The energy-water nexus: energy demands on water resources

Every unit of water saved saves energy, every unit of energy saved saves water

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Abstract

The power sector[1] is one of the biggest users and polluters of water resources in South Africa, including all associated impacts on human habitats and ecosystems. Power generation from fossil fuels, nuclear and renewable energy all have adverse effects on our natural environment. Coal has for some time dominated the South African power sector and with this dependency the associated CO_2 emissions, water abstraction, air and water pollution and health impacts are inextricably linked. Nuclear power and various forms of renewable energy are currently on the country's policy roadmap as contributors to a future energy mix in South Africa.

This paper looks at the interwoven relationships between the water and energy sectors. An overview of the policies governing the mining, water and power sectors is provided, highlighting the complex challenges that a complementary and sufficiently integrated water and energy policy should seek to address.

Contents

Definitions/physical units/abbreviations **5**

Executive summary **6**

1. Power generation and related water demand in South Africa **7**

1.1 An overview *7*

1.1.1 Global climate change 7

1.1.2 South Africa's power sector 8

1.1.3 Mining – ecological and human impacts 10

1.2 Coal-based electricity generation *11*

1.2.1 Mining of coal 12

1.2.3 Water use in coal-fired power stations in South Africa 14

1.2.4 Water pollution through coal-fired power stations 16

1.3 Uranium based power generation – nuclear power *17*

1.3.1 Mining and conversion of uranium 17

1.3.2 Water use in nuclear power stations 19

1.4 Large dams for hydro power *19*

1.5 Wind power *21*

1.5.1 Mining of rare earth elements 21

1.6 Solar thermal power *22*

1.7 Solar power – photovoltaic *23*

1.7.1 Mining and processing of quartz sand for crystalline solar cells 23

2. Future developments in a nutshell – the likely integrated resource planning (IRP2010) and climate change impacts on water resources and related implications for the power sector **24**

3. The policy agenda and the institutional landscape **25**

3.1 The water sector *26*

3.2 Mining sector *27*

3.3 Power sector *27*

4. Key messages **29**

5. Moving forward **30**

6. References **31**

Definitions/physical units/abbreviations

Definitions:

'Non-consumptive' use of water: Water returns to the source, but its quality is changed: temperature, pollution.

'Consumptive' use of water: Water does not return to the source. Even evaporation is consumptive.

Types of water: Rainwater (e.g. collected in dams), surface water (rivers and lakes), groundwater, wastewater (water which needs treatment), greywater (fresh water that is polluted through discharge of untreated wastewater).

Thermal or energy coal: Coal used for electricity generation or industrial heat and steam (includes hard and brown coal).

Synfuel coal: Coal used in the coal to liquid process.

Metallurgical or coking coal: Raw material for the steel industry.

This document uses the words 'energy', 'power' and 'electricity' interchangeably, and our use of the word 'water' generally refers to all types of water. The terms do not include all possible forms of energy or water.

Physical units:

1 m^3 1 cubic meter = 1,000 litre

1 ML 1 Million litre = 1,000m^3

1 Mm^3 1 Million m3 = 1,000,000m^3

1 Mt 1 Million tons

1 Wh 1 Watt-hour

1 kWh 1 kilo = thousand Watt-hours = 1,000 Wh

1 MWh 1 Mega Watt hour = 1,000 kWh

1 GWh 1 Giga Watt hour = 1,000 MWh

1 TWh 1 Tera Watt hour = 1,000 GWh

Abbreviations

AMD Acid Mine Drainage

CSP Concentrated Solar Power

CPV Concentrated Solar Power Photovoltaic

DEA Department of Environmental Affairs

DoE Department of Energy

DEA Department of Environmental Affairs

DWA Department of Water Affairs

DWAF Department of Water Affairs and Forestry

DWEA Department of Water and Environmental Affairs

EWP 1998 White Paper on the Energy Policy of South Africa

IEA International Energy Agency

IEP Integrated Energy Plan

IRP2 Integrated Resource Plan for Electricity 2010–2030

IRP2010 see IRP2

PV Photovoltaic

REE Rare Earth Elements

Executive summary

This study was conducted between June and August 2012 with the main intention of increasing public understanding of the perhaps less obvious impacts of electricity generation on water resources in general and specifically where these apply to South Africa.

Impacts on water resources via the following energy choices are presented here: coal, nuclear and renewable energy.[2]

Mining of coal takes a heavy toll on the environment – on ground and surface water, and in turn on human habitats. These effects often continue long after the mines are closed, mainly through acid mine drainage (AMD). Nuclear power contributes about 5% of electricity generated in South Africa (Koeberg: 2 x 900MW) and according to the IRP2010 is proposed to be expanded by additional capacity of 9,600MW. Mining, extracting and processing of uranium have severe impacts on water resources and globally there are no recognised long-term solutions for safely dealing with nuclear waste. In the event of radioactive leakage during the operation of a power plant like Koeberg in the Western Cape, just 30km away from dense populations, we are informed by emergency officials that the evacuation plan is weak.

The IRP2010 sustains the generation of electricity from coal for the next two decades and places South Africa on a mixed nuclear and renewable energy roadmap.

Renewable energy technologies such as solar and wind have little impact on water resources during operations, given that large-scale solar thermal power plants use dry cooling technology. The major concern in relation to renewable energy and water resources is the need for permanent magnets used in wind-power generators, which are based on rare earth elements (REEs) where impacts on water bodies and communities around the rare earth mining sites are of particular concern. The processing of uranium and REEs creates large volumes of waste water and contaminated tailings, which can impact on the environment for many decades if not managed properly.

Predicted impacts of climate change on electricity generation and on water resource use by the energy sector are considerable. Cooling processes will need to be more effective given higher average water and air temperatures. Reduced water availability during longer dry periods will impact on the operational requirements of thermal power plants.

We conclude that the policy frameworks that should be considered for the power sector – beside the energy sector itself – need to include those governing both water and mining. Here it is pertinent that a number of departments or ministries govern these sectors, including agencies or institutions that are responsible for ensuring the effective implementation of Acts and regulations, and that these sometimes have competing interests.

The contextual complexity makes it a most difficult and challenging task to create an integrated policy framework in which the interwoven issues and competing interests can be taken into account with sufficient care.

1. Power generation and related water demand in South Africa

1.1 An overview

1.1.1 Global climate change

With climate change, as the planet continues to warm, the magnitude of floods is likely to increase and droughts are likely to lengthen and grow more frequent. These conditions are likely to impact on hydro-power supply most directly through higher anticipated evaporation losses. The planned lifetimes of dams are likely to be reduced through increased sedimentation. The functioning and efficiency of cooling systems of thermal power stations is also likely to be negatively affected by higher water and ambient air temperatures.

