bases (published December 2013) implies that water security is now more important than energy security. However, the government still needs to integrate its energy and water policies more fully as some of its energy policy goals could conflict with the need to manage water resources more efficiently.

4 India

India is the second most populous country in the world with more than 1.2 billion people, and is expected to pass China to become the most crowded nation by 2025 (WWAP, 2014b). It was the third largest global economy in 2013, as measured on a purchasing power parity basis (EIA, 2014b). However, the two biggest constraints on the country's continuing growth are energy and water – there is a significant gap between electricity demand and supply, and mounting pressure on limited water supplies from the growing population and industrialisation. Consequently, the availability of water resources has become a key concern.

4.1 Water resources, demand and use

India is a water-scarce country with only about 4% of the world's total usable fresh water resources (Bhattacharya and Mitra, 2013). The main sources of fresh water (glacier melt and rainfall) are unevenly distributed, both geographically and seasonally, and there are wide fluctuations from year to year in the quantity of rain falling in different parts of the country. Average annual rainfall over the country is 1170 mm, but it varies from below 150 mm/y in the northwest desert of Rajasthan to over 10,000 m/y in the Khasi hills in the northeast (Frenken, 2012). About 80% of the total area of the country experiences annual rainfall of 750 mm or more. Total annual average precipitation (including snowfall) is ~4000 billion m^3, of which some 3000 billion m^3 falls during the four months of the summer monsoon (June to September). Natural runoff accounts for 1986.5 billion m^3/y. Loss due to runoff, evaporation and transpiration reduces annual available usable water to 1123 billion m^3. Of this amount, 690 billion m^3 is from surface and 433 billion m^3 from ground water (*see* www.cwc.nic.in/main/webpages/statistics.html).

Before the monsoon rains, many areas experience localised water shortages, which can be severe, and are then subject to flooding during the monsoon period. Severe droughts have occurred in the past few years, particularly in 2009 and 2012. Hence the main problem the country faces is how to store and manage the large quantity of rainfall, which falls in very short periods, so that water is available throughout the year. With only 200 m^3 of storage capacity per person, India's accessible, reliable supply of water amounts to 744 billion m^3, or 29% of its total water resource (2030 Water Resources Group, 2009).

Climate change is likely to exacerbate the situation. About 67% of Himalayan glaciers are receding. As the ice diminishes, glacial flows will at first increase and then decrease over the long-term as the glaciers retreat. Nearly 70% of the water in the Ganga (Ganges) River system comes from these glaciers (Sauer and others, 2010). Water quality is also becoming a major issue in India. Most of the rivers are polluted due to the lack of waste water treatment plants, and ground water from agricultural, municipal and industrial pollutants. This further limits water availability. Water tables are also declining in some parts of India due to over-extraction. This is partly due to farmers not paying the full cost of electricity for pumping ground water to the surface due to government subsidies, and water-inefficient irrigation practices. As a result, 29% of the country's ground water assessment blocks are classified as semi-critical, critical or over-exploited, with the situation deteriorating rapidly (WWAP, 2014a). Ground water is also the property of the land owner, which makes it difficult for the government to regulate its use. River basins that span states have witnessed interstate disputes over water rights. In addition, several major rivers flow from or into neighbouring countries raising concerns over future international disputes over water rights.

Water is fast becoming a scarce commodity in India. The per capita availability of 1600 m^3 in 2011 (WWAP, 2014b) is below the United Nation's threshold for water stress (1700 m^3 per person per year). This situation is likely to worsen in the future with increasing demand from the growing population and rising economic growth. Agriculture is the largest consumer, accounting for about 85% of the total demand in 2010, followed by industry at 9% (which includes power generation) and the domestic sector at 6% (Batra, 2012). Thermal power generation accounted for 1–2% of total water demand (Bhattacharya and Mitra, 2013). In terms of withdrawal, agriculture withdrew 688 billion m^3 (~91%) in 2010, municipalities 56 billion m^3 (~7%) and industry 17 billion m^3 (2%) (Frenken, 2012). Water requirements for power generation are likely to increase with the government's policy to provide everyone with access to electricity by 2019; about 25% of the population currently lacks access to electricity, and about 80% are dependent on solid fuels for cooking and household energy needs (Faeth and others, 2014). Furthermore, total water demand is projected by the 2030 Water Resources Group (2009) to outgrow supply by nearly 50% in 2030, if the current pattern of demand continues; demand is projected to reach 1.5 trillion m^3 in 2030 in their base-case scenario against a current supply of ~740 billion m^3. It has been estimated that India will exhaust all available water supplies by 2050 (Sauer and others, 2010).

4.2 Coal and power generation sector

India was the fourth largest energy consumer in the world in 2013, after China, USA and Russia (BP, 2014). The US Energy Information Administration (EIA) projects energy demand will grow at 2.8%/y to 2040 (EIA, 2014b). Coal is the primary source of energy, with demand more than doubling over the ten years to 2013. India was the third largest global coal consumer (791.2 Mt) and producer (612.8 Mt), after China and the USA. The country has substantial coal resources, with proven reserves of 60.6 Gt at the end of 2013, the fourth largest in the world (BP, 2014). According to the government, total reserves (proven, indicated and inferred) were 342.2 Gt at the end of March 2013 (Central Statistics Office, 2014). The coal deposits are mainly confined to the eastern and south central parts of the country, some of which are in water-scarce areas.

Unfortunately, the majority of the hard coal has a high ash content, low calorific value, variable properties, and is difficult to clean. Although coal production has increased by about 4%/y since

2007 (EIA, 2014b), producers have failed to meet government targets. It has proved difficult to invest in new mining capacity for various reasons, such as planning difficulties and environmental concerns. Meanwhile, demand has grown by more than 7%/y. As production cannot keep pace with demand, particularly from the power sector, imports are increasing. Some 180 Mt of coal (140.8 Mt of steam coal) was imported in 2013, up from 157.7 Mt in 2012 (IEA, 2014a). The IEA predicts that India will overtake China to become the world's largest coal importer before 2025 (IEA, 2014d). This is causing energy security concerns for the government.

Coal is the mainstay of the Indian electricity sector, accounting for about 70% of total usage (IEA, 2014d). Total installed electricity capacity was 255.7 GW at the end of 2014, with fossil fuels accounting for about 70%, hydropower 16%, other renewables ~12%, and nuclear ~2%. Of the fossils fuels, coal made up ~60% (154.2 MW), gas 9% (23 MW) and diesel <1% (1.2 MW) (CEA, 2014). By 2040, the IEA projects, in its World Energy Outlook New Policies Scenario, a coal capacity increase of 340 GW to 500 GW, whilst wind and solar generation expand by 90 GW and 125 GW, respectively (IEA, 2014d).

Thermal power generation depends heavily on water and is one of the largest industrial consumers in India. Many of the power plants are sited in areas of water stress (*see* Figure 9). Figure 9 uses the Falkenmark water stress index, which is based on the per capita availability of usable water resources. Water shortages in dry periods have led to the shut-down of power plants, such as the 1130 MW Parli coal-fired power plant in the Beed district of Maharashtra in February 2013 (Rajput, 2013). A weak monsoon season can force the country to cut back on hydropower generation, with coal-fired power generation increased to make up for the shortfall. However, this can put huge pressure on coal stocks (and on water consumption). Because of insufficient fuel supplies, lack of power generation and transmission capacity, and high transmission losses (24% in 2012–13), the country often suffers from shut-downs lasting from several hours to days. An unprecedented two day blackout occurred in July 2012 that affected an estimated 680 million people across the country's northern states (EIA, 2014b). With a growing gap in power demand and availability (a deficit of 2762 GWh or 3.2% in December 2014 (CEA, 2014)), more power plants are needed.

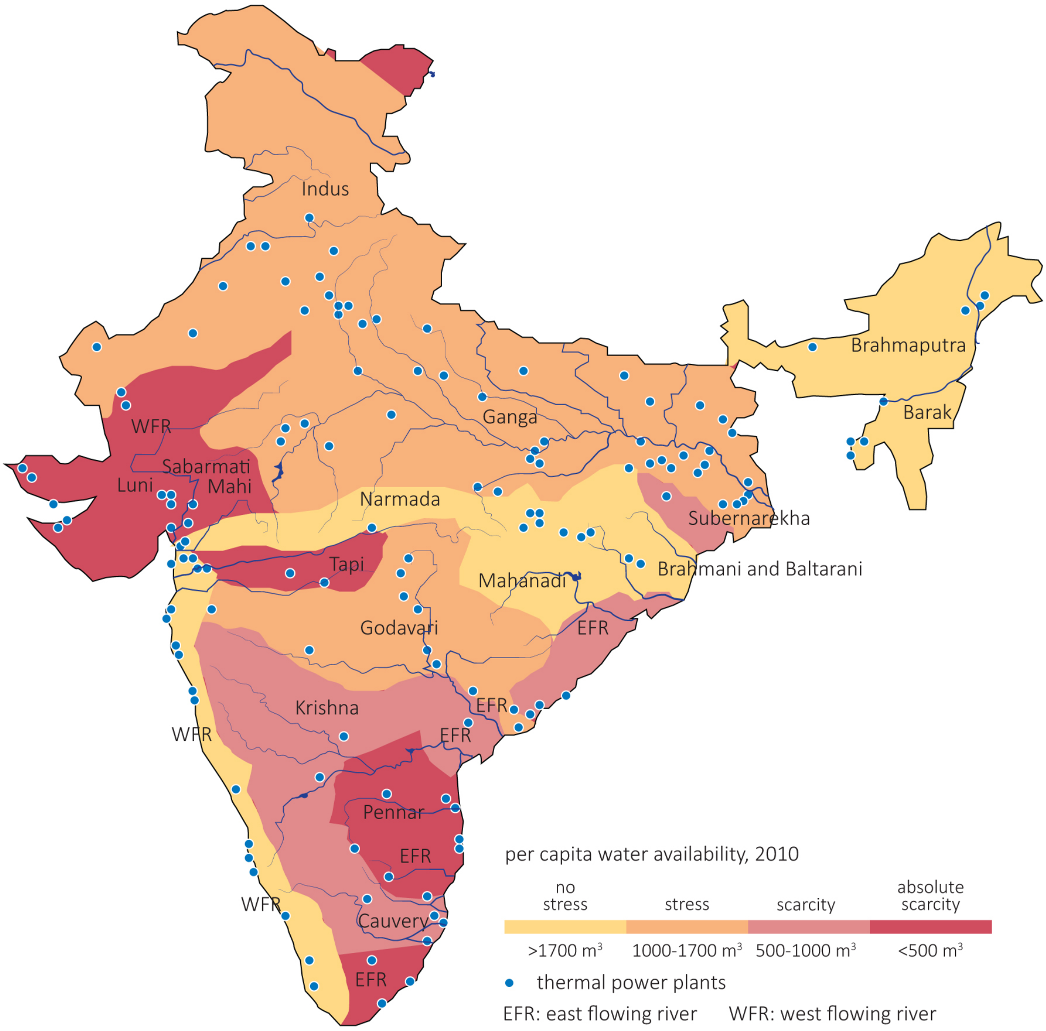


Figure 9 **Water stress level of major water basins and the distribution of thermal power plants** (WWAP, 2014b)

As of July 2012, India had proposed adding 455 coal-fired power plants with a combined capacity of 519.4 GW (Yang and Cui, 2012). Many of these plants will be in areas with limited water availability. An earlier HSBC and WRI 2010 report found that 79% of new capacity (and 63% of existing capacity) planned by the three largest power generators (NTPC, Tata Power, and Reliance Power) is being built in water scarce or stressed areas (Sauer and others, 2010). If built, the new plants could potentially threaten supplies for other water users.

In its New Policies Scenario, the IEA projects water withdrawals for energy production will increase by 45% between 2010 and 2035, or 18 billion m^3 (IEA, 2012). Consumption grows at a faster rate, more than doubling over the period (from 4 to 9 billion m^3). The power sector accounts for 98% of additional withdrawals and 95% of additional consumption. The growth in withdrawals by coal-fired power plants slows between 2010 and 2035 as newer plants are more efficient. A study by Faeth and others (2014) indicated that water consumption by the power sector could increase by about 500% over the period 2010–40 in the baseline scenario, driven by increased coal capacity; the overall share of coal capacity in the generation mix remains at 70%.

Even in the scenario where coal's share declines to 17%, and wind and solar photovoltaic and end use efficiency makes up 60% of the total mix, water consumption more than doubles (from ~1.4 billion m^3 to ~3 billion m^3).

Davies and others (2013) projected water withdrawal and consumption for the power sector in 2095 (which includes a 20-fold electricity expansion from 2005 to 2095) under ten different scenarios. Water withdrawal is forecast to increase by a factor of 13 to over 400 billion m^3/y if no changes are made in the water cooling technologies. In contrast, because of the large share of open-loop cooling systems in existing power plants, scenarios with cooling system changes undergo relatively modest growth in withdrawal volumes from ~65% to 200–250% over 2005 to 2095, depending on the technology level. Growth in water consumption is substantial in all scenarios, reaching between 14 and 24 billion m^3, excluding hydropower, by the end of the period. Consequently, water-saving technologies need to be implemented.

Older coal-fired power plants with open-loop cooling systems have a water use intensity of 80–160 m^3/MWh. Water use intensity for wet towers (closed-loop cooling) is 2.8–3.4 m^3/MWh, over twice the world's average of 1.2–1.5 m^3/MWh. Using dry cooling systems would lower the water intensity to 0.45–0.65 m^3/MWh (Bhattacharya and Mitra, 2013; WWAP, 2014b). The Central Electricity Authority (CEA) puts consumptive water requirements for older subcritical coal-fired plants at 5–7 m^3/MWh, and newer subcritical plants at 3.5–4 m^3/MWh, when using wet towers (CEA, 2012a).

Table 3 gives the specific water consumption for different types of Indian power plants. It shows that recycling water used for handling ash (Indian coals have a high ash content) can save a significant amount of water. Jindal Power's 1000 MW coal-fired power plant in Tamnar, Raigarh district, requires ~55,634 m^3/d and generates 2680 m^3/d of waste water. The waste water is used to slurry the ash before transport to the ash ponds. Treating the ash water pond for reuse in the ash handling plant has saved ~900,000 m^3/y of water (Federation of Indian Chambers of Commerce and Industry, 2011).

Table 3 Specific water consumption of power plants (Federation of Indian Chambers of Commerce and Industry, 2011)

Power plant type	Water consumption, m^3/MW
110 MW old coal-fired	7–8
200 MW coal-fired (without ash water recycling)	4.5–5
200 MW coal-fired (with ash water recycling)	3.5–4
660 MW coal-fired (without ash water recycling)	4–4.5
660 MW coal-fired (with ash water recycling)	3–4
Gas-fired	1.7–2

Significant water savings could be made if a dry cooling system is used. The CEA calculated that a 2 x 500 MW coal-fired power plant with wet cooling would need ~3000 m^3/h of water compared to ~550 m^3/h for one with a dry system (CEA, 2012a). However, high ambient temperatures for much of the year mean that dry cooling on its own would result in significant capacity reduction. Also, it may not be economical to retrofit these systems on old coal-fired plants. It has been estimated that some 20–25% of thermal power plants are still using open-loop systems, although most of these are expected to be retired within the next 10 years or so (Bhattacharya and Mitra, 2013). The use of open-loop cooling systems in new power plants was banned in June 1999, except for those built in coastal regions where sea water is used. This was primarily to prevent thermal water pollution, but has the co-benefit of lowering water withdrawals.

Bhattacharya and Mitra (2013) estimate that if India was to continue using open-loop cooling systems, then some 227 billion m^3/y of water would be required for thermal power generation by 2050; this would be about 20% of the total annual usable water (1122 billion m^3) in the country. With the 1999 policy change forbidding open-loop cooling in inland areas and the gradual retirement of old thermal power plants, water demand drops to ~85 billion m^3/y by 2050. Some 621 GW of inland thermal power capacity (565 MW from coal and 56 MW from gas) is added in this period. The study excluded coastal power plants where sea water would be used. The authors also estimated that if India continues to consume water at the rate of 80 m^3/MWh for electricity generation, then by 2050 per capita consumption (725 m^3) will exceed per capita utilisable water (664 m^3). The situation improves slightly (643 m^3) when the stricter water standard of 3 m^3/MWh is introduced for new thermal power plants. Thus water scarcity will be a problem for power generation in 2050, and difficult decisions will have to be made by the national and state governments on its conservation and allocation to industrial, agricultural and domestic users. Recommendations for addressing the risks to the water supply for thermal power plants, including amendments in the planning criteria and measures to improve water availability, are given.