The IRP2010 estimates that until the mid-2020s the CO_2 emissions from the South African power sector will continue to rise from 230MtCO_2eq in 2010 to a level of about 300MtCO_2eq. Due to the retirement of the old coal-fired power stations and their replacement by more efficient so-called supercritical coal-fired power stations, the electricity output will still increase from coal but CO_2 emissions will start to decline to a level of 270MtCO_2eq in 2030.

1.1.2 South Africa's power sector

Eskom dominates the South African power sector. In 2011 it generated 237TWh electricity with its own power stations, imported 10TWh, purchased 1.8TWh from local independent power producers and exported about 13TWh. The power sector uses about 2% of national water resources.

Eskom's own electricity generation depends largely on coal (92%), nuclear (5%), hydro power (2%) and other (1%). The bulk of the imports are from Cahora Bassa in north-west Mozambique and small volumes are imported from Lesotho and Zambia. Eskom exports power to the national utilities of Botswana, Namibia, Swaziland and Lesotho. And it has trading relationships with Zimbabwe and Zambia. Eskom also exports to three end-use customers, one in Mozambique and two in Namibia.

Some key figures from the Eskom *Annual Report* for 2011 are set out below.

			2011 compared with 2010
Total coal input:	Mt	124.7	up 1.63%
Total water used:	Mm3	327	up 3.49%
Total electricity produced:	GWh	237,430	up 1.98%
Total ash produced:	Mt	36.2	29% from coal
Total CO_2 produced:	Mt	230.3	up 2.5%
kWh produced per kg of coal:		1.90	same as 2010

kg of coal per kWh produced:		0.53	same as 2010
Litres of Water per kWh of electricity produced:		1.38	up from 1.36
Litres of Water used per kg of coal:		2.62	up from 2.58
CO_2 per kWh produced:		0.97	same as 2010

South Africa's future electricity supply has been set out by the Department of Energy (DoE) in the Integrated Resource Plan for Electricity 2010–2030, shortened to IRP2010. According to the IRP2010, coal-based power generation will absolutely increase by roughly 20%. The total contribution of coal will drop from 92% to about 65% in the energy mix, which is the result of planned new nuclear capacity of 9.6GW, renewable energy capacity of 17.8GW, imported hydro power increased by 2.6GW, and new gas power plants of 6.3GW. All planned new capacity is expected to meet the estimated energy demand increase up from 260TWh in 2010 to 454TWh in 2030 (75%) according the moderate demand forecast as applied in the IRP2010. It is important to note that the actual total electricity demand in 2011 was 248TWh, which was about 7% less than the forecasted demand for 2011 of 267TWh. This development provides reason to believe that future iterations of the IRP will have to adjust the demand forecast downwards, which will lead to a successively changed energy mix and less pressure on new capacity to be installed. In addition, the latest successes in natural gas exploration around Africa and the continuing drop in costs of renewable energy will also have an influence on the future optimal energy mix for South Africa in the decades to come.

Water demand in the power sector is mainly determined by the conventional thermal power stations like coal, gas and nuclear, and in the near future by solar thermal power plants. High-quality water is required for the steam process and water of lower quality is used for the wet cooling process, which is the biggest user of water at a thermal power station. Water use in mining for 'energy' coal, uranium, REEs, copper, other minerals and metals adds a significant share to the total water use of the power sector. The quality of water bodies in the mining areas is threatened by the power sector, where AMD contributes the most to water contamination, and at the power station sites where polluted water from the coal ash dumps impacts on water bodies and successively on human habitats and river ecosystems. Leakage of radioactive substances at nuclear plants and nuclear waste deposits are threats from the nuclear power sector.

According to the National Water Resource Strategy from 2004 (DWAF, 2004), the power sector in South Africa uses about 2% of the national water resources. Mining and bulk industries use 6% and agriculture uses 62%. Other major users are urban areas (23%), afforestation (3%) and other rural use (4%). Mining for 'energy' coal adds roughly 0.3% to the water use by the power sector.

1.1.3 Mining – ecological and human impacts

Upstream in the supply chain of all electricity-generating facilities extraction industries provide the necessary raw input materials both for the manufacturing of equipment and the construction of power plants, and, in the case of coal-fired, fossil fuel-fired or nuclear power stations, with the necessary fuel for the power plants' lifetimes, which can extend to 50 or 60 years.

The roughly 0.3% that mining for 'energy' coal adds to water use by the power sector roughly matches the annual water consumption of the City of Cape Town.

Mining for coal, uranium, REEs, copper and other minerals and metals are all part of the supply chain to build and operate power stations. The impacts of mining on groundwater and surface water, and hence on human and wildlife habitats, are severe and manifold and continue long after mines are closed. AMD is one of the major concerns.

Similarly, after the useful lifespan of coal-fired and nuclear power stations they continue to pose a risk of impact on the environment for generations through seepage and dust from mine tailings, piles and contaminated ash-dumps and radioactive waste deposit sites.

Acid mine drainage

Mining in South Africa is almost always associated with sulphide-bearing minerals like pyrite. Such sulphide minerals form sulphuric acid and iron when they come into contact with water and oxygen. These chemical processes in turn leach other metals from the rocks and lead to elevated concentrations of salts and heavy metals and result in a decline in pH values.

AMD is the flow of such polluted water from mining areas, including those where coal, uranium, REEs, copper and gold are mined. AMD decants and pollutes soil and water supplies as it spreads underground and flows into streams and rivers. The far-reaching and long-term consequences include degradation of the quality of natural water systems, which affects ecosystems and wildlife, poisons food crops and endangers human health.

Levels of AMD in South Africa are high, e.g. the Western Basin of the Witwatersrand Gold Field has a typical decant rate of AMD of 15,000–20,000m^3 per day. Treatment of AMD requires huge investments in infrastructure – pump stations, treatment plants, dams. It is also energy intensive and needs substantial quantities of chemical input. It is not quite clear yet who bears the costs. For old abandoned mines it is the government, which actually means the tax payer; for operational mines it is the current owner; for mines that are to be closed, it is not clear how treatment infrastructure and future long-term operations will be funded (IMC, 2010).

Wind energy technology needs REEs as input material for crucial parts of the generators and other electronic equipment. Mining for REEs takes place almost solely in China, where it poses serious health and environmental threats to the affected communities. Mining for REEs in South Africa is under development and will become productive in the forthcoming years.

The main raw material for silicon-based photovoltaic cells is quartz sand, the extraction of which is comparatively unproblematic.

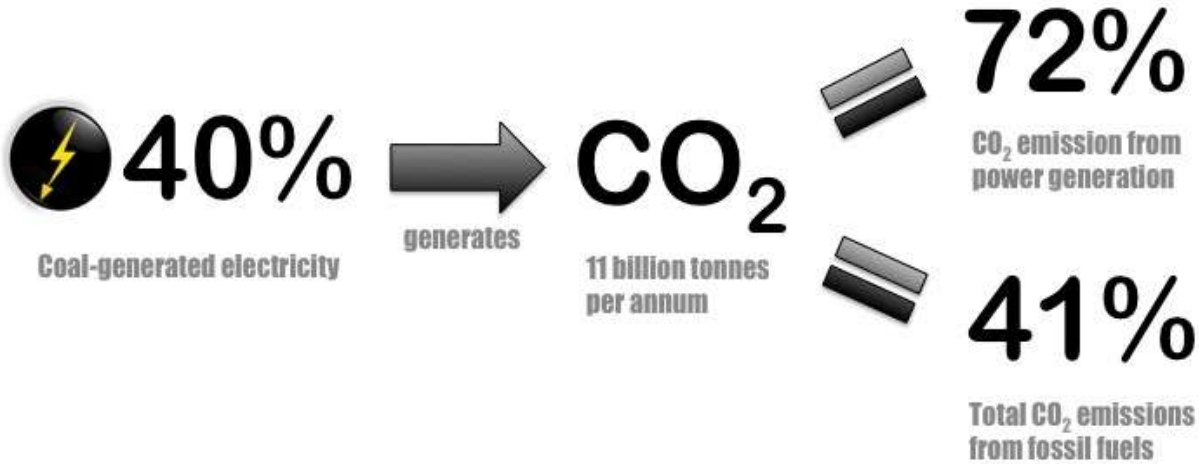
The large dams needed for hydroelectric power generation (and for irrigation schemes) contribute to overall water consumption in power generation – largely through evaporation. In addition, large hydro-power schemes have significant effects on surrounding groundwater levels and streams and can change the climatic conditions of a region and even cause earthquakes.

Other climate-related adverse effects occur through changed siltation and sedimentation patterns – more upstream and less downstream, which impacts on the ecosystems of rivers and river estuaries. Large dams also contribute significantly to climate change through the release of substantial amounts of greenhouse gases. This is mainly due to plant material in flooded areas decaying in an anaerobic environment. The emission factors range from 2–8% compared with thermal power plant generation in non-tropical areas and can go up to more than 200% in tropical regions. Dam methane emissions are responsible for at least 4% of the total warming impact of human activities (Tremblay, 2004; Fearnside, 2011; International Rivers, 2008; Lima, 2008).

Socio-economic and health impacts through displacement of communities and an increase in water-borne diseases around large dams are often neglected by the authorities.

1.2 Coal-based electricity generation

Coal is the most abundant source of fossil fuel energy in the world, considerably exceeding known reserves of oil and gas. About 7.2 billion tonnes of hard and brown coal are produced globally each year. Around 40% of all electricity generated globally is powered by coal, which generates 11 billion tonnes CO_2 per annum and amounts to 72% of CO_2 emissions from power generation and 41% of total global emissions of CO_2 from fossil fuels (IEA, 2011a, 2011b).



Graphic: Project 90 by 2030, 2012

Eskom had a total coal input of 124.7Mt, which is about 50% of the South African annual hard coal production (255Mt in 2010: IEA, 2011a). The other 50% of South Africa's coal goes to the coal-to-liquid industries (Sasol), to steel industries and to exports.

Eskom operates 13 coal-fired power stations with a total installed capacity of 38GW and is currently building Medupi and Kusile with a capacity of 4800MW each. More new coal power builds are planned in the IRP2010, mainly to replace the ageing fleet, but also to add new capacity. Until the mid 2020s, the IRP2010 estimates that the CO_2 emissions from the power sector will continue to rise from 230MtCO_2eq in 2010 to a level of about 300MtCO_2eq. Due to the retirement of old coal-fired power stations and planned replacement with more efficient so-called supercritical coal-fired power stations, the electricity output from coal is expected to still increase, but it is suggested by DoE that CO_2 emissions should start to decline by 2030.

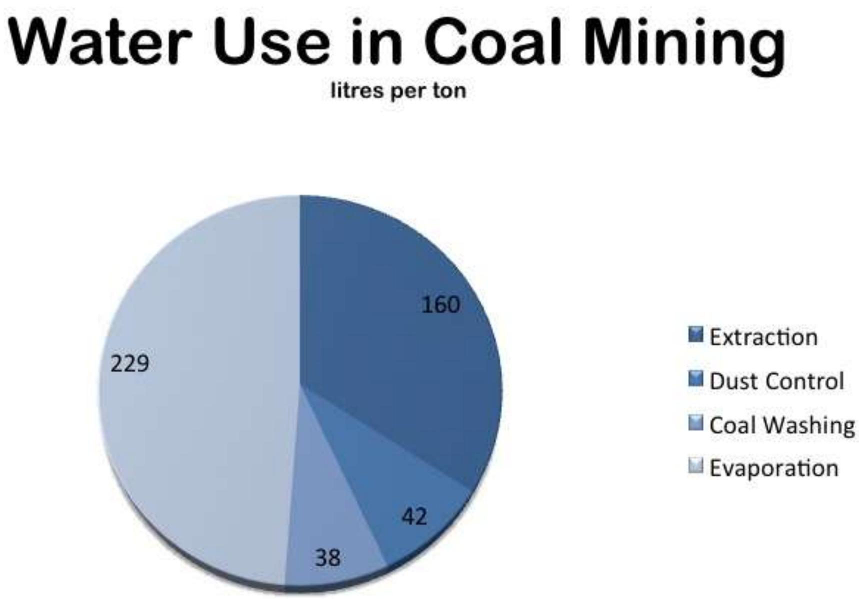
South Africa's coal mines are mainly located in the north-east of the country and the majority of power stations have been built nearby. This concentration of both coal mining and coal-fired power stations, with their huge demands on water supply and their high air and water pollution potential, pose severe threats to both human habitats and ecosystems.

1.2.1 Mining of coal

The water footprint of mining operations can be determined by assessing the quantity of water used and by the level of pollution caused. Acid rock drainage (more commonly known as AMD), heavy metal contamination and leaching, erosion and sedimentation all impact on the water quality of surface and groundwater bodies and consequently on human health, livestock, wildlife and crop productivity (WWF-SA, 2011).