Rising energy demand, underpinned by fossil fuels, has resulted in India emitting over 6% of global CO_2 emissions from fuel combustion in 2012, making it the third largest global emitter. However, per capita emissions, at 1.6 tCO_2, are about one-third of the world's average. In 2012, fuel combustion produced 1954 Mt of CO_2, of which some 70% (1359.3 $MtCO_2$) came from coal. Electricity generation was responsible for 1044.2 $MtCO_2$ or 926 gCO_2/kWh, with coal-fired power plants generating 1219 gCO_2/kWh; 1127.6 TWh was generated. (IEA, 2014c). The IEA's World Energy Outlook New Policies Scenario projects that CO_2 emissions from the Indian power sector will be the second largest globally by 2040, exceeding those of the USA (IEA, 2014d). This is because of the continuing reliance on coal and strong electricity demand growth, and despite the strong deployment of low carbon technologies. It seems unlikely that CCS will be installed on coal-fired power plants unless government policy changes (*see* Section 4.4).

4.3 Energy policy implications for water

This section examines India's energy and economic policies and how they affect water requirements in the power industry, with the emphasis on coal-fired power generation.

4.3.1 Integrated energy policy

The Integrated Energy Policy (IEP), approved by the Cabinet in 2008, is India's first comprehensive energy policy. It states that India needs to increase its power generation capacity by about five times from the 2003–04 level to nearly 800 GW by 2031–32 in order to help sustain an economic growth rate of 8–9%/y. Coal remains the dominant fuel in the energy mix in the long term, and consequently clean coal technologies should be developed. The building of coastal power plants based on imported coal is recommended, as is the need to wash coal before it is sold (which will increase water demand). Although energy and water are recognised as the two biggest constraints on India's economic growth, the IEP does not consider the issue of long-term water availability or the environmental consequences of the large increase in power generation. It does recognise that renewable energy will save water, and that biofuel uptake in water scarce regions will be problematic. Moreover, it states that the development of hydropower, especially storage schemes, is critical to India's water security, and for flood and drought control.

4.3.2 12th Five-Year Plan

The Indian government implements economic policy, like China, through five-year plans. The plans are formulated, executed and monitored by the Planning Commission, and are traditionally focused on reducing poverty. Instead of adopting a set of notional targets, and outlining how to achieve them, the latest 12th Five-Year Plan (2012–17), which has the aspiration of 'faster, sustainable and more inclusive growth', outlines three scenarios. The first scenario of 'strong inclusive growth' would yield an average GDP growth rate of around 8% over the Plan period, the preferred outcome. The second and third scenarios result in a 6% and 5% growth rate, respectively (Planning Commission, 2013a). One of the most important goals is to achieve universal access to electricity.

The demand for energy during the Plan rises as the economy grows and as access to electricity in rural areas expands. Coal remains the dominant fuel source for power generation, accounting for ~69% of total generation in 2017, and 58% in 2030. A target of 88.537 GW of new capacity (excluding renewables) has been set, with coal (including lignite) accounting for 69.8 GW (79%), gas 2.54 MW (3%), hydro 10.897 MW (12%) and nuclear 5.3 MW (6%). Renewable energy (wind, solar, small hydro, and biomass) grows the most rapidly, adding an extra 30 GW. In addition, captive power plants are expected to add around 13 GW (Planning Commission, 2013b). Table 4 gives the projected change in the fuel sources from 2012 to 2030. By early 2014, more than a third of the planned new capacity had been brought online (EIA, 2014b).

Table 4	**Projected fuel sources for power generation through 2030** (Planning Commission, 2013b)					
	Capacity, %			**Generation, %**		
	2012	**2017**	**2030**	**2012**	**2017**	**2030**
Coal	56	57	42	70	69	58
Oil	1	1	0	0	0	0
Natural gas	9	6	3	7	5	3
Hydro	20	15	13	14	12	11
Renewables	12	17	33	6	9	16
Nuclear	2	4	9	3	5	12

For the first time, a FYP has identified water as a scarce natural resource. Total demand is projected to increase 50% by 2031 from current levels under business-as-usual conditions. About 20% of the increase can be met through augmenting supply, primarily through additional storage and ground water retention measures. The remaining gap will be bridged through greater water use efficiency (Planning Commission, 2013a). The Plan emphasises the need to design policies for promoting water use efficiency through a combination of regulation and appropriate pricing. Industry is required to use water efficient technologies, and to reuse and recycle waste water. In addition, industry (including mining) has to carry out comprehensive water audits during the Plan's period. There are proposals for companies to include the results of the audit (such as fresh water consumption and volume of water that was reused and/or recycled) in their annual reports. Furthermore, measures to levy charges for the use and discharge of water are to be examined. A National Groundwater Management Programme is to be launched to help mitigate the impending ground water crisis, and the development of a National Water Framework Law (*see* Section 4.5.2) is recommended.

The 12th FYP recognises that water availability poses a challenge for future thermal power plants. Many of the new plants are expected to be built near coal mines to avoid fuel transport problems. But difficulties are already being faced in selecting suitable sites due to the non-availability of water in states such as Orissa, Jharkhand and Chhattisgarh (Ministry of Power, 2012). In addition, drinking and irrigation uses currently have priority in the allocation of water. To meet the future water demand of thermal power plants, the Plan recommends:

- Adopting technical measures for reducing water consumption, such as dry cooling. About 80–85% of water can be saved with dry cooling and dry ash handling systems (CEA, 2012b);
- Creating large reservoirs/dams on potential rivers to retain flood waters; and
- Encouraging the building of coastal power plants that can utilise sea water for cooling.

About 50% of new coal-fired power plants will use supercritical technology and, in the 13th FYP (2017–22), all new coal-fired plant would be supercritical. While not targeted at reducing water consumption directly, the improved efficiency lowers overall consumption. A new policy by the Modi government allowing the transfer of fuel linkages will help power utilities replace aging inefficient plants with new supercritical plants on the same site with assured coal supplies.

A number of large capacity plants (ultra-mega power plants) are planned to achieve faster capacity addition targets. Five new ultra-mega power plants, each of 4000 MW, are proposed in the 2015–16 Budget. The plants will be built at coal mines or in coastal regions (where imported coal will be used). Land is also becoming a scarce resource and its availability is posing a challenge for future power plants. The optimum utilisation of land is therefore crucial.

The Ministry of Environment and Forests (2014) issued a notification requiring thermal power plants located away from coal mines or in ecologically sensitive areas to use coal with an ash content below 34%. This means building more coal washeries with the consequent increase in water consumption. Coal India Ltd intends to build 20 new washeries with an aggregate capacity of 11 Mt in the 12th Plan period (Planning Commission, 2013b). The regulation is not applicable to FBC or IGCC power plants. In addition, the recent doubling of the tax on coal may encourage investment in washeries (Singh, 2015). The higher tax could also encourage the upgrading of power plants to increase fuel efficiencies and hence, lower water consumption.

Coal production needs to increase to around 730 Mt to meet the planned generation capacity goal, with consequent impact on water resources. However, only 550 Mt is projected to be available at the end of the plan period (Planning Commission, 2013b). In addition, some 46 Mt of lignite is required, all of which is expected to be met by domestic production. The new government, under Narendra Modi, plans to double production to 1 Gt by 2019 in order to meet its goals of supplying round-the-clock electricity to all Indians and to reduce reliance on imports. Opening up new mines is proving difficult, due to public opposition, water use conflicts and other factors. The bulk of proven coal reserves are located in ecologically sensitive or densely populated areas of the country. Reform of the inefficient coal industry is seen as essential in order to meet the government targets.

4.4 Climate policy and initiatives

India ratified the Kyoto Protocol in 2002 but, as a Non-Annex I Party, it has no obligations to reduce its CO_2 emissions. In 2008, the government published its National Action Plan for Climate Change where it states that 'India is determined that its per-capita GHG emissions will at no point exceed that of developed countries even as we pursue our development goals'. This goal should be easily met considering the country's burgeoning population. In the following year the government announced that by 2020 it would reduce emissions intensity by 20–25% relative to 2005 levels. A number of green goals, such as increasing the role of renewables within the energy production sector to 20% by 2020 were also declared. Last year, Prime Minister Modi reemphasised that climate change is a priority for India, and announced ambitious clean energy goals to help meet the country's growing energy demand.

Although CO_2 emissions from power generation will have increased by the end of the 12th FYP, there is little government support for the application of CCS technologies on thermal power plants, although the IEP notes that CCS will become crucial in the future. Amine-based CO_2 capture technologies, however, consume significant amounts of water.

4.4.1 National Action Plan for Climate Change

The National Action Plan for Climate Change (NAPCC) outlines existing and future policies and programmes for mitigating and adapting to climate change. The Plan's aim is to 'achieve a sustainable development path that simultaneously advances economic and environmental objectives' (Prime Minister's Council on Climate Change, 2008). Eight core national missions that would run through 2017 were identified, with each mission given the task of developing strategies, plans of action, timelines, and monitoring and evaluation criteria. Among the eight missions are:

- National Water Mission, which aims to conserve water, minimise wastage, and ensure more equitable distribution both across and within states through integrated water resources development and management (*see* http://wrmin.nic.in/forms/list.aspx?lid=267). One goal is to improve water use efficiency by 20% in all sectors by 2017 through pricing and other regulatory measures (Ministry of Water Resources, 2011). Thus power generators will need to optimise their conservation, recycling and reuse practices. A comprehensive water database is to be developed that will include information on resources, utilisation and future requirements, including power generation needs, information that is currently difficult to find (Ministry of Water Resources, 2008). A web-based Water Resources Information System is now available at www.india-wris.nrsc.gov.in/wris.html;

- National Solar Mission, which promotes the development and use of solar energy for power generation and other applications with the ultimate objective of making it competitive with fossil-based energy options (*see* www.mnre.gov.in/solar-mission/jnnsm/mission-document-3/). Specific goals include increasing production of photovoltaic to 1 GW/y over the 11th and 12th FYP periods, and establishing at least 1 GW of CSP capacity by 2017 (Prime Minister's Council on Climate Change, 2008). In November 2014, the Modi government raised the solar capacity target from the original 20 GW by 2022 (the end of the 13th FYP) to 100 GW (Williams, 2014). But utility-scale CSP plants can consume large amounts of water (*see* Section 2.5) and land, which could impede their scaling up. Nevertheless, solar power could provide clean off-grid energy to rural communities. The cost of electricity from utility-scale solar photovoltaic has halved since 2010 (Nichols, 2015), but both solar photovoltaic and CSP are still more expensive than coal-fired power generation (Banerjee, 2014);

- National Mission for Enhanced Energy Efficiency, including a new market-based mechanism (implemented in the Perform, Achieve and Trade Scheme) to improve energy efficiency in energy intensive industries and large facilities (*see* www.beeindia.in/content.php?page=schemes/schemes.php?id=8). It requires power generation plants to reduce their specific energy consumption by improving overall plant efficiency, which has the co-benefits of lowering their water consumption and CO_2 emissions. Energy efficiency improvements achieved elsewhere by industry also indirectly save water due to a reduction in power demand, and hence the need to generate less electricity from thermal power plants. Over 19 GW of additional capacity could be avoided by the end of 2015 (Planning Commission, 2013a); and

- National Mission on Strategic Knowledge of Climate Change to gain a better understanding of climate science, impacts and challenges. It will serve as a support mission to generate and provide strategic knowledge to the other seven national missions (*see* www.dst.gov.in/scientific-programme/nmskcc_july_2010.pdf).

A new National Mission on Clean Coal (Carbon) Technologies to reduce CO_2 emissions from power plants is being set up. The mission would foster work on IGCC, advanced ultra-supercritical technology, and CCS, amongst other areas. More advanced clean coal technologies have a higher thermal efficiency, thus requiring less water per unit of power generated.

A National Wind Energy Mission, as recommended in the 12th FYP, is being launched with the aim of creating a long term stable policy framework that minimises the risks and costs of wind power deployment, while sharing such reduced costs and risks amongst all relevant stakeholders. A goal of 100 GW of utility-scale wind power and 1 GW of distributed wind power by the end of 2022 has been proposed (Choudhury, 2014). Land availability for large-scale wind farms may be a concern in some areas, although a mixed land use policy could be introduced. Wind is now considered to be cost competitive with new coal capacity (Singh and others, 2013).

4.4.2 Expert Group on Low Carbon Strategy for Inclusive Growth

An Expert Group on Low Carbon Strategy for Inclusive Growth was set up by the Planning Commission to develop a roadmap for low carbon development within industry, power generation, transport and other sectors. It found that if India implements its current climate change initiatives under a 'baseline inclusive growth' scenario, then by 2030 the country could lower its GDP emission intensity by 22% relative to 2007 levels; the emission intensity could be reduced by 42% under the 'low carbon inclusive growth' scenario. Power demand is the same in both scenarios, although coal demand falls from 1,568 Mt in the 'baseline inclusive growth' scenario to 1,278 Mt in the 'low carbon inclusive growth' scenario. The latter scenario sees installed wind and solar power capacities increase to 118 GW and 110 GW respectively (Expert Group on Low Carbon Strategies for Inclusive Growth, 2014). The implications of the proposed energy mix on water resources are only discussed in general terms, although the report notes that there may be issues from competing water users. It is recognised, for instance, that developing utility-scale solar power may be difficult because of the large amount of water (in the case of CSP). The report also recommends the development of advanced clean coal technologies.

4.5 Water policy

The demand for water (and electricity) by a rapidly industrialising economy and urbanising society comes at a time when the potential for augmenting supply is limited, water tables are falling and quality is declining. This section discusses water policy in relation to power generation.

4.5.1 National Water Policy

The central government can provide guidance, funding and broad policy frameworks, but the final implementation of all water policies is the responsibility of the state governments. Many states have their own water policy, which has resulted in inconsistencies. Surface water is owned by the state, but ground water is the property of the landowner. The situation is different in China (*see* Chapter 3) and South Africa (*see* Chapter 5) where water is a national resource, and policies are formulated and executed by the national governments. Both of these national governments are also the custodian of their nation's surface and ground water.

The first National Water Policy (NWP) was adopted in1987, and revised in 2002 and 2012. The 2012 NWP, approved by the national Water Resources Council on 28 December 2012, outlines a number of principles for future water management in India. It recognises that water is a scarce natural resource that is fundamental to life, livelihood, food security and sustainable development. The objective of the NWP is to take cognizance of the current situation, propose a framework for the creation of a system of laws and institutions, and draw up an action plan that considers water as a unified resource (Ministry of Water Resources, 2012).

The 2012 NWP recognises the need for a national water framework law that provides general principles that can lead the way for essential legislation on water governance in every state (*see* Section 4.5.2). The utilisation of water for domestic requirements, agriculture, hydropower, thermal power generation and other diverse uses should be optimised, and an awareness of water as a scarce resource fostered. This is the only mention of thermal power generation, as such, in the NWP document. Unlike the 2002 NWP where water allocation to the domestic and agricultural sectors was given priority over power generation, there are no priorities, as such, in the 2012 NWP. This is apart from the necessity of ensuring access to a minimum quantity of potable water for essential health and hygiene for all its citizens, and a portion of the water in rivers that must be kept aside to meet minimum ecosystem needs. All other water uses are viewed as an 'economic good', which have to be conserved and used efficiently. Industrial processes, which include power generation, are required to become more water efficient. Climate change impacts must be taken into consideration in water management decisions. The availability of water should also be periodically reviewed and reassessed. New additional strategies listed for augmenting utilisable water resources to help meet increasing demand are the direct use of rainfall, desalination and avoidance of inadvertent evapotranspiration.

The 2012 NWP recommends developing benchmarks (water footprints and auditing) for water uses for different purposes to ensure its efficient use. The inclusion of water audits in company annual reports was recommended in the 12th FYP (*see* Section 4.3.2). Recycling and reuse of water is recommended and will be encouraged through water tariffs. Recycling water at power plants, such as waste water for handling ash, can save significant amounts (*see* Section 4.2). Water polluters will be heavily fined, and there is a need to ensure that pollutants do not contaminate ground water. The principle of differential pricing is retained for the pre-emptive uses of water for drinking and hygiene, ensuring food security, and supporting the livelihood of the poor. Other than these considerations, water should be subjected to allocation and pricing on economic principles so that it not wasted, and is utilised more gainfully. Each state is to establish a Water Regulatory Authority to ensure equitable access to water for all users, and to fix and periodically review and regulate the tariff system and water charges according to the principles of the NWP. A Water Disputes Tribunal is recommended to resolve differences in competing demands by water users.

Roadmaps (action plans) for implementation of the 2012 NWP are being drawn up by the State governments.

4.5.2 National Water Framework Law

Both the 12th FYP and 2012 NWP recognised there was a need for a broad over-arching national legal framework of general principles on water to lead the way for essential legislation on water governance in every state, and the devolution of necessary authority to the lower tiers of government to deal with the local water situation. The proposed National Water Framework Law would be legally binding, unlike the 2012 NWP, which has no legal status. The draft Law, published in May 2013, reiterates many of the ideas outlined in the 2012 NWP, such as the need for recycling and reuse of water by industry, and the pricing of water based on economic principles (Ministry of Water Resources, 2013). The states retain their right to allocate water for power generation. They will also hold water (both surface and ground) in public trust for the people and will be obliged to protect water resources for the benefit of all. However, there has been strong opposition to the draft law by the state governments, particularly over the interlinking of river basins.

4.6 Comments

Water is fast becoming a scarce commodity in India, where resources are unevenly distributed, both geographically and seasonally. The per capita availability of 1600 m^3 in 2011 (WWAP, 2014b) is below the United Nation's threshold for water stress of 1700 m^3 per person per year.

The situation is likely to worsen in the future with increasing demand for water and energy from the growing population and rising economic growth. Total water demand is projected by the 2030 Water Resources Group (2009) to outgrow supply by nearly 50% in 2030, if the current pattern of demand continues. Water withdrawals for just energy production (including power generation) are projected to increase by 45% between 2010 and 2035, or 18 billion m^3 under the IEA's New Policies Scenario (IEA, 2012); consumption grows at a faster rate, more than doubling over the period (from 4 to 9 billion m^3). The power sector accounts for 98% of additional withdrawals and 95% of additional consumption.

More power plants are needed to meet the government's goal to achieve universal access to electricity and to solve the growing gap in power demand and availability (there was a deficit of 2762 GWh or 3.2% in December 2014 (CEA, 2014)). The Modi government plans to help meet this through renewable energy, which will also improve energy security and lower CO_2 emissions. The solar power capacity target has risen fivefold, to 100 GW in 2022, and wind power to 60 GW. Consequently, the proportion of coal in the energy mix decreases, although it remains the dominant fuel source. Renewables will save water, but the amount depends on the chosen solar power technology (and the cooling system, where necessary). The importance of water is seen in the setting up of the National Water Mission in 2010. In addition, national missions on solar, wind and clean coal (carbon) are being, or have been, set up.

It was recognised in the 12th FYP (2012–17) that water availability poses a challenge for future thermal power plants. This will partly be solved by making power plants more water efficient (a requirement in the 2012 NWP). Under the 13th FYP (2018–22), all new coal-fired power plants must be supercritical. While not targeted at reducing water consumption directly, the improved efficiency lowers overall consumption.

India's energy and water policies need to be integrated to avoid conflicting demands. This may be difficult as the final implementation of water policies is the responsibility of the state governments – the central government can only provide guidance, funding and broad policy frameworks.

5 South Africa

South Africa is a semi-arid, water scarce country, currently ranked as the 30th driest in the world. With a population of over 54 million in 2014 (Statistics South Africa, 2014), there is less water per person than countries considered to be to be much drier, such as Namibia and Botswana. South Africa is facing a growing gap between water supply and demand. Thus it is essential that all available water is used effectively, efficiently and sustainably.

5.1 Water resources, demand and use

Annual rainfall in South Africa is low, just 450 mm/y, well below the global average of 860 mm/y (DWA, 2013a). Only about 9% of this is available as surface water, one of the lowest conversions in the world. The poor spatial distribution of rainfall means that the natural availability of water is also highly uneven. This is compounded by its strong seasonality, and the high within-season variability, over virtually the entire country, and consequently, of runoff. More than two-thirds of the runoff is stored in dams. However, there are few opportunities for developing new and economic dams. There is also a high level of evaporation due to the hot climate, reducing water availability.

Mean annual runoff is about 49.2 billion m^3/y, including about 4.8 billion m^3/y of water coming from Lesotho, and about 0.7 billion m^3/y originating in Swaziland, which naturally drain into South Africa. However, only some 10.24 billion m^3/y (<20%) is available at high assurance. An estimated 9.5 billion m^3/y is required to satisfy the total ecological reserve requirement in order to maintain functional ecosystems. Some 8% is estimated to be lost through evaporation from storage and transport along rivers, and 6% through land-use activities (DWA, 2013a; Government Communications, 2014). There are few major ground water aquifers that can be used on a large scale due to the predominantly hard rock nature of the country's geology. Nevertheless, ground water is used extensively in the rural and more arid areas. About 2 billion m^3/y of ground water is consumed, although this may be an underestimation. The potential reliable yield is estimated to be 5 billion m^3/y. Return flows from irrigation, urban domestic uses, and bulk industrial and mining effluents could offer re-use opportunities of up to 1.9 billion m^3/y (DWA, 2013a).

Water availability is often mismatched with demand. Most urban and industrial developments have been established in remote locations away from large water courses. As a result, the requirements for water already exceed its natural availability in several river basins. The rapid population growth and economic development is exacerbating the problem of adequate supply. Widespread, and often large-scale, transfer of water across the catchment areas has been implemented to augment the required supply. This includes the importation of water from neighbouring countries, in particular Lesotho. South Africa shares four of its major river systems with six neighbouring countries, thus requiring international cooperation to manage the watersheds.

South Africa is facing fresh water scarcity, which is exacerbated by increasing demand, pollution, unsustainable use and climate change. There has been a noticeable increase in temperatures across the country in the past 40 years. Rainfall levels have declined, resulting in less ground water recharge. South Africa is already using 98% of its available supply, and demand has overtaken supply in 60% of the country's water management systems. At least 37% of drinkable water is lost through leaking pipes, dripping taps and other inefficient ways. Recently Gauteng's water supply had to be switched off (Thelwell, 2014). Pollution from agriculture, industry, mining (in particular, acid mine drainage from gold and coal mining) and domestic users has led to a deterioration in water quality. Almost 40% of the waste water treatment systems are 'in a critical state'. It has been estimated that water pollution costs the country 1% of its annual national income (WWAP, 2012a).

According to the Department of Water Affairs (DWA, 2013a), agriculture (irrigation) is the largest user of water at 60%, followed by municipal/domestic use at 27%. Power generation accounts for 4.3% (although a lower figure of 2% has been quoted elsewhere (DWA, 2013b)), mining for 3.3%, industry for 3%, and livestock watering and nature conservation for 2.5%. Water demand is projected by the 2030 Water Resources Group to reach 17.7 billion m^3 in 2030 in their base case scenario (2030 Water Resources Group, 2009). Of this amount, power generation would require 0.4 billion m^3 and mining 0.6 billion m^3, whilst household demand accounts for 3.6 billion m^3. Current supply (in 2009) is 15 billion m^3, thus giving a potential deficit of 2.7 billion m^3 in 2030. According to the DWA's Water Authorisation and Registration Management System database, the total registered water usage (not actual use), has already reached 17.3 billion m^3/y. Current usage is estimated to be between 15 and 16 billion m^3/y. Without effective metering and billing, consumption in urban and rural areas could rise to over 7.3 billion m^3/y, resulting in an increase in total water use to ~20 billion m^3/y (DWA, 2013a). Thus South Africa will have to resolve trade-offs between agriculture, key industrial activities such as mining and power generation, and the large and growing urban centres.

5.2 Coal and power generation sector

South Africa's economy is heavily dependent on coal, which is the top resource revenue earner at over R100 billion in 2013 (Jeffrey and others, 2014). Currently, South Africa is the world's seventh largest coal producer and the sixth biggest exporter. In 2013, it produced some 255.9 Mt, of which 72.4 Mt was exported, mainly to India, China and Europe (IEA, 2014a). According to BP (2014), proven coal reserves (anthracite and bituminous coal) were 30.156 Gt in 2013. However, a new report by the Council for Geoscience more than doubles this figure, with an estimate of 66.7 Gt of run-of-mine coal reserves, more than enough to supply the power generation and export markets for some time to come (Ryan, 2014).

There are only limited proved reserves of natural gas and oil, and consequently, South Africa is heavily reliant on its coal to meet its energy needs. However, shale gas deposits in the Karoo basin, with estimated recoverable resources of ~11 trillion m^3 (EIA, 2014c), could change this. Environmental concerns regarding water usage and fracking in the water scarce basin led the government to enact a moratorium in April 2011 on permitting new exploration licenses for shale gas exploration. The moratorium has now been lifted. However, in September 2013, the Ministry of Water Affairs issued a notice of intention to declare fracking a controlled activity under the National Water Act.

In 2013, ~72% of South Africa's total primary energy consumption came from coal, followed by oil (~22%), natural gas (~3%), nuclear (~2.5%), and renewables, including hydropower (<1%) (BP, 2014). Some 187 Mt of coal was consumed, making South Africa the seventh largest global consumer (IEA, 2014a). About 93% of electricity and 30% of liquid fuels are produced from domestic coal, the highest level in the world. Coal is additionally used in the steel and other industries, and for domestic heating and cooking. In 2013, 256.1 TWh of electricity was generated, of which Eskom produced 244.9 TWh. Some 13.9 TWh was exported and 9.4 TWh imported (Statistics South Africa, 2014). The country is a net importer of hydroelectricity.

The state-owned utility, Eskom, dominates the electricity sector, providing over 95% of the country's electricity, and consuming over 60% of domestic coal production. It is the largest user of fresh water resources, responsible for ~2% of annual consumption. Eskom operates thirteen coal-fired power plants with a total installed capacity of 37.745 GW; their total net output is about 35 GW (Jeffrey and others, 2014). Two new supercritical coal-fired power plants (4764 MW Medupi and 4800 MW Kusile) are under construction. Total generating capacity was 41.995 GW at the end of the 2013/14 financial year. Some 317,052 ML of water or 1.35 L/kWh sent out were consumed over this period. This was an improvement over the previous year when 334,275 ML or 1.42 L/kWh was consumed. The improvement was mainly due to an increase in the proportion of electricity generated by the dry-cooled power plants. However, Eskom is unable to comply fully with the National Emission Standards as the additional water required is currently unavailable (Eskom Holdings, 2014).

Most of Eskom's power plants are grouped around the mines in the Mpumalanga region (Central Basin) classified as a medium water stress area in the WRI Aqueduct's baseline stress case (*see* Figure 10). Medium stress areas are where 20–40% of the available renewable water supply is withdrawn every year. The area receives major water transfers from the Inkomati, Usutu and Upper Vaal catchments, but availability in the Vaal is itself augmented by further transfers from the Usutu and Thukela Water Management Areas and Lesotho (The Green House, 2011). The water catchments of the Central Basin are under considerable stress, and the water quality is becoming too poor for power plant use. Therefore, the Komati Water Scheme Augmentation Project was undertaken to provide an additional 57 million m^3/y to improve the security of supply for Eskom's Duva and Matla power plants, and for the new Kusile plant (Tibane and Vermeulen, 2014).

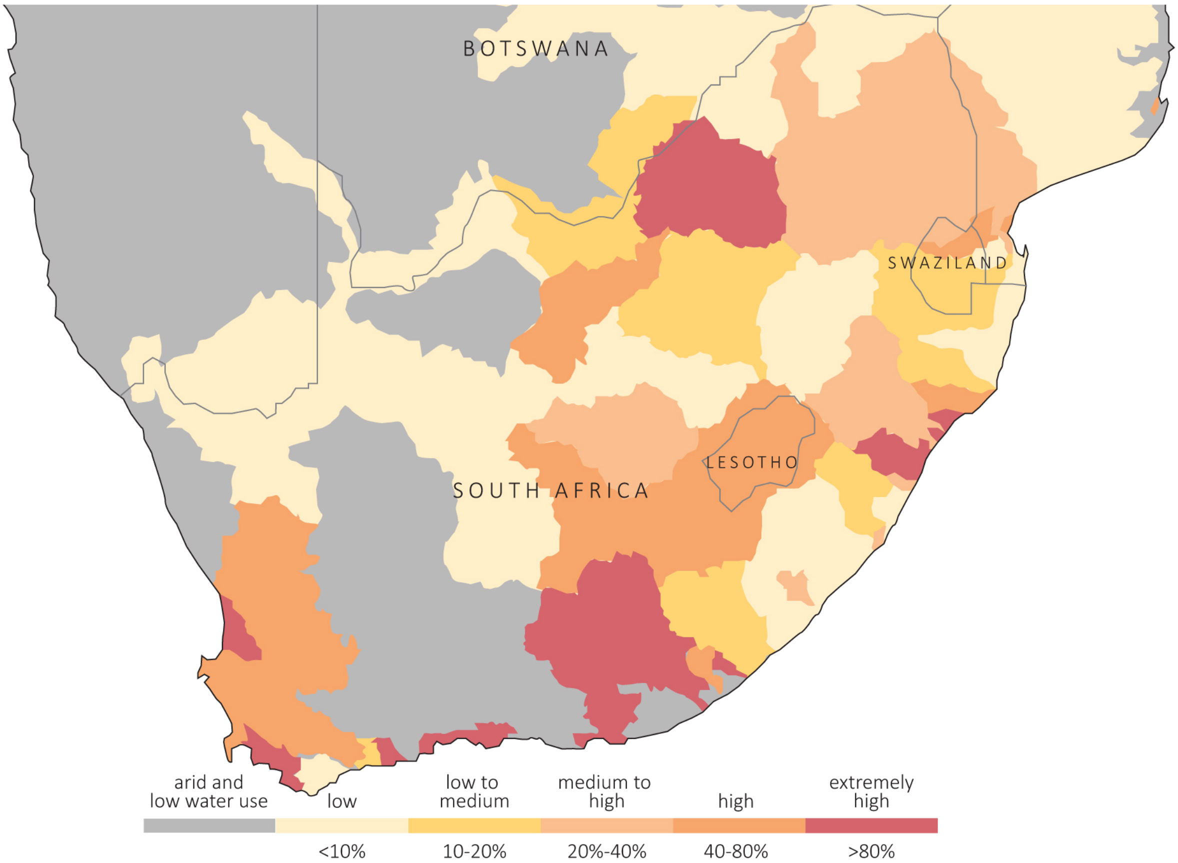


Figure 10 Baseline water stress (WRI, 2014)

Many of the coal mines in the Mpumalanga region are nearing exhaustion. Consequently, new mines will need to be opened in the Waterberg coalfields in northern Limpopo, and elsewhere. These mines will also supply the new Medupi power plant near Lephalale and other planned coal-fired power plants in the region. Water use for coal mining in Limpopo is significantly higher than for Mpumalanga due to the coal, lower rainfall and increased evaporation losses. Water requirements for a 16 Mt/y mine to supply the Medupi plant will be up to 6 million m^3/y to mine and wash the coal (Govender, 2013).

Water resources in the Limpopo Water Management Area have already been developed to close to their limit. Consequently, water will need to be transferred into the region to meet demand. The Trans-Caledon Tunnel Authority has procured funding to implement the Mokolo and Crocodile River West Water Augmentation Project's first two phases at a cost of about R2 billion, to deliver water to the Medupi power plant and supply other needs in the area. The first water delivery is expected in 2014 (Tibane and Vermeulen, 2014). Water demand for the first three units of Medupi without FGD will be met by unused allocations to the Matimba power plant from the Mokolo Dam (2.9 million m^3/y). The additional water requirement to operate all six dry-cooled units is 6 million m^3/y when fully operational (without FGD), and 14 million m^3/y when wet FGD is installed (The Green House, 2011). Eskom is guaranteed water for its power plants as electricity is of strategic importance to the economy (*see* Section 5.5). Although coal mining is not classified as a strategically important water user, the reliance of Eskom on domestic coal indirectly sees these mines as strategic water users.

Electricity supply has been struggling to meet growing demand. During 2013, Eskom was operating with a reserve margin as low as 1%, against an international benchmark of 15%, and power outages are not uncommon (Fisher, 2013). Power capacity needs to be increased to meet increasing demand. In July 2012, there were eight new coal-fired power plants planned (Yang and Cui, 2012). Eskom is responsible for five of the eight plants (which include Kusile and Medupi). Coal is expected to remain the dominant fuel for power generation, although its percentage in the electricity mix is expected to fall by 2040 due to energy policy changes (*see* Section 5.3). The IEA projects a reduction to 61% by 2040 in its New Policies Scenario, despite an increase in coal-fired capacity of 14 GW (IEA, 2014b).

In 2012, South Africa emitted 376.1 $MtCO_2$ from fuel combustion, of which 298.4 $MtCO_2$ came from coal, reflecting its dependence on coal. This makes South Africa the seventh largest global emitter of CO_2 from coal combustion, but the sixteenth largest in terms of overall fuel combustion. Electricity and heat production accounted for 233 $MtCO_2$ or 914 gCO_2/kWh; 255.1 TWh of electricity was generated. Coal-fired power generation produced 973 gCO_2/kWh (IEA, 2014c). CO_2 emissions from the electricity sector are likely to increase in the short-term when the new Kusile and Medupi coal-fired power plants are built. Capturing the 50 tCO_2/y from these two plants will increase water consumption. However, utilising dry cooling systems lowers the cooling water demand of the amine process. Water use with FGD, but without CCS, is estimated at 0.4 L/kWh, whilst adding CCS increases consumption by 0.1 L/kWh (Pietersen and others, 2013).

5.3 Energy policy implications for water

This section examines South Africa's energy policy and how it impacts water resources and demand from coal mining, coal preparation and power generation.