About 46.5% of South Africa's coal mining is conducted underground and about 53.5% is produced by opencast methods. Ownership of the coal-mining industry is highly concentrated, with only six companies (Anglo American – Thermal Coal, BHP Billiton, Sasol Mining, Exxaro Coal, Kumba Coal and Xstrata Coal) accounting for 90% of saleable coal production. The eight largest mines account for 61% of the output.[3] Depending on the mining method and coal quality, the water consumption for coal mining can range from 60 litres per tonne (l/t) to 600l/t (Energy Technology Innovation Policy Research Group [ETIP], 2010).

Coal mines process or prepare thermal coal for use in power plants through washing, which usually takes place at the mine. Washing separates impurities such as shale or stone from the coal. Besides washing, water is used for a potable water treatment plant, for domestic water users (drinking and ablution water for mine workers and other staff), sewage treatment, irrigation of treated sewage, mine workings, slurry dams and road wetting for dust suppression. In total the water directly used to mine a ton of coal can be calculated to be in the region of 160l/t (extraction) + 42l/t (dust control) + 38l/t (coal washing) + 229l/t (evaporation) = 469l/t. If upper-end figures for coal washing are used, water use can rise to 581l/t (Wassung, 2010; Pulles et al 2001).



Several mines have introduced the re-use and recycling of some of their water. Recycling cuts down on the mine's need to abstract fresh water. Recycling water used in mining operations and in the beneficiation plant (washing) is estimated to be around 26% of the total volume of water used (Pulles et al 2001). The figure of 469 to 581l/t can therefore be adjusted downwards to approximately 347 to 430 litres of fresh water per ton of coal ready for use at a coal-fired power plant.

With its annual coal production of roughly 255Mt (2011), South Africa's coal mining industry consumes about 102Mm^3 of water annually or 280,000m^3 daily considering an average water use of 400l/t of mined coal.

Eskom used 124.7Mt of coal in 2011 (Eskom, 2011), hence if we add 50Mm^3 water consumption to Eskom's reported water input of 327Mm^3 in 2011, this would accurately reflect the water use in coal mining. This increases the 2% share of national water consumption (DWAF, 2004) in the power sector significantly.

1.2.2 Coal mining and water pollution

Besides the fact that mining operations use large amounts of fresh water, which makes access to clean and safe water increasingly difficult for both humans and livestock around mining operations, the resulting mine effluent is typically a stew of hazardous acid-generating sulphides (also known as AMD), toxic heavy metals, waste rock impoundments and water, and it is often deposited nearby in large free-draining piles, where it can pollute land and water supplies for decades to come. Detrimental effects on rivers and ground water can be observed many miles downstream from mine sites (WWF-SA, 2011).

In 2011 WWF presented a case study on the Olifants River catchment, which is an area that has experienced over 100 years of coal mining. By 2004, an estimated 50,000m^3 of mine water was discharged into the river from operational mines and 64,000m^3 from closed mines – daily. Pollution levels have impacted on downstream users, including people living in the catchment as well as tourists and wildlife of the Kruger National Park. The case study concluded that the Olifants catchment has the poorest water quality in the country (WWF-SA, 2011).

1.2.3 Water use in coal-fired power stations in South Africa

Eskom uses about 2% of South Africa's national freshwater resources, mainly for the operation of the coal-fired power stations. The water used is abstracted largely from government water schemes (dams). In 2011 Eskom used 327Mm^3 water for steam generation and cooling purposes. This is roughly the same amount of water as the City of Cape Town needs annually.[4]

Most of Eskom's thermal power stations, which include coal and nuclear, use wet cooling technology. Efficient cooling technologies such as dry cooling can reduce the water consumption at a thermal power station by 90% and more. Eskom has installed dry cooling at two of its existing coal-fired power stations, a mixed technology at one, and all new coal-fired power stations will use dry cooling.

Dry cooling technology has its drawbacks, including higher capital costs, auxiliary operating power requirements and fan noise, and an overall lower plant performance (US-DoE, 2009 and Dersch, 2007).

Despite Eskom having adopted a 'long-term water strategy' (Eskom, 2011), in which it declares that the scarcity of water resources in South Africa is at the forefront of its strategic thinking and acknowledges itself as a strategic water user, not much has changed in its water consumption to date. Between 2006 and 2011, Eskom's water use dropped from around 1.38l/kWh to 1.29l/kWh.[5]

Dry cooling reduces water consumption of a thermal power station by up to 95%. Given that all Eskom's new coal-fired power stations will be dry cooled, this will have a significant impact on the average specific water consumption of the fleet in the next decades as old power stations will be retired from the early 2020s onwards:

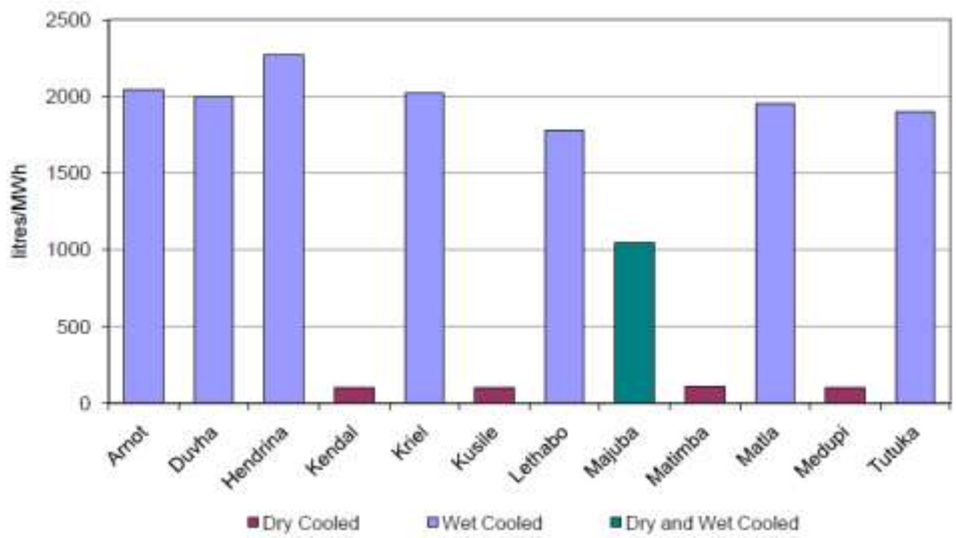


Figure 2: Eskom's specific water consumption per power station.[6] Note: The power stations Camden, Grootvlei and Komati (all wet cooled) are not presented in the above figure. These were mothballed in the late 1980s and early 1990s, but were successively returned to service from 2003 onwards.