5.3.1 Integrated Energy Plan

Water scarcity and the need to conserve water is a key theme in South Africa's energy and climate policies. The national Integrated Energy Plan (IEP), published in 2003, provides a roadmap of the future energy landscape in order to guide future energy infrastructure investments and policy development. The intention was to review and update the Plan each year. Among the key objectives in the latest draft 2012 update (Department of Energy, 2013a) are to:

- Ensure security of supply;
- Minimise the cost of energy;
- Increase access to energy;
- Diversify supply sources and primary sources of energy;
- Minimise emissions, particularly CO_2, from the energy sector; and
- Promote the conservation of water.

It is recognised that any changes in energy policy will have to take into account the impact on water resources. The draft IEP does not provide recommendations, but instead presents modelling outcomes from a 'base case' and various test cases, which are premised on a set of core assumptions relating to factors such as demand growth and energy prices. The cases take into account national government policies that influence the energy sector, such as the National Development Plan, Integrated Resource Plan for Electricity and climate change policies (discussed below). The possible implications of pursuing alternative energy policy options can therefore be seen. Recommendations will be included in the final report.

In the base case, new coal technologies will continue to contribute to the electricity supply. Total electricity generation capacity increases by an additional ~52 GW by 2050 compared to 2010. Coal's share decreases to around 64%, and is replaced largely by solar power (25%). Although coal-fired power plants with CCS were considered as an option, no CCS technologies were selected for the test cases with CO_2 emission limits due to their relatively high cost, and the availability of cheaper alternatives (namely, wind and solar technologies). Water demand is expected to decrease in the long-term because of more dry cooling in electricity generation and the increased use of renewable technologies that use less water.

5.3.2 Integrated Resource Plan for Electricity

The 2010 Integrated Resource Plan (IRP) for Electricity 2010–30 sets out the projected demand for electricity up to 2030, and then addresses how this demand is going to be met, in terms of electricity generation capacity (Department of Energy, 2011). The 'policy-adjusted' scenario was adopted as the preferred scenario. It incorporates a number of government objectives, including affordable electricity, reduced water consumption, gradual decarbonisation of the electricity sector, and security of supply. An average electricity growth projection of 2.9%/y is employed. There is a shift in the energy mix in 2030 from coal towards renewable energy sources with coal supplying 46%, renewable energy (wind, CSP and solar photovoltaic) 21%, nuclear 13%, gas 8%, diesel 3%, hydro 5%, pumped storage 3%, and others 1% of electricity demand; total capacity is 89.5 GW. All the scenarios tested show an initial increase in water usage before it decreases to below the 2010 level by 2030. According to Govender (2013), water requirements (based on the policy-adjusted IRP 2010) are projected to grow from 268 million m^3 in 2011 to a peak of 380 million m^3 in 2021, due to significant demand in the Waterberg and Mpumalanga regions. By 2030, water requirements decrease to 275 million m^3 as existing coal plants are decommissioned. However, compared to the baseline case, water requirements in 2030 increase by 23 million m^3 if coal replaces new nuclear capacity and FGD is retrofitted on new power plants. If there is no decommissioning of coal power plants and FGD is required on all existing and new plants, then water requirements rise by 174 million m^3. Currently, new power plants have to meet a SO_2 emission limit of 500 mg/m^3, and existing power plants a limit of 3500 mg/m^3 by April 2015 and 500 mg/m^3 by April 2020.

There have been a number of developments in the energy sector since the IRP 2010 was promulgated. In 2013, a draft update was published (Department of Energy, 2013b), but until the final plan is agreed, the IRP 2010 remains the official government plan. The revised IRP will then be incorporated into the IEP. Electricity demand in 2030 is now projected to be in the range 345–416 TWh in the updated IRP instead of 454 TWh in the policy-adjusted IRP 2010. This is partly due to rising electricity prices dampening demand and new energy efficiency programmes. The updated IRP reflects the country's ambitious economic growth aspirations set out in the National Development Plan. The growth rate (an average of 5.4%/y until 2030) is also aligned with a shift in economic development away from energy intensive industries. However, the projected electricity demand is likely to be lower due to a lower growth rate than expected. The updated IRP base case projects that life extension will increase the existing coal fleet to 36.23 GW by the end of 2030, and puts new coal at 2.45 GW, substantially less than the IRP 2010 (6.3 GW). The proportion of coal in the updated IRP is lower than the IRP 2010, whilst the proportion of gas and solar energy has increased (*see* Table 5). In the short-term, it is recommended that a new set of FBC coal generation should be launched with a total capacity of 1000–1500 MW (as a preferable implementation of the 'Coal 3' power plant programme). These would be based on discard coal. FBC plants typically consume less water than pulverised coal ones, and can use lower quality water. The updated IRP also provides electricity demand projections to 2050 under different economic scenarios.

Table 5 Technology options in IRP 2010 and updated IRP base case in 2030 (Department of Energy, 2013b)

Technology option	IRP 2010[1], MW	IRP Update base case, MW
Existing coal[2]	34746	36230
New coal	6250	2450
Combined-cycle gas turbines	2370	3550
Open-cycle gas turbines/gas engines	7330	7680
Hydro imports	4109	3000
Hydro domestic	700	690
Pumped storage (including imports)	2912	2900
Nuclear	11400	6660
Solar photovoltaic	8400	9770
CSP	1200	3300
Wind[3]	9200	4360
Other	915	640
Total	89532	81350

1) Demand Response options added to IRP 2010 to ensure comparability (previously not considered in IRP)
2) 'Existing coal' includes Medupi and Kusile
3) The reduced wind capacity (in the Update relative to the IRP 2010) results from incorporating new wind data into the model. The combination of these new wind sites and the application of annual limits (1600 MW per year) resulted in some wind sites being selected in the model (preferred to Nuclear as the next option) and others falling below Nuclear. Revision of these assumptions would greatly alter the wind outcomes

5.3.3 National Development Plan

A number of other government policies refer to the importance of water conservation and management. The National Development Plan (National Planning Commission, 2012) aims to eliminate poverty and reduce inequality in South Africa by 2030. It outlines a 2030 vision for the energy sector, which reaffirms that coal will continue to be the dominant fuel for the next 20 years. Consequently, a national coal policy is necessary to ensure a sustainable domestic supply for power, synthetic fuels and industrial chemicals, while expanding the growing export market. However, coal contributes proportionately less to primary energy requirements, while gas and renewable energy resources play a larger role by the end of the period (as outlined in the IRP 2010). The development of a coherent plan to use water more sustainably and for the country to emit less CO_2 is recommended. The Plan aims to ensure that all people have access to clean, potable water, and that there is enough for municipal users, agriculture, mining and industry, although this will involve trade-offs. There is need to develop a national water conservation programme to improve use and efficiency, and reduce the need for additional new sources through the optimal use of existing water and the reduction of losses and wastages. Nonetheless, a number of new water schemes to supply the urban and industrial centres, such as the Waterberg coalfields, will be required.

5.3.4 South African Coal Roadmap

Despite the dependence of South Africa's economy on coal, especially for power production, the country has no explicit coal policy. A coal policy roadmap has been published to help fill the gap. The South African Coal Roadmap was developed to explore the short-, medium- and long-term activities and interventions needed to support the coal industry in order to maximise its contribution to the economy. It is recognised that the results of the analysis will need to be updated with the release of the updated IEP and IRP. The Roadmap takes a scenario-based approach, where two drivers, the global climate change response and South Africa's mitigation response, were used to define a set of four distinct future worlds with different implications for the coal value chain (The Green House, 2013a,b). The four future worlds are:

- More of the same, where limited action is taken on climate change globally and in South Africa. Coal-based power generation using existing supercritical technologies dominates the electricity mix, and the life of existing power plants is extended. The plan for building new electricity plants follows the IRP 2010 base case scenario to 2030, under which new power plants are mostly coal-fired. From 2030–40, new build is a mix of pulverised coal ultra-supercritical with FGD, FBC, underground coal gasification (UCG)–combined-cycle gas turbine, and a smaller proportion of gas combined-cycle gas turbines;
- Lags behind, where the world moves ahead with GHG emissions mitigation, but South Africa continues to pursue coal as its primary energy source. Thus coal-based power generation still dominates local electricity supply, but with clean coal technologies such as ultra-supercritical power plants, CCS and UCG, as they become available. The plan for building new electricity plants follows the

IRP 2010 base case scenario to 2030, and the new build mix from 2030–40 uses the same technologies as the 'more of the same' scenario;

- At the forefront, where South Africa joins the global leaders in emissions mitigation, while much of the remainder of the world takes limited action. The energy mix in South Africa is diversified to include renewables and more nuclear generation, following the policy-adjusted IRP 2010 scenario to 2030. New coal-fired power plants (after Medupi and Kusile) are ultra-supercritical with FGD, and smaller power plants (including FBC) are built; and
- Low carbon world, where strong action is taken globally and locally on GHG emissions mitigation. The energy mix moves towards renewable and nuclear, with no new coal-fired power plants built beyond Medupi and Kusile.

One of the key constraints in the analysis was water demand. Under all four scenarios, demand decreases substantially, both in absolute terms and in the intensity of water consumption for electricity supply. This is largely due to the introduction of dry-cooled plants as the older wet-cooled ones are closed and replaced by new power plants in the Waterberg region. The dry-cooled Matimba power plant, for example, uses about 3.5 million m^3/y of water compared with an equivalent wet-cooled plant usage of ~50 million m^3/y (Bushart, 2014).

The coal intensive scenarios ('more of the same' and 'lags behind') are more water intensive than 'at the forefront' and 'low carbon world'. Although water consumption of solar electricity technologies is small, many of the solar plants would be built in arid regions where additional water infrastructure is likely to be required, even to supply the relatively small volumes.

Water consumption and quality effects are analysed in more detail by The Green House (2011, 2013b,c), prepared in conjunction with the Coal Roadmap. A 2001 paper by Pulles and others found that coal mining in South Africa consumes on average 130 L of water per tonne of coal mined (The Green House, 2011); surface mining required on average ~160 L/t coal in 2001 and produced ~1.2 L of liquid effluent/t coal (Wassang, 2010). The main use of water in surface mining is for dust suppression at ~20 L/t. About 60% of the 321 Mt/y coal mined in 2007 was beneficiated (The Green House, 2011). This proportion is likely to increase as higher ash coals are mined in order to meet export and local coal quality requirements. Estimates for water use for beneficiation vary considerably depending on the design of the plant, number of washing stages and other factors – values of ~38–150 L/t coal have been quoted (Wassung, 2010). With shortage of water for beneficiation becoming a serious concern, new dry technologies are actively being developed.

Mining water demand in the Central and Waterberg basins under the four scenarios is shown in Figure 11. In the Central Basin (Mpumalanga coalfields), demand peaks at about 12 million m^3/y between 2015 and 2020 under the 'more of the same', 'lags behind' and 'at the forefront' scenarios, and in 2015 in 'low world carbon'. It then decreases to between 15% and 30% of 2010 levels by 2040, depending on the scenario. The scenarios follow similar trajectories, since water demand tracks existing mining projects, which are common to all scenarios. Water stress is already being experienced in most of the water catchments supplying the Central Basin. Therefore, solutions will have to be found to supply the increased water demand up to 2020. These include expensive desalination of contaminated mine water and higher re-use of effluents.

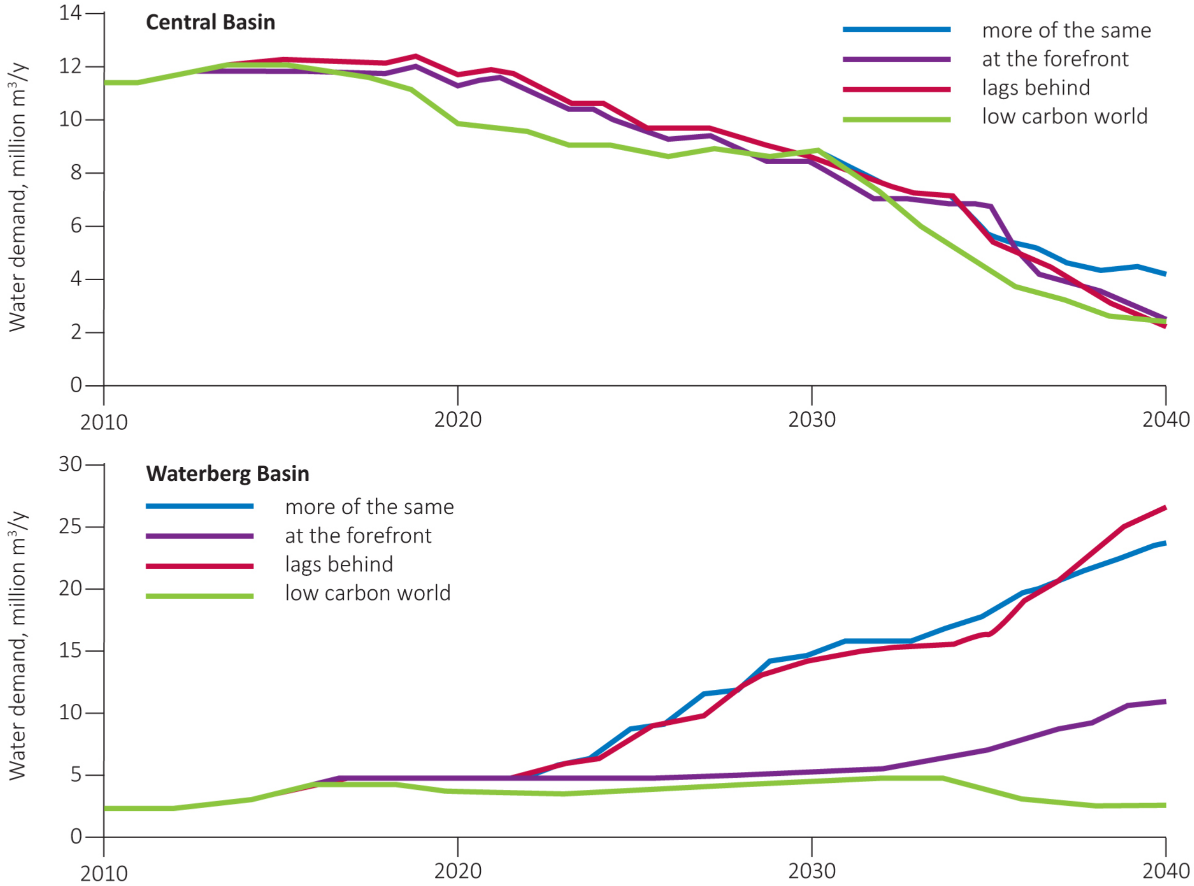


Figure 11 Water demand for mining in the Central and Waterberg Basins (The Green House, 2013c)

Mining water demand in the Waterberg Basin is very different for the four scenarios. 'More of the same' and 'lags behind' show that ~25 million m^3 of water will be required by 2040 for the mines supplying the new Waterberg power plants. 'Low carbon world' shows essentially constant water demand as the mine supplying the existing power plants first ramps up to full coal supply for the Medupi power plant, but then declines towards the end of the period when the Matimba power plant is closed. 'At the forefront' shows moderate growth, particularly after 2030, with demand rising to ~10 million m^3 by 2040 (The Green House, 2013c). Water will have to be brought in to support the development of the Waterberg coalfield and the operation of new coal power plants in the area. Securing a stable and cost-effective water supply to this region is therefore crucial to long-term energy security under three of the scenarios; only under the 'low carbon world' it is not an issue. Furthermore, water demand to support additional industry and population growth in this area will be considerable. The Mokolo and Crocodile River West Water Augmentation Project is currently being built to transfer water into the area.

Eskom used 316,202 ML of water in 2010. Specific fresh water consumption at coal-fired power plants varied from 1.9–2.1 L/kWh (sent out) for wet-cooled plants, 0.12–0.16 L/kWh for dry cooling, and 0.37–0.41 L/kWh for dry cooling with FGD. The one nuclear plant consumed some 0.05 L/kWh for cooling purposes (The Green House, 2011). Table 6 gives the water intensity factors employed in the models to calculate water demand for electricity generation in the four scenarios in the Coal Roadmap. Actual data for Eskom power plants were used where available.