Carbon capture and sequestration or storage

Carbon capture and storage (CCS) refers to technology aimed at capturing CO_2 from fossil fuel use in power generation and other industries to prevent the release of large quantities of CO_2 into the atmosphere. In theory, the captured CO_2 would be pumped into deep geological formations underground to securely store it away from the atmosphere.

South Africa is actively developing and seeking to implement a roadmap for the commercial application of CCS. A test injection experiment is scheduled to take place in 2016, a demonstration plant is expected to be operational in 2020 and the commercialisation of the technology is expected by 2025 (South African Centre for Carbon Capture and Storage, www.sacccs.org.za).

CCS would substantially increase water consumption if applied to power generation. Water consumption levels increase by two-thirds, or almost double when compared with wet cooling technology. These estimates are for greenfield plants. Retrofitted CCS would be higher still on a net energy output basis (Mielke, 2010).

According to the 2011 Eskom Annual Report the total water use for generation was 327Mm^3. Adding the coal mining-related consumption results in a total water use for electricity generation of 377Mm^3 in 2011. The specific water consumption per kWh sent out thus increases from 1.38l/kWh to 1.59l/kWh.

1.2.4 Water pollution through coal-fired power stations

On-site storage and transport of coal requires water for dust suppression. Coal-fired power stations produce large amounts of coal ash: Eskom produced 36.2Mt in 2011, which is almost a third of the input amount of coal. This solid waste ash from coal-fired power stations has to be removed. Some ash is recycled or sold on for production of building materials – like cement and bricks – but the bulk is deposited next to the power stations in so called ash dumps, ponds or dams. Eskom sold 2Mt, recycled 5.5% and disposed of 34.16Mt in 2011.[7]

Power-plant produced coal ash contributes to air pollution through fugitive dust and water pollution at the disposal sites, contaminating the ground water through slow leakage of toxic elements from these sites. Contaminants include lead, thallium, barium, cadmium, chromium, mercury, nickel and selenium [8] (Gottlieb, 2010). Arsenic has been shown to cause skin, bladder and lung cancer, and leads to damage of the nervous system.[9] When mercury enters the aquatic environment, it can be transformed by micro-organisms into the much more toxic form, methyl mercury. This accumulates in fish and subsequently in the people who eat them. A mother passes on the mercury that has accumulated in her body to her developing foetus, which affects the development of its central nervous system.[10] Some studies also point out that ash from coal-fired power stations includes significant amounts of radioactive elements, such as uranium and thorium.[11]

The recycling of coal ash, such as its use in construction materials and as structural fill for buildings and roads, is another pathway for the toxic elements from coal ash to reach human living environments.

1.3 Uranium based power generation – nuclear power

The contribution of nuclear power to global electricity generation was 13.8% in 2011 (or 2,630 billion kWh = 2,630 million MWh = 2,630 thousand GWh = 2,630 TWh). An estimated 68,971 tonnes of uranium were required in 2011 to power the 440 reactors in operation worldwide (WNA, 2011).

South Africa (Eskom) owns and operates two pressurised water reactors of 900MW capacity each, both at Koeberg, only 30km north of Cape Town. Koeberg contributed 12TWh to Eskom's electricity generation in 2011, or 5.1% (Eskom, 2011). The IRP2010 plans to add 9,6GW nuclear capacity on three coastal sites in the next decade to meet forecasted demand.

Uranium mining, milling, conversion, enrichment, fabrication of fuel assemblies and waste handling are the major steps of the front-end of the nuclear fuel cycle. Transport and interim storage of fuel and spent fuel are additional steps towards the actual use of the fuel in the reactor. Reprocessing, plutonium and uranium recycling and final disposal of nuclear waste form the back-end of the nuclear fuel cycle.

Namibia has two significant uranium mines capable of providing 10% of world mining output.[12] Uranium mining in South Africa takes place mainly by re-processing tailings from gold mining activities. By 2009 Namibia and South Africa together held about 10% of the known recoverable resources of uranium.[13]

South Africa does not operate any conversion and enrichment for uranium or plutonium, nor do reprocessing facilities for used nuclear fuel rods exist locally. Such facilities were built for the Apartheid regime's nuclear bomb programme, but this programme was dismantled in 1993 and the facilities have been shut down and decommissioned (Fig, 2005). This means that nuclear fuel rods for Koeberg have to be procured on world markets and after their useful lifetime, stored and cooled on site at Koeberg in the absence of any long-term high-level nuclear waste deposit storage facilities. Low- and intermediate-level nuclear waste is deposited at Vaalputs Radioactive Waste Disposal Facility, managed by NECSA.[14] In the event of leakages at nuclear waste deposit sites, ground and surface water will become radioactive to unknown levels, depending on the waste grade stored at the site. Health impacts on humans and wildlife can be expected in such cases.

1.3.1 Mining and conversion of uranium

Uranium mining in Africa and South Africa often goes hand in hand with gold mining. African countries produce about 18% of the world's demand. Future projects involving uranium mining include one of the world's largest suppliers of nuclear fuel, Areva, setting up a uranium processing plant in the Karoo region – establishing a bigger market for uranium mining in Africa as a buyer of processed ore.[15]

Mining and milling

Uranium is the fuel used in nearly all existing nuclear reactors. It is very widely distributed in the earth's crust and oceans, but can only be economically recovered where geological processes have increased its concentration. Almost all economically workable uranium-bearing ores have in the past typically contained less than 0.5% of uranium. One kilogram of uranium has as much energy potential as three million kilograms of coal.

Uranium ore is mined either by conventional open-pit or underground mining methods, and the uranium is extracted from the crushed ore in a processing plant (mill) using chemical methods appropriate to the specific mineral form. These usually extract some 85% to 95% of the uranium present in the ore. The radioactivity of the separated uranium is very low. The radioactive daughter products are left with the mill tailings, stabilised and put back into the mine or otherwise disposed of.

In some cases it is possible to pass chemical solutions through the ore bodies and dissolve the uranium directly. This process is known as solution mining, or in-situ leaching. Uranium can also be recovered as a by-product of the extraction of other metals from their minerals, for example copper and gold, and as a by-product of phosphoric acid production from phosphate rocks.

The uranium concentrate (U3O8) produced in the ore processing plant is known as yellowcake and usually contains between 60% and 85% uranium by weight. Depending on its quality, the concentrate is sometimes further purified in a refinery near the mine before being shipped in metal containers to a conversion plant.

Conversion, fabrication and enrichment

These are the next steps in the process to manufacture a potent nuclear fuel in the form of nuclear fuel pins or rods. The yellowcake is chemically dissolved and reconverted into uranium oxide and dioxide for processing in the fuel fabrication plant, or further processed into uranium hexafluoride (UF6) for use in the enrichment process. Highly enriched uranium (HEU) is typically used in nuclear bombs. Fuel pellets are created in the fuel fabrication plant from UF6, which are loaded in tubes of corrosion-resistant zirconium alloy with a low neutron absorption. These loaded tubes, called nuclear fuel pins or rods, are put together in a lattice of fixed geometry called a fuel assembly.

Uranium mining and water pollution

The uranium mining process is similar to coal mining, with both open pit and underground mines. It produces similar environmental impacts, with the added hazard that uranium mine tailings are low-level radioactive. Groundwater can be polluted not only from the heavy metals present in mine waste, but also from the traces of radioactive elements still left in the waste.[16] When pumps are shut down after the closure of mines the risk of water contamination increases, very similar to the AMD challenges from coal and gold mines, with the additional threat of radioactive pollution.

Wastes arising in the front-end of the fuel cycle

Waste rock from uranium mining and milling wastes include radium and other naturally occurring radioactive substances. These wastes are optimally disposed of in engineered geological facilities which are covered on top and sealed underneath and on the sides in order to reduce radon emissions and the movement of ground water. Wastes from the conversion process may contain uranium, acids and some organic chemicals. Some conversion facilities recycle such wastes to uranium mines in order to recover the uranium content while others dispose of their waste directly. Wastes arising from the uranium enrichment and fuel fabrication processes contain essentially small amounts of uranium and the associated naturally occurring radioactive elements. Uranium is considered to have a low radio-toxicity, but the same is not true for plutonium. The treatment of wastes in order to separate the plutonium and uranium, and the subsequent waste conditioning, results in a typical value for the quantity of plutonium finally present in wastes of 0.01% of the initial plutonium (OECD, 1994; MIT, 2010).

Potential hazards from uranium mill tailings

Radon – a radioactive gas – occurs through continuous decay of radioactive substances in uranium mill tailings. Radon escapes from the piles and spreads with the wind and increases the lifetime lung cancer risk of residents living near a tailing pile. The dry, fine sands from a pile are blown by the wind over adjacent areas and elevated levels of radium can subsequently be found in dust samples in nearby communities. Seepage from tailings is another major hazard and poses a risk of contamination of both ground and surface water. Radioactive and other hazardous substances like arsenic may contaminate drinking water supplies and fish in the area.[17]

1.3.2 Water use in nuclear power stations

Koeberg (and other proposed nuclear developments in South Africa) use salt water for cooling purposes. At peak operation levels, Koeberg uses 80,000l of sea water per second and about 1,000l of fresh water (for steam and other purposes) per day.[18] Fresh water for the proposed nuclear power plants is predicted to be produced on site through desalination.

Known impacts on marine life are through the returned brine from the desalination plants and the water used for cooling, which returns at higher temperatures.

1.4 Large dams for hydro power

Large dams needed for hydroelectric power generation (and for irrigation schemes) contribute to water consumption largely through evaporation. Depending on the climate at the actual site the evaporation losses – or water consumption – through hydro power range from 47 to 208.5l/kWh. The average for about 2,300 hydroelectric dams is 68l/kWh. Natural-state evaporation would only be 3.2% of that of a reservoir (Torcellini, 2003).

The known adverse effects of large hydro-power schemes range from displacing people to altering ecosystems, changing climate conditions and causing earthquakes. Dams often deliver considerable benefits but in many cases, the price paid to secure those benefits has been unacceptably high. In many cases the dams underperform, are more expensive than planned and take a heavy toll on affected communities.[19]

South Africa has comparably small power generation capacity from hydro-power schemes. In total only 2% of electricity generated by Eskom is from its own hydro-power stations. Less than half of this is from run-of-river plants (Gariep, 360MW and Vanderkloof, 240MW on the Orange river) while 60% is from pumped storage plants (Drakensberg, 1000MW and Palmiet, 400MW pumped storage schemes) – where the energy for pumping largely comes from the overcapacity of coal-fired power stations at night and during other low-demand periods. An additional 4% hydro power is imported from Cahora Bassa in north-west Mozambique and small volumes from Lesotho and Zambia (Eskom, 2011).

In the future renewable energy from solar photovoltaic and wind power plants, which cannot be accommodated in the grid, will also need to be stored. Pumped storage schemes are one viable option for such utility-scale storage. Eskom is about to complete the Ingula pumped storage scheme in 2013 with 1,332MW capacity and has plans for the Tubatse pumped storage scheme with 1,500MW.

Large dams contribute to climate change in various ways. They release substantial amounts of the potent greenhouse gas, methane. This is due to plant material in flooded areas decaying in an anaerobic environment. The construction of large dams leads to massive transformation of land use, deforestation and the loss of carbon sinks.

Besides water loss through evaporation, large hydro-power schemes come with other significant impacts on the environment and human habitats, which are expected to increase in severity as the planet continues to warm. These impacts include (Greeff, 2011):

Dam safety: Dam failures through increased flooding are a potential risk. A collapsed dam releases millions of cubic metres of water into downstream river beds, which will cause dams in its path to collapse and human settlements to disappear.

Increased catchment erosion, reservoir sedimentation and the sinking of deltas. As flood magnitudes are expected to increase, erosion and sedimentation of upstream river beds and dams will accelerate, consequently reducing the life expectancy of dams. As dams hold sedimentation back, rivers carry less sediments downstream causing river beds and deltas to sink. In conjunction with climate-change-induced rises in sea levels, the area of land vulnerable to flooding (river estuaries and upstream) will increase significantly in the decades ahead.

Drought and hydro dependency. As flood magnitudes are expected to increase, droughts are likely to increase, too, in both frequency and duration, and hence become more severe as the planet continues to warm. Increases in both flood magnitudes and drought severity reduce the predictability of the hydro power-generation capacity of existing and future schemes. Most of Africa's great rivers are trans boundary, which results in regional water implications and conflicts over water are likely to become more frequent and serious as climate change undermines water resources.

Health risks associated with dams and the predicted increases in water temperature. Evaporation will increase significantly in a warming world and accelerate the impact of droughts. Rising water temperatures also lead to increasing invasive alien plant infestations, such as water hyacinth and algal blooms. These mats of floating plants can increase evaporation rates by as much as six times when compared with open waters. Large dams are associated with water-borne diseases, such as malaria, schistosomiasis, river blindness and others. As water temperatures are expected to increase significantly, the incidences of water-borne diseases are set to rise too.