Table 6 Water demand in electricity generation (The Green House, 2013c)

Application	**Value applied, L/kWh (sent out)**	**Comments**
Fossil fuels		
Pulverised coal, wet-cooled power plant: existing	1.7–2.01	–
Pulverised coal, dry-cooled power plant: existing	0.12	–-
New coal: supercritical pulverised coal, dry-cooled with FGD	0.36	Value for Medupi and Kusile, as well as future supercritical build. Value comprised of 0.11 and 0.25 L/kWh sent out for dry-cooled supercritical and FGD, respectively
New coal: ultra-supercritical pulverised coal, dry-cooled with FGD	0.31	Water usage as for supercritical with FGD, but assumes 5% increase in thermal efficiency
Retrofit supercritical pulverised coal, dry-cooled with FGD and CCS	0.67	Calculated taking into account cooling load of CCS (assuming wet-cooled) and net efficiency drop of plant. This figure applies to Medupi and Kusile when retrofitted with FGD and CCS
New coal: ultra-supercritical pulverised coal, dry-cooled with FGD and CCS	0.59	Calculated taking into account cooling load of CCS (assuming wet-cooled) and net efficiency drop of plant
FBC: dry-cooled with sorbent injection	0.11	Assumed to have same water consumption as dry-cooled supercritical pulverised coal plant
UCG–combined-cycle gas turbine	0.26	Figure is for integrated gas combined-cycle. The water consumption thus excludes water for UGC component, which is highly variable depending on the resource, that is, can either be a net producer of water (because of need to maintain hydraulic gradient) or a net consumer of water
Open-cycle gas turbines	0.02	Air-cooled
Combined-cycle gas turbines	0.013	Air-cooled
Nuclear		
Nuclear at coast	0.055	Consumption only, excludes sea water which is returned
Renewables		
CSP, parabolic trough, 9 hours storage (dry-cooled)	0.3	Air-cooled condensers, primary use of water is for mirror washing
Solar photovoltaic	0.024	Water for washing photovoltaic panels

Figure 12 shows total national water demand for electricity generation for each of the four scenarios, whilst Figure 13 indicates the water intensity of electricity supply. 'More of the same' is more water intensive than 'lags behind' due to supercritical power plants being built in the former as opposed to ultra-supercritical in the latter. However, both show a significant decline in water intensity over the period as wet-cooled power plants are replaced by dry-cooled ones. 'At the forefront' and 'low carbon world' (which is the least water intensive) show an on-going decline in water demand as coal-fired power plants are retired and replaced with lower water intensive nuclear and renewables. Nevertheless, water demand and intensity in 'low carbon world' exceed 'at the forefront' for a short period after 2029. This is because of the water penalty from the retrofit of Medupi and Kusile with CCS. The retrofit of Medupi with FGD in 2021 under all of the scenarios also causes a spike in total water consumption in all scenarios (The Green House, 2013c).

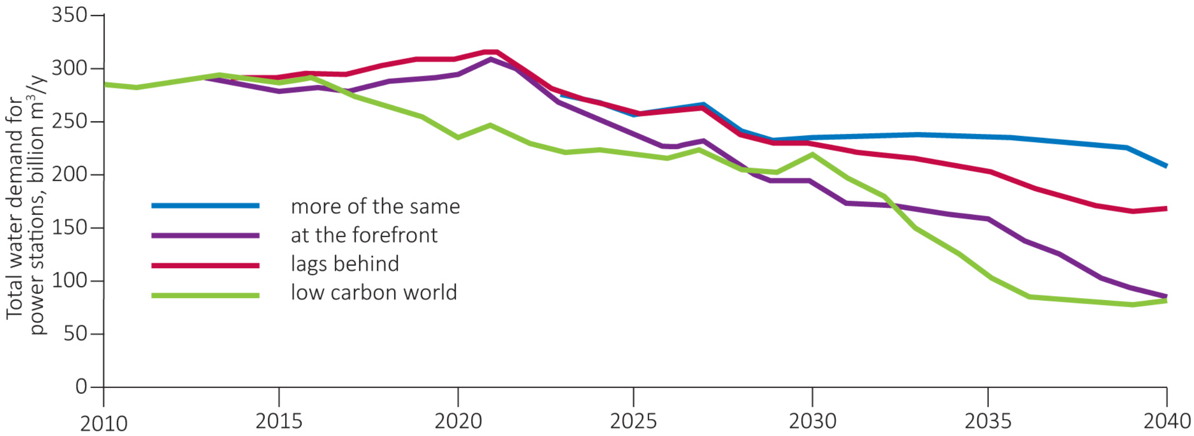


Figure 12 National water demand for power plants under the four scenarios (The Green House, 2013c)

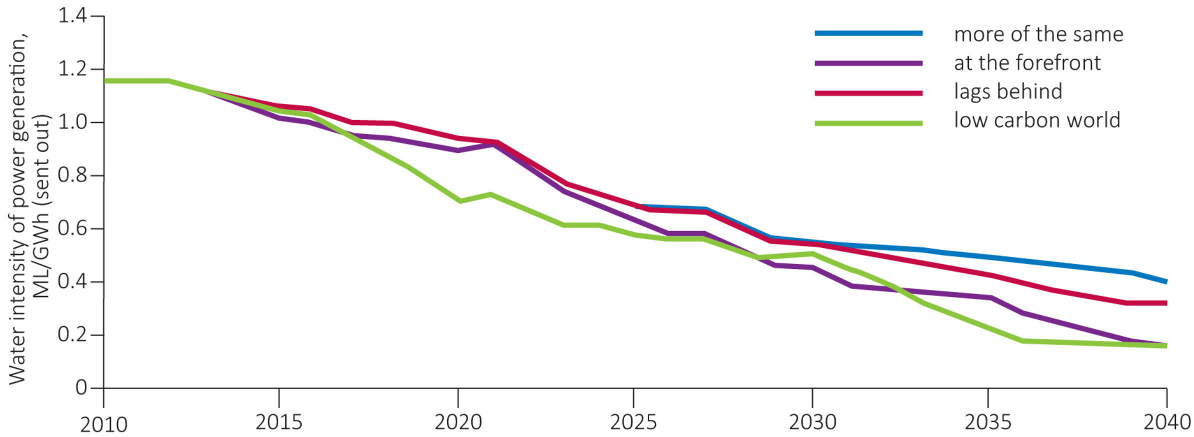


Figure 13 Water intensity of electricity generation (The Green House, 2013c)

The Coal Roadmap calculated the water requirements in the Central and Waterberg basins when coal-to-liquid plants and municipal use are incorporated. It includes the building of one 80,000 barrels/d coal-to-liquid plant in 'lags behind' and two 80,000 barrels/d plants in 'more of the same' in the Waterberg region. Total water demand in just the Waterberg basin by 2040 is estimated at around 220 million m^3/y in 'more of the same' and 240 million m^3 in 'lags behind', compared with 20 million m^3

in 'low carbon world' and 60 million m^3 in 'at the forefront'. Power generation had the greatest impact on water consumption in all the scenarios (The Green House, 2013b,c). Meeting the demand in the 'more of the same' and 'lags behind' would require significant investment in water supply infrastructure. There is also a need to develop and introduce more water-saving technologies, such as dry beneficiation and dry-cooled CCS. Expensive desalination may also be required.

5.4 Climate policy and initiatives

Since South Africa is a Non-Annex I party to the Kyoto Protocol, it has no obligations to reduce its CO_2 emissions. However, President Jacob Zuma, at the Copenhagen summit in 2009, committed South Africa to reducing GHG emissions by 34% below business-as-usual projections by 2020 and 42% by 2025, on condition that it received the necessary financial and technological support from developed countries. The government's vision for an effective climate change response and long-term transition to a low-carbon economy is outlined in the ***National Climate Change Response White Paper***, adopted in October 2011 (Department of Environmental Affairs, 2011).

The White Paper recognises that climate change poses significant risks to water availability and security. A two-pronged approach is advocated. Firstly, in the short-term, urgent short comings in the water sector are addressed and effective, efficient and sustainable water resources and services management measures are implemented. Secondly, there is a long-term strategic focus on planning, adaptation and the implementation of new concepts and approaches to managing water resources. Adaptation strategies will be incorporated into the National Water Resources Strategy (*see* Section 5.5.3).

The most substantial climate change mitigation contributions will have to come from energy generation and use. The majority of South Africa's CO_2 emissions from energy result from electricity generation, which constituted around half of its energy emissions and just under 40% of total emissions in 2000. Eight near-term flagship programmes were identified to help address climate change issues, some of which were already underway when the White Paper was published. Some of these could lead to lower water consumption, such as the Water Conservation and Demand Management, Renewable Energy, and Energy Demand and Energy Efficiency Flagship Programmes. The *Water Conservation and Demand Management Flagship Programme* includes the accelerated implementation of the National Water Conservation and Water Demand Management Strategy in industry, mining, power generation, agriculture and water services sectors. However, the *Carbon Capture and Sequestration Flagship Programme* could increase water consumption at power plants. This Programme aims to build a demonstration plant by 2020 to capture, transport and store ~100,000tCO_2/y underground (*see* www.sacccs.org.za/roadmap).

Carbon taxes and emission trading schemes are being explored by the government to help put economic growth on a more sustainable path. Hood and Guelff (2013) discuss the integration of the proposed carbon tax with the country's energy policies, and issues that may arise. Deploying CCS at coal-fired power plants would reduce the carbon tax liability but increase water consumption.

5.5 Water policy

This section examines South Africa's water policy and legislation in relation to power generation and coal mining.

5.5.1 White Paper on a National Water Policy for South Africa

The White Paper on a National Water Policy for South Africa (*see* www.polity.org.za/polity/govdocs/white_papers/water.html), adopted in 1997, provides the overarching policy for water in the country. The government was established as the custodian of the nation's water, and all major water use sectors were required to develop a water use, conservation and protection policy. The White Paper was translated into legislation in the National Water Act (no. 36 of 1998) and the Water Services Act (no. 108 of 1997), and together these (and later amendments) provide the legislative environment for water conservation and demand management (The Green House, 2011). The DWA is currently reviewing national water policy, including the White Paper, National Water Act and Water Services Act. It is planned to combine the latter two Acts into one piece of legislation governing the entire water chain (DWA, 2014).

5.5.2 National Water Act

The 1998 National Water Act (*see* www.energy.gov.za/files/policies/act_nationalwater36of1998.pdf) ensures that the country's water resources are protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner for the benefit of all people – this is the fundamental principle underlying all water policy in South Africa. The government was given the authority to regulate the allocation, use, flow and control of all of the nation's water. All water use, with the exception of reasonable domestic use, home garden use and stock water requirements, must be licensed. However, some mines are operating without the necessary licence. Power generation was recognised as a strategic user of water. Thus Eskom has priority in the allocation of water and is generally guaranteed water supply at a 99.5% level of assurance.

5.5.3 National Water Resource Strategy

A National Water Resource Strategy, called for in the National Water Act, was published in 2004 (*see* www.dwa.gov.za/Documents/Policies/NWRS/Default.htm), and revised in 2013. The purpose of the revised National Water Resource Strategy (NWRS2) is to 'ensure that national water resources are protected, used, developed, conserved, managed and controlled in an efficient and sustainable manner towards achieving South Africa's development priorities in an equitable manner over the next five to 10 years' (DWA, 2013b). NWRS2 responds to priorities within the National Development Plan and National Water Act that support sustainable development. It also incorporates aspects of the *Water for Growth and Development Framework* (*see* www.dwaf.gov.za/WFGD/documents/WFGD_Frameworkv7.pdf) that pertain to water resource management.

NWRS2 recognises that South Africa is facing a number of water challenges and concerns, which include security of supply, environmental degradation and resource pollution, and inefficient use. The country is fast approaching full utilisation of available surface water yields, while demand is likely to grow at a rate of about 1.2%/y over the next 10 years. Therefore new ways of reducing demand and increasing availability must be found – ways that move beyond the 'traditional engineering solutions' of infrastructure development. This will require a multitude of strategies, including water conservation and water demand management (WC-WDM), further utilisation of ground water, desalination, water re-use, rain water harvesting, and recovering water from acid mine drainage. Acid mine drainage from defunct mines is a concern. The government is now imposing strict regulations in the form of environmental impact assessments and mine closure insurances on operating mines to avoid future water pollution problems.

The DWA will continue to develop and maintain reconciliation strategies for balancing water supply and demand in critical and water scarce catchments. The reconciliation strategies for nine water management areas (which include water for coal-fired power plants) are provided in an annex to the report.

WC-WDM is an important theme since South Africa cannot afford to waste any water. Furthermore, prices are rising. The WC-WDM strategy aims to reduce the need for new sources of water through the optimal use of existing water and the reduction of loss and wastage by all water users (including power generation and mining). Municipalities are estimated to lose about 25% (~1000 million m^3/y), about half of which (500 million m^3) could realistically be saved by, for example, fixing household leaks. Losses in the irrigation sector, which uses up to 60% of the country's water resources, are 35–45%.

The power generation sector is a relatively high water consumer. Thus implementing measures to improve the overall efficiency of water use within the energy sector is essential. Eskom plans to use dry cooling technologies at its new power plants. However, it is recognised that the demand for water will increase when air pollution control systems are fitted, as required by the National Environmental Management Act. Therefore research and development for less water intensive technologies is recommended. There is also scope for continuous improvement at existing power plants to improve water efficiency, for example, by retrofitting hybrid dry and wet cooling systems. Eskom is researching different types of generation technologies, cooling systems and other water-saving technologies to reduce consumption and usage. The NWRS2 also recommends integrating and implementing WC-WDM into mining operations.

Coal-bed methane extraction can extract valuable gases from coal beds in areas such as Limpopo and Mpumalanga. The NWRS2 states that the current regulatory framework, policies and legislation should be amended to protect water resources. In addition, a regulatory framework will be developed to protect ground water resources from the development of shale gas deposits.

Water re-use is regarded as an important strategy to balance availability with requirements in the future. It currently accounts for about 14% of total water use, mostly through waste water returned to rivers for downstream use. Re-use of returned water could be significantly increased. DWA produced a *National Strategy for Water Re-use*, published in June 2011; it is included as an annex in the NWRS2. Water re-use and recycling are already practiced in the power generation industry, where a zero effluent discharge policy is in place at some plants. Mining and minerals processing facilities use large volumes of water, and recycling and re-use is already widely practised to reduce costs and meet environmental requirements. Several acid mine drainage treatment and re-use projects have been implemented in South Africa, demonstrating the technical feasibility, financial viability and acceptance of such projects. However, the issue of appropriate and long-term (post-mine closure) operation and maintenance of the acid mine drainage re-use schemes need to be addressed.

Power generation remains a strategic water user in NWRS2, but is only prioritised above general economic purposes (which includes commercial irrigation and forestry). Water allocation for the purposes of the Reserve, for meeting international water requirements, and for the eradication of poverty, improvement of livelihoods of the poor, and uses that will contribute to greater equity all take precedence over power generation. Nonetheless, water use designated as being of strategic importance is still subject to the same efficiency criteria and demand management requirements as is applied to other uses.

The importance of integrating energy and water policies is highlighted in NWRS2, which states that 'DWA will work with the Department of Energy (DOE), the Department of Public Enterprises (DPE) and Eskom to ensure the integration of medium- and long-term planning for the development of energy and water resources'.

NWRS2 projected that capital investment in new infrastructure to meet South Africa's water needs and the refurbishment of existing infrastructure requires an estimated R670 billion over the next 10 years. An additional investment of ~R30 billion is needed for sustainable water management programmes. Currently, only R30 billion/y is being accessed for water sector investment, leaving a shortfall of R40 billion/y. It seems unlikely that the funding shortfall will be met in the current economic climate.

5.6 Comments

South Africa is already using 98% of its available fresh water supply, and demand has overtaken supply in 60% of the water management systems. Water quality is deteriorating due to pollution, and 40% of the waste water treatment plants are in a critical state. The rapid population growth and economic development is exacerbating the problems. The 2030 Water Resources Group (2009) has projected a potential 2.7 billion m^3 deficit in 2030, if the current pattern of demand continues.

The power generation industry is a relatively high water consumer due to its reliance on coal. Eskom, who provides over 95% of the country's electricity, is responsible for ~2% of annual water consumption; it is the largest user of fresh water resources. It plans to use dry cooling on all its new power plants to conserve water, accepting the ~2% energy efficiency penalty. South Africa is a pioneer of dry cooling systems. Water re-use and recycling is already practiced, where a zero discharge policy is in place at some power plants. However, water demand will increase if wet FGD systems are fitted in order to comply with the National Environmental Management Act. Coal's share in the electricity mix will decrease in the future, being replaced by renewables (wind, CSP and solar photovoltaics), partly to reduce water usage. The amount of water consumed will depend on the cooling technology employed (when required).

The problem of water scarcity is clearly recognised by the government in its energy and water policies. Furthermore, the need to integrate the policies is acknowledged in the NWRS2. Somewhat surprisingly, the country has no explicit coal policy. A coal policy roadmap has been published to help fill the gap, and water demand was one of the key constraints in the analysis. Overall, the government takes water conservation and efficiency seriously and recognises that trade-offs have to be made in order to deliver a secure energy and water future.

6 USA

The USA has the largest economy in the world, with a nominal gross GDP of US$15.7 trillion in 2012 (US Department of State, 2014). It is the third most populous country (after China and India), with a population of over 320 million at the end of 2014 (*see* www.census.gov/popclock/), and is the world's third largest water user. Water availability is becoming an important issue with the growing demand for water and energy, and the increasing prevalence of droughts and heat waves in some parts of the USA.

6.1 Water resources, demand and use

As a whole, the USA is a relatively water-rich country, with 7% of the world's fresh water resources (Reig and others, 2014). Total renewable water resources (surface and ground water) were 3069 billion m^3/y or 9589 m^3/person/y in 2014, and average precipitation was 7030 billion m^3/y (*see* www.fao.org/NR/Water/aquastat/dbase/index.stm). But the water is unevenly distributed, both geographically and seasonally. Water is generally more abundant in the northeast and northwest of the country, whilst it is scarcer in the west and southwest. Annual precipitation can be less than 30 cm in the intermountain west and southwest (US Department of State, 2014).