Hydro power has brought, and continues to bring, considerable benefits to people but it is important to consider: at what cost? and at what cost in the future?

1.5 Wind power

By 2011 the worldwide installed capacity of wind turbines was 239 GW[20] and the growing trend in this sector continues unabated. South Africa's IRP2010 plans to install 8.4GW of wind energy supply by 2030, and more wind power is likely to be economically feasible in the near future. The impacts of wind power on water resources originate mainly from the need for REE, which are used in the permanent magnets of wind power generators.

Considering an average wind turbine size of 1.5MW with about 160,000 turbines currently installed, each using roughly 1,000kg of permanent magnets or 250kg of rare earth material, this amounts to 40,000 tons of REE.

The planned wind farms in South Africa with 8.4GW total capacity will use about 1,400 tons of REE. Substitution of REE is considered difficult or impossible. Future design of products containing REE need to consider easier recycling of such materials (Gschneidner, 2011).

Wind power plants do not consume water for power production during their operational life time.

1.5.1 Mining of rare earth elements

REE are utilised for many products in daily use: electric motors and generators, computers, mobile phones, iPods, navigation systems, displays, TVs, fluorescent lighting, vehicles, etc. REE are sufficiently available in the earth's crust, but seldom in concentrations that allow economically feasible mining operations. Such concentrations are mainly located in China, the USA, in some states of the former USSR, and Southern Africa.

Currently about 90% of the rare earth metal alloys are produced in China, which manufactures 75% of the magnets containing REE (Humphries, 2012). The REE worldwide production amounted to 130,000 tonnes in 2010. The high dependence on China for REE has triggered some new mining developments in the USA, South Africa and elsewhere, which are expected to be productive in the next few years.

Every ton of rare earth produced generates approximately 8.5kg of fluorine and 13kg of dust; and using concentrated sulphuric acid high temperature calcination techniques to produce approximately one ton of calcined rare earth ore generates 9,600 to 12,000m^3 of waste gas containing dust concentrate, hydrofluoric acid, sulphur dioxide, and sulphuric acid, approximately 75m^3 of acidic wastewater, and about one ton of radioactive waste residue (containing water) (Hurst, 2010).

Furthermore, according to research conducted within Baotou, where China's primary rare earth production occurs, 'all the rare earth enterprises in the Baotou region produce approximately ten million tons of all varieties of wastewater every year' and most of that waste water is 'discharged without being effectively treated, which not only contaminates potable water for daily living, but also contaminates the surrounding water environment and irrigated farmlands' (Hurst, 2010). The disposal of tailings also contributes to the problem as producing a ton of rare earth elements creates 2,000 tons of mine tailings (Hurst, 2010).

South Africa's REE mines are located in the Northern Cape at Steenkampskraal and Zandkopsdrift.[21] As these mines go into operation in the next few years, it will be critical that all necessary measures are sufficiently prescribed by the authorities and implemented by the companies to avoid significant pollution of surface water and groundwater, as has happened in China. As with all other mining activities in South Africa, the risk of AMD needs to be associated with the REE mine developments.

1.6 Solar thermal power

The most attractive sites for solar thermal power generation (or concentrated solar power: CSP) are those with a high annual number of sunshine hours and high level of direct irradiation. Unfortunately such areas are deserts – arid or semi-arid regions, which means that the accessibility and availability of water for the steam and cooling process is limited. Solar thermal power plants in South Africa are proposed in the IRP2010 and will be located in the Great Karoo.

The water requirements for solar thermal power plants are determined by the steam process and the chosen cooling technology. Applying the water-saving dry cooling technology is a pre-condition for solar thermal power plants located in arid or semi-arid regions, like the Great Karoo.

CSP – a large-scale solar thermal power technology – uses similar amounts of water during operation as coal-fired power stations where wet cooling technology is used.

Because of this, dry cooling systems are the only feasible cooling technology to be considered for CSP generating plants in South Africa. The technical and performance limitations facing CSP through a dry cooling process are comparable to those for coal-fired power plants. An average wet cooling process requires 1,500 to 2,000l/MWh. Dry cooling reduces this by up to 95%, to 75 to 100l/MWh. The water consumption for cleaning the parabolic troughs or the mirrors is design dependent and ranges between 100 and 200l/MWh. For the proposed CSP power stations in the Great Karoo, with a nominal power output of 100MW, an operating time of 18 hours a day and generating conservatively 1,500MWh per day, a rough estimate of the water use through dry cooling would be between 262,500 and 450,000l/day or up to 164,000m^3/year. Downstream pollution of water bodies through CSP is non-existent (DoE-US, 2008; DoE-US, 2009).

1.7 Solar power – photovoltaic

Almost all parts of South Africa are highly suitable for solar photovoltaic (solar PV). Utility-scale installations of 8.4GW are planned in the IRP2010 and procurement for this is under way. The rollout of small-scale rooftop installations are expected to accelerate substantially given ongoing steady dropping costs of this technology along with ongoing sharply increasing tariffs for grid electricity.

During operations solar PV does not consume water, except in very dusty and dry areas where regular cleaning of the panels with water and detergents is necessary to maintain efficiency.

Concentrated solar PV (CPV) is an advanced technology that uses optics such as lenses or curved mirrors to concentrate large amounts of sunlight onto a small area of solar photovoltaic cells to generate electricity. CPV technology requires two-axis solar tracking and cooling. Passive waterless cooling is sufficient for low-concentration CPV but medium- to high-concentration CPV requires active cooling, which can be water or air circulated behind the cell modules or by immersing the cell in a dielectric cooling medium (Røyne, 2005; Darwish, 2011). Depending on the type of heat exchangers used, a large scale CPV-cooling system could be comparable in terms of water use to the wet or dry cooling technology used for thermal power plants. It is assumed that CPV power plants in South Africa will either use passive cooling, or active dry cooling technology.

1.7.1 Mining and processing of quartz sand for crystalline solar cells

The lifecycle of PV systems starts with the mining of quartz sand (for silicon-based PV). The mining of quartz or sand is an established process, and the product is widely used (not only for solar cell manufacturing). Since sand is a very abundant material, raw material supply for silicon solar cells is not expected to become a problem, whatever the future size of solar cell production. After mining, the sand is transported, classified, scrubbed, conditioned, flotated and deslimed. Emissions from these processes are negligible, except for the release of respirable dust containing about 17% of crystalline silica particles. Water-use requirements are determined by the need for dust suppression on piles and roads.