Population growth and regional migration trends indicate that the population in arid regions, such as the southwest, is likely to increase. The population in the country as a whole is projected to rise from 319 million to 417 million between 2014 and 2060, reaching 400 million in 2051 (Colby and Ortman, 2015). This will increase the demand for both water and energy, intensifying the pressure on water resources. Climate change will exacerbate the situation – it has already begun to affect precipitation and temperature patterns across the USA. As temperatures steadily rise, power generation at existing thermal power plants will decline due to less effective cooling from using warmer water. Extended droughts and heat waves can affect the quantity and quality of water, and increases competition between users.

More than 60% of the country experienced drought during the summer of 2012, including some areas of exceptional drought (Zamuda and others, 2013). Severe droughts have occurred, for example, in Texas in 2011, and the southeast in 2006 and 2007, constraining the operation of power plants, and even forcing some to temporarily shut-down and/or find new water sources. The 2011 drought in Texas also led to the temporary cessation of hydraulic fracturing and other natural gas extraction operations. Low water levels on parts of the Mississippi have stalled coal barges travelling to power plants, forcing the dredging of channels to maintain commercial barge traffic (Wagman, 2013). A report by the National Energy Technology Laboratory (Elcock and Kuiper, 2010) found that 347 coal-fired power plants, out of an analysis set of 580 plants, are located in areas subject to water stress, that is, with limited supply and/or competing demand from other sectors. About a third of the vulnerable plants are situated in the southeast (*see* Figure 14). In this region, thermal power plants account for more than two-thirds of withdrawals (Rogers and others, 2013), thus potentially leading to more conflicts between states which share water basins, and between local users. Some hydropower plants in the USA are also at risk (Bauer and others, 2014). The vulnerability of the energy sector to current and potential future impacts of climate change was examined by the Department of Energy (Zamuda and others, 2013). Nearly every region in the USA was found to have experienced water constraints in power generation. Water issues, though, vary in the different regions of the country. The drier southwest has been grappling with water scarcity for decades, whereas the issues in the water-abundant northeast often relate to quality and temperature.

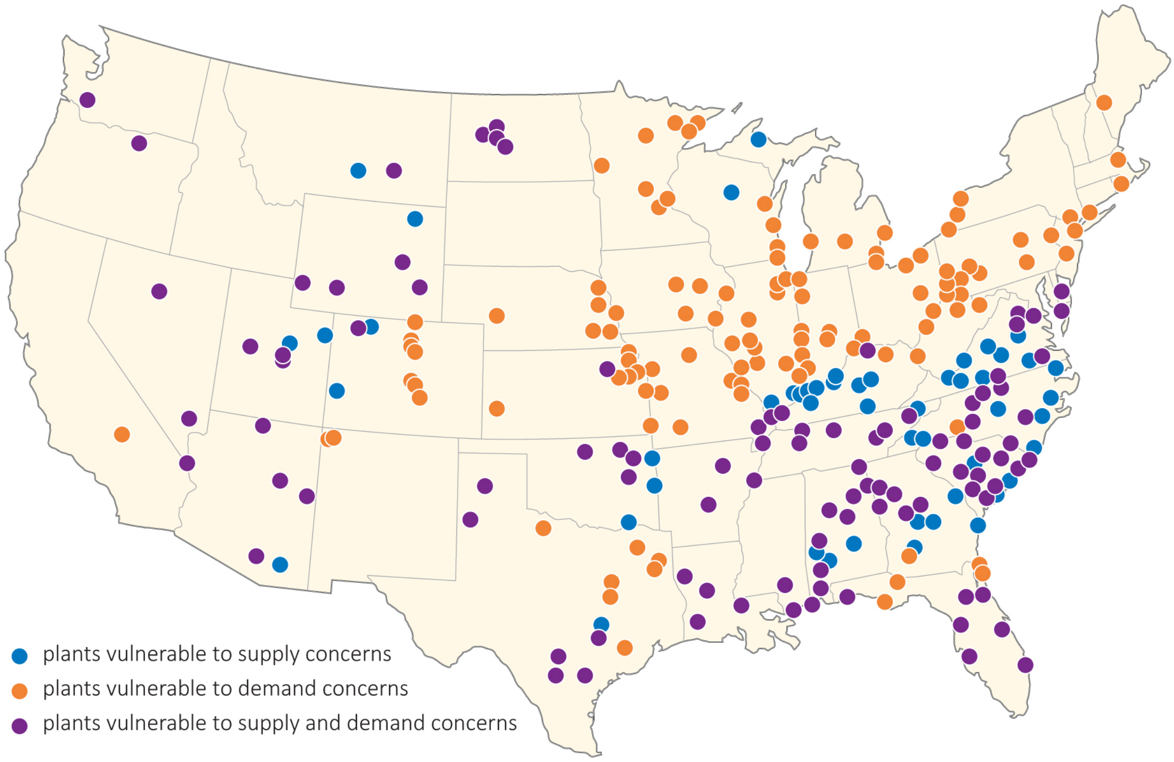


Figure 14 Location of coal-fired power plants with water demand and/or supply concerns (Elcock and Kuiper, 2010)

Total per capita water withdrawal in the USA was 1575 m³/y in 2005 (*see* www.fao.org/NR/Water/aquastat/dbase/index.stm), one of the highest in the world. Total withdrawals more than doubled from 1950 to 1975, but have generally remained flat since then, despite population and economic growth (IEA, 2012). However, the latest US Geological Survey (USGS) report showed a decline of 13% in withdrawals across the country between 2005 and 2010 (Maupin and others, 2014). This is a result of conservation and improvements in water use technologies and management. About 1341 million m³/d (490 billion m³/y) of water was withdrawn during 2010. This consisted of 1158 million m³/d of fresh (86%) and 183 million m³/d of saline water (14%). Most saline withdrawals were sea and brackish coastal water used for thermal power. Four states accounted for over 25% of all fresh and saline water withdrawals, namely California, Texas and Idaho in the drier west and Florida in the southeast.

Thermal power withdrew the most water nationally, accounting for 45% of all withdrawals, followed by irrigation (33%), public supply (12%), self-supplied industry (4%), aquaculture (3%), self-supplied domestic (1%), mining (1%) and livestock (1%). Nevertheless, agriculture consumed the largest amount, as most of the water used for power generation is returned to the source. The USA extracted over

609 million m^3/d for thermal power generation. This was 20% less than in 2005 (Maupin and others, 2014); fresh water withdrawals have decreased by 18%. A number of factors contributed to the decline, including the use of more efficient cooling technologies, power plant closures, a decline in coal-fired generation and an increase in natural gas usage. About 86% of thermal power withdrawals were in the eastern states; many of the western states rely on hydropower generation (not included in the USGS report) for a significant portion of their power needs.

Fresh surface water supplies are declining over many areas of the USA, and this could lead to water issues in the future. In 2010, surface water was the source for over 99% of total thermal power withdrawals, of which 73% was from fresh water sources. Power plants with open-loop (once-through) cooling systems accounted for 94% of total withdrawals and 47% of net power generated; most of the water would have been returned to the source. Plants with closed-loop (recirculating) cooling systems made up the remainder (6%) and produced the majority (53%) of net power generated. Diehl and Harris (2014) estimated that 1290 thermal power plants consumed about 3% of the total volume of water withdrawn in 2010; an estimated 488 million m^3/d was withdrawn and 13.3 m^3/d consumed. Only fossil fuel-fired and nuclear power plants with a wet cooling system were included in the analysis. Most of the open-loop fresh water cooling systems are associated with coal-fired plants, whereas open-loop saline water cooling systems are mostly at nuclear power plants. Shifting from open- to closed-loop cooling could reduce vulnerability to water disruptions, thereby increasing power reliability.

Water risk for power plants is ultimately a local and regional issue. The majority of fresh water extracted in California (the nation's largest withdrawer at 11%) goes to agriculture (>60%), with just 17% used for thermal power. About 25 million m^3/d of saline water was withdrawn for thermal power generation (85.4 GWh), 100 times the amount of fresh water (0.25 million m^3/d). On the other hand, in Texas (which at 7% was the second largest withdrawer) about 45% of withdrawals were for thermal power and 28% for irrigation. About 40 million m^3/d of fresh and 2.5 million m^3/d of saline water were extracted for thermal power generation (249 GWh). The largest total withdrawals for thermal power were in Texas (Maupin and others, 2014). Both California and Texas have been suffering from droughts, but California mostly uses sea water for cooling power plants, whereas Texas relies on fresh water. Florida had the largest saline water withdrawals, accounting for 18% of the nation's total, with most of the surface saline water used for thermal power generation.

Fresh water withdrawals already exceed precipitation in many areas across the country. Current demands are being met with ground water pumping or transport of surface water from other localities. More energy producers may turn to ground water to supplement supplies. Unfortunately, some regions are already withdrawing more water from underground aquifers than is replenished. Between 1900 and 2008, ground water depletion totalled ~1000 billion m^3, with maximum rates occurring during 2000 to 2008, when the depletion rate averaged almost 25 billion m^3/y (Konikow, 2013). Texas withdrew 0.15 million m^3/d of ground water for thermal power generation in 2010 (Maupin and others, 2014). California extracted the second largest amount (0.31 million m^3/d), after Hawaii (0.39 million m^3/d).

More information on the nation's water resources, quality and use can be found in the National Water Information System (*see* http://waterdata.usgs.gov/nwis).

Collective water demands already exceed availability in 9% of the U.S. watersheds examined by Averyt and others (2013). Moreover, water usage already exceeds availability in the west and southwest, which faces growing water and electricity demand as the population increases. Carson (2014) reports that demand for water by the energy sector could outstrip sustainable supply by as much as 40% by 2030. Sanders (2015) provides a comprehensive review of recent literature discussing the US electricity-water nexus, including future projections on the water requirements of electricity generation. The projections vary considerably due to differences in temporal and spatial boundaries, modelling frameworks and scenario definitions. Dodder (2014) reviews recent system-level studies that try to quantify how the electricity sector water demands may change in the future. The following section examines the energy projections from the Energy Information Administration (EIA)'s Annual Energy Outlook 2015 Reference scenario and some of the implications for water usage.

6.2 Coal and power generation sector

The USA is the second largest energy consumer in the world (after China), consuming some 2265.8 Mtoe in 2013 (BP, 2014). Oil accounted for 37%, followed by natural gas (30%), coal (20%), nuclear (8%), hydro (3%) and renewable (2%). Some 843 Mt of coal was consumed in this year, and about 904 Mt was produced (IEA, 2014a), making the USA the second largest global coal producer and consumer (after China).

Coal consumption has generally been declining since 2005 due to lower power sector demand (the biggest coal consuming sector). The decline was largely because of low natural gas prices (partly due to the expansion of shale gas production), the retirement of coal power plants in response to tightening emission regulations, and uncertainty about future regulations. However, coal consumption is projected to increase from 839 Mt in 2013 to 896 Mt in 2040 in the EIA's Reference scenario (EIA, 2015). Total net electricity generation is projected to grow from 4070 to 5056 TWh over this time period, a 24% increase (*see* Figure 15). Figure 15 shows that coal is expected to remain the largest component of the electricity mix in 2040, but its overall share continues to decline. Coal-fired capacity drops from 304 GW in 2013 to 260 GW in 2040. Both natural gas and renewables increase their share of the electricity mix, whilst nuclear power's share decreases to 16%. Renewable electricity grows substantially, by 72% from 2013 to 2040, accounting for more than one-third of new generation capacity. New generation capacity added through the projection period includes 144 GW of natural gas, 77 GW of renewable (including 45% wind and 44% solar), 9 GW of nuclear, and just 1 GW of coal. The EIA's Reference case is one of six scenarios considered, none of which factor in the proposed Clean Power Plan (*see* Section 6.4), which could substantially change the electricity mix. The scenarios only include laws and regulations in effect at the end of October 2014.

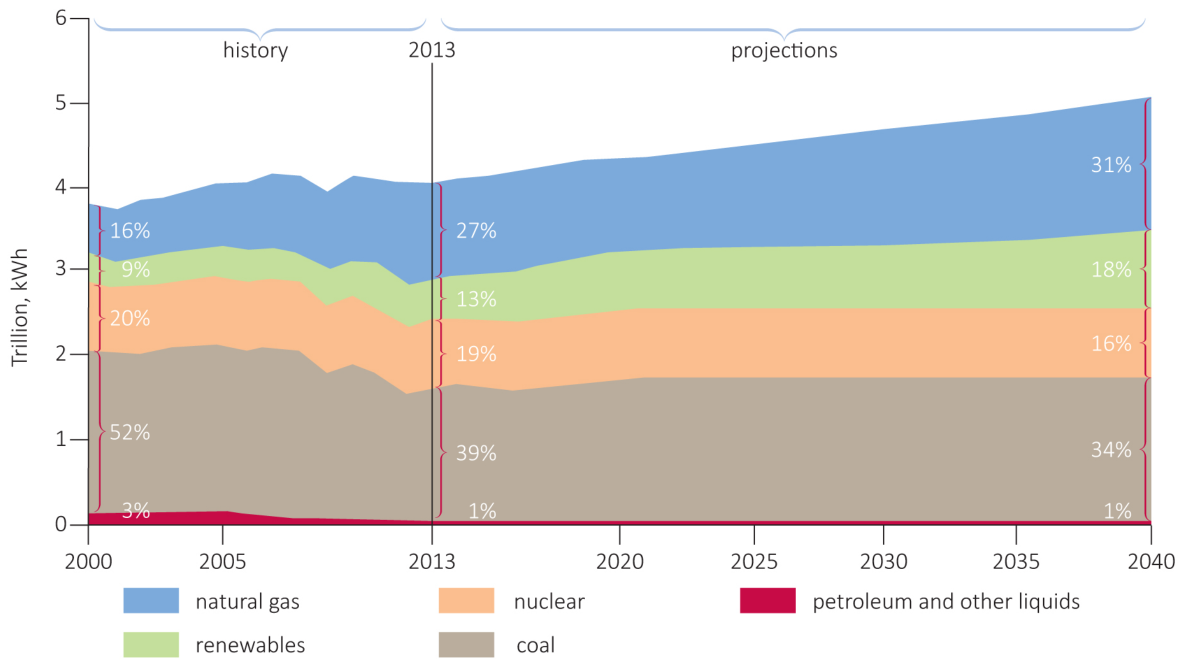


Figure 15 Projected electricity generation by fuel (EIA, 2015)

The future development of the electric power sector has important implications for water resources. Meeting the fresh water demands of the additional capacity in the Reference scenario could be difficult in regions that already have availability issues, such as the southwest. Even in areas with relative abundance of fresh water, it may already be fully allocated. Water requirements will depend on the chosen generation technology, type of cooling system, and other factors.

Water withdrawal and consumption values per unit of generation for various thermal generation and cooling technologies are shown in Figures 16a and 16b, respectively. The data in the Figures were collected from a number of sources and harmonised to common performance parameters and boundaries by Meldrum and others (2013) as part of a life cycle analysis of water use for power generation in the USA; the median values are used. It can be seen that shifting from coal-fired power generation to combined-cycle natural gas plants offers significant water reductions. The amount saved depends on the cooling system used. Although closed-loop systems lower withdrawals, consumption is higher. Some states only allow new thermal power plants to install closed-loop systems.

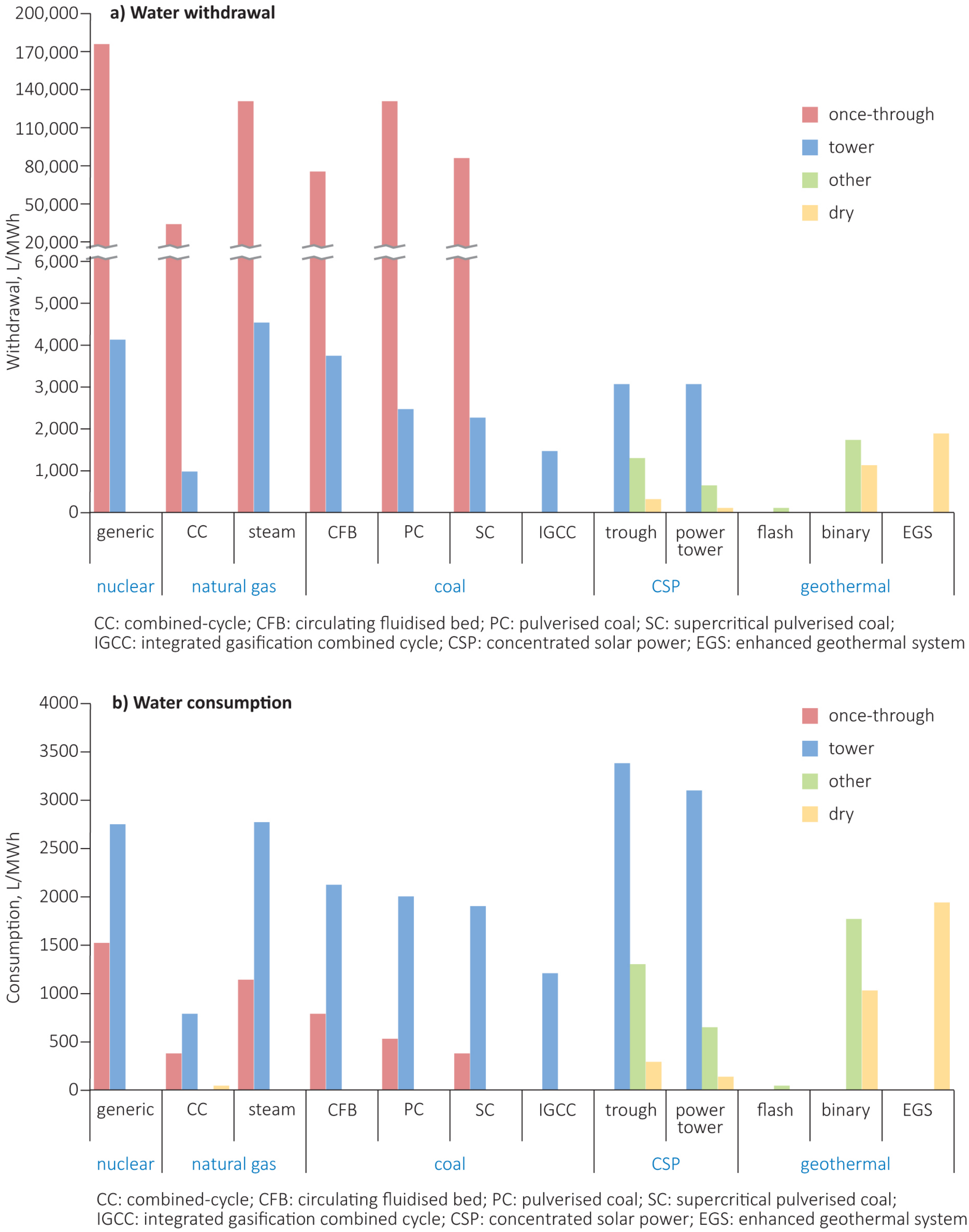


Figure 16 Water withdrawal and consumption for various thermal generation and cooling technologies (Bauer and others, 2014)

However, shifting to natural gas power plants means more natural gas production, notably from shale and tight gas extraction. The USA has 567 trillion m^3 of technically recoverable shale gas resources, with over 35% in areas that are either arid or under high or extremely high baseline water stress (Reig and others, 2014). Fracking requires considerably more water than a conventional gas well (*see* Section 2.4).

Consequently, water stressed areas are likely to see high competition amongst local users, increased depletion of water resources over time, and growing concerns over contamination of dwindling supplies. Water recycling and the development of drier fracking techniques could lower water consumption.

Nonetheless, shifting from coal to natural gas still offers significant water reductions from a life cycle perspective. Table 7 shows water withdrawal and consumption figures (using median harmonised estimates) for extraction, processing, transport, and end-of-life treatment for coal, natural gas and nuclear fuels. Withdrawals and consumption are assumed to be equal for most of the categories due to data limitations, and the nature of water use. It can be seen that the natural gas component withdraws and consumes the least amount of water on a L/kWh basis, and nuclear power the highest. The additional life cycle stages can add as much as 10% to the water consumption of coal with closed-loop cooling systems relative to plant operations, less for natural gas plants, and 20% to nuclear plants with closed-loop systems (Bauer and others, 2014). A life cycle analysis by Grubert and others (2012) found that replacing all the coal-fired power plants in Texas with natural gas combined-cycle plants could reduce fresh water consumption in the state by some 200 GL/y. Since fracking is generally carried out in areas some distance from the power plants, it could still increase net water consumption in the local area.

Table 7 Water withdrawal and consumption for electricity generation fuels (Meldrum and others, 2013)

	Withdrawal, L/MWh			Consumption, L/MWh		
	Extraction	Processing	Transport	Extraction	Processing	Transport
Coal	11.4 (surface) 102.2 (underground) 170.3 (not specified)	68.1	3.8 (train) 416.4 (slurry)	11.4 (surface) 102.2 (underground) 170.3 (not specified)	68.1	<3.8 (train) 416.4 (slurry)
Natural gas	3.8 (drilling) <3.8 (other fracture stimulated gas) 45.4 (fracturing, shale gas)	<3.8	15.1 (pipeline) 30.3 (LNG)	3.8 (drilling) <3.8 (other fracture stimulated gas) 45.4 (fracturing, shale gas)	<3.8	11.4 (pipeline) 3.8 (LNG)
Nuclear	68.1 (in situ leaching) 121.1 (surface) 113.6 (underground) 56.8 (not specified)	41.6 (milling) 37.9 (conversion) 15.1 (centrifugal enrichment) 314.2 (diffusion enrichment) 3.8 (fuel fabrication) 11.4 (end-of-life storage and disposal) 2725.5 (end-of-life reprocessing spent fuel)		68.1 (in situ leaching) 121.1 (surface) 113.6 (underground) 56.8 (not specified)	41.6 (milling) 137.9 (conversion) 15.1 (centrifugal enrichment) 132.5 (diffusion enrichment) 3.8 (fuel fabrication) 11.4 (end-of-life storage and disposal) 26.5 (end-of-life reprocessing spent fuel)	

The nuclear power plants planned for the southeast may have significant water implications due to their high consumption (*see* Figure 16b). Water requirements for the additional renewable capacity projected in the EIA's 2015 Reference scenario depends on the technology – CSP and enhanced geothermal systems can consume significant quantities of water (*see* Figure 16b). Closed-loop (wet towers) CSP has the highest water consumption of all the technologies. Consequently, it might be restricted if dry cooling is not employed in water-constrained regions. Dry cooling, though, reduces thermal efficiency (*see* Section 2.5). The water-stressed areas in the western states that are expected to experience some of the greatest climate change impacts are planning to use renewable electricity to meet future demand. Over 30 states have policies in place stipulating the share of electricity that has to be supplied from renewable resources by a certain date. New large hydropower power projects are unlikely to be built due to public opposition, and the best sites have already been tapped.

At the end of 2012, 64% of coal-fired power generating capacity had FGD scrubbers or dry sorbent injection systems installed (EIA, 2014d). Plants will need to be equipped with either scrubbers or dry sorbent injection systems and activated carbon injection in order to comply with the Mercury and Air Toxics Standards regulations. Installing wet scrubbers increases water use by about 265 L (70 gal)/MWh and some dry FGD technologies (the 'semi-dry' ones) by about 150 L (40 gal)/MWh (Meldrum and others, 2013). Consequently, fresh water consumption will increase, unless alternative sources are used in the wet and semi-dry FGD systems.

The USA is the second largest global emitter of CO_2 (after China), although in cumulative and per capita terms, it is the largest emitter. In 2012, electricity and heat production released 2.09 $GtCO_2$ or 481 gCO_2/kWh (IEA, 2014c). Coal-fired power generation produced 912 gCO_2/kWh and natural gas 403 gCO_2/kWh. CO_2 emissions from power generation have generally been declining since 2000, mainly due to the increasing replacement of coal with lower carbon fuels. The EIA projects that, although electric power generation will increase by 24% from 2013 to 2040, CO_2 emissions only rise by some 7% over the same period (from 2053 to 2195 Mt, an average growth of 0.2%/y). Energy-related CO_2 emissions from all sectors are projected to be 5549 Mt in 2040, still below 2005 levels (EIA, 2015).

Widespread deployment of CCS on coal and natural gas power plants to control CO_2 could have a significant impact on water use. Figure 17 shows the additional water withdrawal and consumption requirements expected for current CCS technologies combined with various generation technologies using closed-loop cooling systems. The data use the median harmonised estimates from the life cycle analyses reviewed by Meldrum and others (2013). CCS technology can double water use in some cases, raising questions about its feasibility for arid regions, such as the southwest. Using treated waste water generated from amine-based CCS systems could help meet the higher water requirements. The EIA Annual Energy Outlook 2014 Reference scenario projects some 930 MW of capacity with CCS will come online by 2040 (EIA, 2014d), but no figure is given in the 2015 scenario.

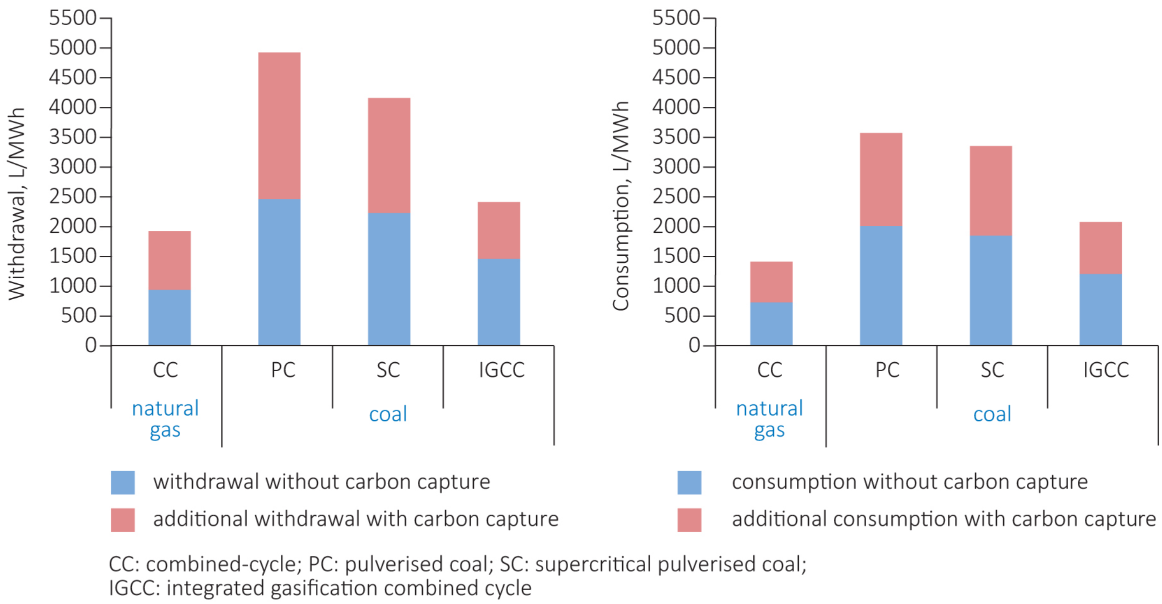


Figure 17 Additional water withdrawal and consumption requirements with CCS (Bauer and others, 2014)

6.3 Energy policy implications for water

Energy policy is set by both the Federal and State governments. It has typically focused on three major goals: assuring a secure supply of energy, keeping energy costs low, and protecting the environment. In pursuit of these goals, government programmes have been developed to promote domestic production of conventional energy sources, develop new energy sources, and improve the efficiency of energy utilisation.

The energy sector is the fastest growing water consumer in the USA. Consequently, water implications need to be closely considered in order to provide a secure and sustainable supply of energy. For instance, although shale gas reduces the USA's reliance on imported gas, fracking can consume significant volumes of water. The more water used by the energy sector, the more vulnerable energy production and reliability is to competition from other water users and water constraints.

The current energy policy landscape is mainly influenced by three recent acts, namely the 2005 Energy Policy Act, the 2007 Energy Independence and Security Act, and the American Recovery and Reinvestment Act of 2009. These acts authorised numerous provisions for energy development, but did not explicitly consider the water requirement implications. Historically, policies for energy and water resources have been made independently of each other. The necessity to coordinate these policies has been recognised. The Government Accountability Office (GAO, 2012), for example, identified the key energy-water nexus issues that Congress and federal agencies should consider when developing and implementing national policies for energy and water resources. It included the need for better coordination among the federal agencies and various stakeholders, such as state and local agencies, and industry. King and others (2013) discuss ways to increase the coherence between energy and water policies.

6.3.1 Energy Policy Act

The Energy Policy Act of 2005 (Public Law 109-58, *see* www1.eere.energy.gov/femp/pdfs/epact_2005.pdf) was the first comprehensive energy policy act since 1992, and was intended to help promote secure, affordable and reliable energy. The Act covers energy efficiency, renewable energy, oil, gas, coal, nuclear, vehicles and fuels, hydrogen, electricity, and research and development, among other issues. For coal, it includes measures for promoting clean coal technologies and CCS. Promoting CCS is likely to increase water requirements for power plants (*see* Sections 2.5 and 6.2), whereas promoting renewable energy, depending on the technology and cooling system (if used), could lower water use in the electric power industry.

For the first time the Act, under Section 979, required the Department of Energy (DOE) to examine the water-related issues associated with the provision of adequate energy supplies, and the energy-related issues associated water supplies (that is, the energy-water nexus). The resulting report to Congress on the independency of energy and water, *Energy demands on water resources* (DOE, 2006) identified concerns regarding water demands of energy production, and discussed technologies to address water use and management in the context of energy production and use. Energy and water were seen as essential interdependent resources.

6.3.2 Energy Independence and Security Act

The Energy Independence and Security Act (Public Law 110-140, *see* www.gpo.gov/fdsys/pkg/PLAW-110publ140/html/PLAW-110publ140.htm) was passed in 2007 with the intention to move the USA towards greater energy independence and security. Among its provisions are measures to increase the production of clean renewable fuels (such as biofuel), and to promote research on, and the deployment of, CCS options. Energy efficiency measures for industry, the residential sector, and federal and public institutions should help to lower electricity demand, and hence the water requirements for power generation. Accelerating research on CCS could enable new technologies to be developed that are less water-intensive. Research and development of renewable sources could also help reduce water usage. Again, accelerating research on CSP and geothermal energy could lower their water requirements. Biofuel production, though, consumes significant amounts of water, and concerns over consumption have already been raised in the High Plains area.

6.3.3 American Recovery and Reinvestment Act

The 2009 American Recovery and Reinvestment Act (*see* www.recovery.gov/) was designed to stimulate the US economy after the global financial crisis. It included funding for energy and water development programmes and projects. Some US$3.4 billion were provided for fossil energy research and development. The funding was intended to stimulate private sector investment by cost sharing. Money was also set aside for a temporary programme for the rapid deployment of renewable energy, including hydropower, and US$126 million for water reclamation and reuse projects. The Act provided a boost for CCS research and development, and also provided funding for one water-energy project that examined water availability for thermal power cooling and competing uses under water stressed conditions (Bauer and others, 2014). As noted before, some of the measures (such as deployment of CCS) will affect water requirements for power plants, although this is not considered in the Act.

6.4 Climate policy and initiatives

Climate change is expected to increase air and water temperatures, reduce precipitation, and cause more frequent and intense droughts in parts of the USA that will affect electricity production and demand. In June 2013, President Obama set out a broad ***Climate Action Plan*** (Executive Office of the President, 2013) to:

- Cut carbon pollution in the USA;
- Prepare the country for the impacts of climate change; and
- Lead international efforts to combat global climate change.

In the absence of congressional agreement on climate policy, the Plan relies mainly on executive powers. The President reaffirmed his 2009 commitment to reduce GHG emissions by 17% below 2005 levels by 2020 (equivalent to 4% on 2005 levels) if all other major economies agreed to limit their emissions as well. In November 2014, a new more ambitious target to cut net GHG emissions by 26–28% below 2005 levels by 2025 was announced (The White House, 2014).

A key element to help meet the emission goals is to cut CO_2 emissions from power plants. Power plants are the largest concentrated source of emissions in the USA, accounting for about one-third of all domestic GHG emissions. Therefore, the President directed the Environmental Protection Agency (EPA) to establish carbon pollution standards for new and existing power plants. Furthermore, the Plan sets a goal to once again double electricity generation from renewable sources by 2020; renewable energy generation had already doubled under the President's first term in office.

A series of standards to limit CO_2 emissions from coal- and natural gas-fired power plants is currently being developed by the EPA under Section 111 of the Clean Air Act. The latest proposal (September 2013) for new power plants (*see* www.federalregister.gov/articles/2014/01/08/2013-28668/standards-of-performance-for-greenhouse-gas-emissions-from-new-stationary-sources-electric-utility) requires new natural gas plants of 100 MW or higher to emit no more than 450 kg (1000 lb) CO_2/MWh gross, and for smaller gas plants to achieve a less stringent standard of 500 kg (1100 lb) CO_2/MWh gross. The more stringent limit can achieved with the latest combined-cycle technology. However, new coal plants will be unable to meet the proposed CO_2 standard (500 kg (1100 lbs)/MWh gross averaged over a 12 month period or a 7 y average emission rate of 450–480 kg (1000–1050 lb)/MWh gross) without installing a CCS system. But widespread deployment of conventional CCS could increase water usage. Talati and others (2014) estimated that using amine-based CCS to capture the 40% of CO_2 required to meet the proposed standard increases plant water use by ~30% in new supercritical pulverised coal-fired power plants with closed-loop cooling systems; the specific amount varies with power plant and CCS system designs. Moreover, CCS is expensive and lowers plant power output. Consequently, it seems unlikely that many new coal-fired power plants will be built. If more stringent emission limits are imposed in the future to mitigate climate change, then natural gas combined-cycle power plants would need to install CCS, with subsequent effect on water resources.

The proposal for existing power plants, referred to as the ***Clean Power Plan***, was issued in June 2014 (www.federalregister.gov/articles/2014/06/18/2014-13726/carbon-pollution-emission-guidelines-for-existing-stationary-sources-electric-utility-generating), along with standards for modified and reconstructed power plants. The Clean Power Plan sets different emission rates (in terms of lb CO_2/net MWh) for each state due to regional variations in the generation mix, as well as electricity consumption, but overall aims to reduce power sector CO_2 emissions by 30% from 2005 levels by 2030. How each state plans to meet its emission target is left up to the state. EPA expects every state to be able to meet the proposed target emission rates without the need to install CCS at existing plants. It is projected that coal and natural gas would still remain the two leading sources of electricity generation, with each providing more than 30% of projected generation. But EPA anticipates that the Plan will result in the retirement of some 46–49 GW of coal-fired power plants by 2020.

The generation mix is likely to change in each state, but it is difficult to predict how this will change water requirements in the power sector. The introduction of the Clean Power Plan, and other air pollution standards (such as the Mercury and Air Toxics Standards and the Cross-State Air Pollution Rules), is likely to accelerate the retirement of older coal-fired power plants and discourage the building of new ones. Water usage in the power sector will therefore depend on the technology employed to meet future electricity demand (*see* Section 6.2).

Faeth (2014) investigated how Texas could be affected by the Clean Power Plan. Texas is the largest generator and consumer of electricity in the country and is subject to droughts and heat waves. He found that, under the Plan, water consumption by the power sector could be cut by over 20% (about 109 million m^3/y) compared with 2012 water consumption by moving to combined-cycle natural gas and wind power. This equates to an 81.4 million m^3/y saving in 2029 compared to the baseline scenario. The cost per unit of electricity produced would increase by 5%, but total system costs would decline by 2%.

There is currently no legislation pending to introduce a CO_2 emissions price in the USA, but if one was introduced, then the energy mix for electricity generation could significantly change. It might also encourage CCS expansion, which may have negative water consequences. The EIA Annual Energy Outlook 2014 considered the effects of a US$10 and $25/t$CO_2$ fee introduced in 2015 that rises at a rate of 5%/y to 2040. It found that natural gas-fired generation is favoured in the first few years, with coal's share falling to between 1 and 19% by 2040. However, natural gas would be supplanted in the later period as more nuclear and renewable plants are added (EIA, 2014d). Fewer coal-fired power plants would lower water withdrawals. But if the additional natural gas generation used combined-cycle technology with closed-loop cooling systems, then water consumption would rise. Water usage by the nuclear plants is dependent on the type of cooling system employed, and for the renewable energy component on the type of generation technology and cooling system (if needed).

6.5 Water policy

The USA has no overarching national water policy, but instead has a number of governance and policy structures at the federal, state and local levels. Unlike China, India and South Africa, there is no separate federal water department. Instead, some 30 federal agencies in ten different agencies are involved in managing and regulating water resources, although some only play a minor role (Bauer and others, 2014). Many of their responsibilities for water quantity and quality overlap. This fragmented approach has created difficulties in managing the nation's water. Water management and planning are becoming more important with energy's rising demand for water and the potential effects of climate change on its availability. Federal agencies with major water management interests include the EPA, Army Corps of Engineers, Department of Agriculture, US Geological Survey, and Bureau of Reclamation. The Bureau of Reclamation, for example, currently manages hundreds of dams and reservoirs in 17 western states, providing water to farmland and around 31 million people, as well as 58 power plants capable of producing 40 TWh/y (Cody and others, 2015). It also has responsibility for beneficial use of non-traditional water sources. The EPA is mainly concerned with water quality, and has no authority to regulate quantity. The US Geological Survey is responsible for water-related data and modelling.

The states (and power generators) have the most influence on managing and meeting the demand for water for power generation. The states are in charge of water allocations and permits, and some also have their own water policies. Water allocation policies vary between states, with those in the east and west historically following two different systems of water law. Furthermore, ground water rights are treated under a different system to surface water rights. Ground water allocation is becoming increasingly complex as the states face growing concerns with depletion of aquifers. An analysis by the DOE (Bauer and others, 2014) found that open-loop cooling systems at power plants are more prevalent in the east, where water is relatively abundant. Water rights in the eastern states are based on the riparian doctrine, and are tied to land ownership. Power plants in the west use more ground water and alternative sources. The western states generally follow the prior appropriation doctrine, under which water allocation is made on a 'first-come, first-served' basis, and is not tied to land ownership. In times of shortages, those who last obtained a legal right to use the water must yield to senior right holders. Some power generators are now considering 'water insurance', that is, paying a regular premium to senior water right owners, so that if a bad drought occurs they can exercise an option to buy water at the pre-agreed price (Larson, 2015).

The price of water is based on principles that include affordability and accessibility by either public or private entities. It does not reflect region-specific water conditions or relative scarcity/abundance (Bauer and others, 2014). As a result, the cost of water can form a small part of overall production costs for power plant operators and other water-intensive energy producers. The low cost of water can promote inefficient use of water, and is not conducive to the introduction of water-saving technologies.

The principal federal law of relevance to the power generation sector is the Clean Water Act. Other acts of interest include the Safe Drinking Water Act, which affects power plants that discharge water into drinking water sources. The Endangered Species Act has been used to prevent the construction of new power plants in some regions. The Federal Power Act requires federal licensing of all private hydropower facilities. The federal government (through the federal agencies) sets the water quality standards, while the states are largely in charge of establishing plans and policies for meeting the standards.

6.5.1 Clean Water Act

The Clean Water Act (*see* www2.epa.gov/laws-regulations/summary-clean-water-act), passed in 1972, established the basic structure for regulating discharges of pollutants into American waters, and surface water quality standards. It employs a variety of regulatory and non-regulatory tools to reduce direct pollutant discharges into waterways, finance municipal waste water treatment facilities, and manage polluted runoff. The Act only applies to surface water – it does not deal directly with ground water or quantity issues.

EPA was given the authority to implement pollution control programmes and set standards and regulations. All point sources, which include power plants, have to obtain a permit in order to discharge pollutants into surface water. Power plants discharged daily some 2.65 GL of waste water in 2009 (Carter, 2013). EPA established the National Pollutant Discharge Elimination System (NPDES) permit programme to control discharges. States can also set their own pollutant discharge limits and water standards. These can be more stringent than the federal ones, but never less so. EPA is currently revising the effluent limit guidelines and standards to reduce waste water discharges of pollutants from thermal and nuclear power plants (*see* http://water.epa.gov/scitech/wastetech/guide/steam-electric/proposed.cfm). EPA estimated that the proposed requirements would reduce water use by 190–390 GL/y through the use of technologies that require little or no water.

Regulations for thermal water discharges from cooling systems at power plants are authorised under Section 316(a) of the Clean Water Act. States typically require surface water to remain under 32°C when heated cooling water is discharged. This has caused some plants to reduce power output or even shut-down at times (for example, during heat waves) to ensure they do not exceed the permitted discharge temperature.

Section 316(b) of the Act requires EPA to issue regulations on the design and operation of cooling water intake structures in order to minimise adverse environmental impacts, such as loss of aquatic organisms. This requires the use of 'best available technology'. Regulations for new power plants are already in force, but a new rule (*see* http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/) covering existing thermal power plants went into effect on 14 October 2014. The new rule covers power plants (and other facilities) withdrawing more than 7.57 ML (2 million gal)/d of water and using at least 25% of it exclusively for cooling purposes. It applies to facilities that have or require a NPDES permit. No one technology is recognised as the best available technology. Instead, the operator can choose between seven options for meeting the rule.

The new regulation will affect some 544 power plants (EPA, 2014), as well as new units at existing plants. The cost of compliance, and to meet future stricter pollutant discharges, may accelerate the retirement of some existing power plants. The rule discourages the use of open-loop cooling systems in favour of closed-loop (one preferred option), hybrid or dry cooling technologies. The rise in water consumption from the use of closed-loop and hybrid cooling systems is unlikely to have an adverse effect on water supply in the eastern states, where water is more abundant. Dry cooling is unlikely to be extensively installed in the west because retrofitting it is expensive. At plants which are already equipped with a wet cooling tower, the cost of upgrading to a dry cooling structure is 3–7 times higher than building a wet cooling tower, and it results in a 2% energy penalty (Ackerman and Fisher, 2013). However, the majority of the power plants that will remain operating in California are expected to retrofit dry cooling systems due to limited fresh water supplies (Sanders, 2015); retrofitting closed-loop systems that can instead use sea water is typically prohibitively expensive.

6.6 Comments

Water availability is becoming an important issue with the growing demand for water and energy, and the increasing prevalence of droughts and heat waves in some parts of the USA. Water usage already exceeds availability in the west and southwest, which faces growing water and electricity demand as the population increases. Even in the water-abundant north-east, the power generating industry faces issues of water quality and temperature. Power plants have had to close down at times to ensure they do not exceed the permitted water discharge temperature. The demand for water by the energy sector could outstrip sustainable supply by as much as 40% by 2030 (Carson, 2014).

Thermal power generation is the largest withdrawer of water nationally, accounting for 45% of all withdrawals in 2010. However, this was 20% less than in 2005 (Maupin and other, 2014). The decline in water withdrawals for power generation is likely to continue as the proportion of natural gas and renewables in the electricity mix increases, replacing coal and nuclear, and more efficient cooling technologies are employed. Few coal-fired power plants are likely to be built due to uncertainty over future environmental legislation. Meeting the fresh water demands of the additional capacity could be difficult in regions that already have availability issues, such as the southwest. Even in areas with relative abundance of fresh water, it may already be fully allocated.

Water management and planning are becoming more important with energy's rising demand for water and the potential effects of climate change on its availability. But the USA has no overarching national water policy, but instead has a number of governance and policy structures at the federal, state and local levels – there is no separate federal water department. This fragmented approach is creating difficulties in managing the country's water. The need to coordinate energy and water policies has been recognised, with the Government Accountability Office (GAO, 2012), for example, identifying the key energy-water nexus issues that Congress and federal agencies should consider when developing and implementing policies for energy and water resources.

7 Discussion and conclusions

Global energy demand is rising primarily as a result of population and economic growth in the emerging economies. Meeting this growing demand will place increasing stress on limited fresh water resources with repercussions for other users in the agricultural, industrial and domestic sectors. Hence multiple strategies are required across all sectors in order to meet the increasing demand for energy, whilst managing water resources more efficiently and sustainably. This involves governments making tough choices involving energy and water trade-offs in order to deliver a secure water and energy future.

China, India, South Africa and the USA all have national energy policies, which aim to provide a sustainable, secure, affordable and reliable energy system. However, water policy is managed differently in these countries. Water is considered a national resource in China and South Africa, and the central government acts as the custodian of the nation's surface and ground water. Both have a national water department, the Ministry of Water Resources in China and the Department of Water Affairs in South Africa. The central government sets the nation's water policy, which is implemented by the states and local organisations. It has the authority to regulate the allocation, flow and end use of all of the nation's water. Consequently, changes in water policy and allocations can be more easily enforced. Power generation in South Africa is currently classified as a strategic user of water, and therefore has priority in its allocation; the national utility, Eskom, is generally guaranteed water supply at a 99.5% level of assurance. But even so, Eskom is subject to the same efficiency criteria and water management requirements as other uses.

In India and the USA, the central governments have less control over water policy and its implementation. The USA has no overarching national water policy, but instead has a number of governance and policy structures at the national (federal), state and local levels. Unlike China, South Africa and India (Ministry of Water Resources), there is no national (federal) water department. India has a national water policy that provides a broad framework; its implementation is the responsibility of the state governments. Many states in India and the USA have their own water policies, and in India, this has resulted in inconsistencies. In practice, the states have the most influence on managing and meeting the power sector's water demands in their respective countries. They control the allocation of water resources, the policy for which can vary between states. Historically, states in the east and west of the USA follow two different systems of water law. Water rights in the eastern states are based on land ownership, whereas water allocation in the western states is made on a 'first-come, first-served' basis. Furthermore, ground water rights in the USA are treated under a different system to surface water rights. In India, surface water is owned and controlled by the state, but ground water is the property of the landowner.

Countries need to integrate their energy and water policies so that energy policies take into account water requirements and, conversely, water policies should consider the energy implications. Energy and water policies have largely been developed in isolation from each other. Moreover, potential consequences of policies to mitigate climate change need to be taken into account. Many of the solutions favoured by governments, such as nuclear power, are water intensive. In addition, as air emission regulations are tightened on carbon dioxide and other pollutants (such as sulphur dioxide), water use at power plants is likely to increase. South Africa has recognised the need for integration in its second National Water Resource Strategy. The World Bank Group is promoting integrated water and energy planning for emerging economies. Its 'Thirsty Energy' initiative includes designing assessment tools and management frameworks to help governments coordinate decision making (Rodriguez, 2014).

One barrier to greater integration concerns water data. Without good data on water resources, flows and use, it will be difficult for policy makers to assess and respond to energy and water trade-offs. Data on water quantity, quality and use are often outdated, limited, inconsistent or unavailable. Moreover, the data are prone to errors and inconsistency. When available, the data are often based on estimates rather than actual measurements. National databases on water use (withdrawals and consumption) for power plants contain errors, possibly due to differences in units, formats and definitions between state and central government reporting requirements (WWAP, 2012b). For example, the definitions of water use, withdrawal and consumption are not always clear.

The power generation sector is typically a country's largest industrial user of fresh water. Water consumption per unit of electricity produced can vary enormously, depending on the mix of fuels and the technologies employed. The energy mix is constantly evolving, determined in a large part by national energy policy, which is itself influenced by markets, technologies, and social and environmental concerns. Decisions will last for many decades as the life of power plants is around 20–40 years. National government plans are including more renewable energy sources, partly driven by climate change concerns. Although wind and solar photovoltaic use negligible amounts of water, concentrated solar power consumes large amounts for cooling purposes (unless dry cooling is employed). Moreover, the intermittent service provided by these sources has to be compensated for by other sources of power, mostly thermal power plants that consume large volumes of water. Developments in energy storage could reduce this need.

Coal still remains the backbone fuel for electricity generation in China, India and South Africa as it provides a secure energy source. These countries all have large coal reserves and are planning to build more coal-fired power plants. Water concerns have been recognised with the implementation of policies to reduce the water intensity of the power plants. On the other hand, the USA is moving away from coal towards natural gas, wind and solar energy. But producing natural gas from unconventional gas shales by hydraulic fracturing (fracking) is water intensive. Fracking is likely to increase in China and South Africa as their shale gas resources are exploited. Some fracking operations are beginning to use on-site deep salt aquifers instead of bringing in water. Some of the energy coming from the gas field could be used to recover the fracking ingredients from the water, and then to further desalinate and purify it. The clean water can then supply local water users, provided the economic value of the water is high enough, making fracking a net water producer instead of consumer.

There are a number of options for reducing the water demand of thermal power generation, including the deployment of better technologies. Government policy in China, India and South Africa is to shift to more efficient supercritical or ultra-supercritical coal-fired power plants, which use 15–20% less water than a subcritical plant with the same capacity. Both China and South Africa promote the use of dry (air) cooling and accept the negative consequences (such as higher capital costs and lower thermal efficiency). Significant volumes of water could be saved by encouraging power plant operators to upgrade their cooling systems to less water intensive ones. Water capture and recycling/reuse technologies within a power plant can also be adopted to conserve water. Many power plants already operate zero discharge systems, treating and recycling all their waste water. Non-fresh water sources (such as municipal waste water, mine water, and brackish ground water) could also be exploited to relieve pressure on fresh water resources.

Regulatory and fiscal initiatives are being introduced to promote the adoption of more efficient technologies to reduce both water and energy consumption. For example, the recent doubling of the tax on coal in India may encourage the upgrading of power plants to improve efficiency, thus requiring less water per unit of power generated. The revenue generated will be used to invest in clean coal technologies and renewable sources. The price of water should reflect its true economic value. Assigning water a more appropriate economic value in regions where it is underpriced, or even free, would encourage more efficient use, not only in power generation, but for all users. The cost of water can form a small part of overall production costs at a power plant. Higher prices will encourage investment in water-saving technologies.

The vulnerability of the power generation industry to constraints in water availability can be expected to increase. There is an array of opportunities and technical solutions available to reduce water use in power plants and exploit the benefits of possible synergies in water and energy, such as the coproduction of electricity and water. According to the United Nations World Water Assessment Programme (WWAP, 2015), "there is enough water available to meet the world's growing needs, but not without dramatically changing the way water is used, managed and shared. The global water crisis is one of governance, much more than of resource availability". Hence strong integrated water and energy policies are required in order to achieve a water and energy secure future.

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