Metallurgical grade silicon is produced from quartz sand in an arc furnace and further purified into 'electronic' grade or 'solar' grade silicon. Silicon processing and manufacturing steps use significant amounts of energy and water, and release substantial amounts of highly potential greenhouse gases to the working environment. Such manufacturing environments contain the airflow in a closed system in order to eliminate contamination of the product but also to minimise the amount of these gas emissions to reach the atmosphere. When not filtered, contained, disposed of or converted properly, these gases will contribute to climate change.

Though fluorine and chlorine emissions into water are much lower than for a coal-fired power plant, they are still too substantial to be neglected (20–25% of the equivalent emissions of a coal-fired electricity plant). Contaminated water from electronic- or solar-grade silicon manufacturing is submitted to waste-water treatment before discharging (Phylipsen, 1995).

2. Future developments in a nutshell – the likely integrated resource planning (IRP2010) and climate change impacts on water resources and related implications for the power sector

The IRP2010 sets out the future mix of electricity supply in South Africa. To the existing energy mix it aims to add new nuclear capacity of 9.6GW as well as 6.3GW of new coal capacity (in total, 16.4GW new coal from 2010 including Medupi and Kusile with 4.8GW each), and 17.8GW of renewable energy capacity. The continued and planned increased use of coal in the energy sector, in particular, comes with dire consequences for water resources, human habitats and ecosystems through water abstraction, water and air pollution around coal mines and CO_2 emissions. The IRP2010 estimates that the CO_2 emissions from the power sector will continue to rise from 230MtCO_2eq in 2010 to a level of about 300MtCO_2eq in the mid 2020s. Due to the retirement of old coal-fired power stations and their replacement by more efficient, so-called supercritical coal-fired power stations, it is estimated that the electricity output will still increase from coal but that CO_2 emissions will start to decline by 2030.

In addition, the demand on water through coal-fired power stations will reduce due to the retirement of wet cooled power stations and the use of dry cooling technology in new developments. But the load on water bodies through abstraction and pollution will increase in the coal mining sector, where old mines will continue to pollute through AMD.

Nuclear power stations will cover their water demand for cooling from the oceans and their fresh water demand with on-site desalination. Solar thermal power plants in the Karoo will operate with dry cooling, and other forms of renewable energy, such as wind and solar photovoltaic, have no or very little demand for water during operation. Nuclear power and wind power pose threats to water bodies through their upstream mining activities. The mining of uranium and REEs in South Africa is under development and will increase their world market share in the forthcoming years and of course also increase their local impact on humans and nature. Environmental impacts through mining for silicon-based solar photovoltaic can be negligible when compared with the impacts by coal, uranium or REE mining. Processing for solar grade silicon, however, involves large water use and chemical processes that emit pollutants into both water and air, some of them with high toxicity and greenhouse gas potential. If these emissions from the solar industry are not controlled and contained properly the already large and further growing scale of this industry and its associated emissions will need to be taken seriously and impacts understood properly.

Hydro power, both run-of-river plants and pumped storage, currently provides a share of only 2% to electricity supply in South Africa through domestic hydro-power stations. Additional pumped storage is planned in the IRP2010. A warming planet will increase water losses in reservoirs through evaporation. Increased flooding will increase catchment erosion and reservoir sedimentation, which reduces dam lifespans. Unexpected magnitudes of flooding pose risks to dam safety. As dry periods are likely to increase too, the expected electricity output of hydro-power schemes is expected to decline. Impacts on the local population of such dams also include relocation during the construction period and an expected rise in incidents of water-borne diseases caused by warmer water temperatures.

Increased average temperatures of both water and air have significant impacts on the cooling processes used in thermal power plants, which results in higher energy demand for cooling and hence reduces the efficiency and output of the power station. Should temperatures rise above certain levels, thermal power stations might need to shut down due to lack of cooling capacity. Beside the climate change impact of water and air temperature increases, the possibility of reduced availability of water may pose a future risk for the operation of power stations as it does for communities. We can conclude that the impacts of climate change on electricity generation and on water resources used by the energy sector are considerable.

3. The policy agenda and the institutional landscape

The policy frameworks to be considered for the power sector also include those governing water and mining, as well as the energy sector itself. Affected ministries include, at the least, the Departments of Water Affairs, Mineral Resources, Energy, and Public Enterprises, which oversees the state-owned enterprise Eskom. A number of agencies or institutions are responsible for ensuring the implementation of Acts and regulations in the above-mentioned sectors. The complexity and number of stakeholders involved makes it a most difficult and challenging task to create an integrated policy framework where the interlinked issues and competing interests can be appropriately considered.

An alignment of policies in these sectors for overlapping issues like water and the environment is a huge challenge for any government. Since 1994 South Africa has successfully developed sound legislation for the mining, water and environmental sectors. The energy sector has entered a transition phase towards an open electricity market, where the adaptation of the legislation framework is still ongoing. The IRP2010 has set out what new-generation capacity will have to be built to meet the forecasted demand. This will include the continuation of coal dependency at a similar level, but reduces the relative share of coal for electricity generation from above 90% to about 60% over the next decades. Renewable energy, nuclear power and natural gas are expected to be implemented as set out in the IRP2010.

The development of the Integrated Energy Plan was started early in 2012 by DoE, and DWA is in the process of updating the 2004 National Water Resource Strategy (NWRS). Participating stakeholders from public and private sector will need to ensure that these new plans consider the inter-dependencies between the mining, water and power. We include here an outline of the policy contexts for each of these sectors.

3.1 The water sector

Internationally the human right to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic use is outlined in the UN General Comment No. 15, which in international law is the legal basis for the right to water and its relationship to other human rights.[22]

South Africa's Constitution guarantees everyone the right of access to water. Legislation and plans have been put in place to make this a reality. The Free Basic Water project of the DWA[23] sets out the target of a supply of 25 litres of potable water per person per day, supplied within 200 metres of a household, with an implementation status of 86% of households served in July 2012.[24]

Two acts govern the international and constitutional right to water in South Africa. The Water Services Act of 1997 deals with water services and the National Water Act of 1998 with water resources. Further regulations give more details to aspects of the acts.

Water institutions are aligned with the Acts and are divided into those that manage water resources and those responsible for water delivery services.

DWA retains responsibility for the country's water sector and oversees the implementing water sector institutions. Other institutions (proposed or established) to take over some specific resource management and service delivery responsibilities from DWA include catchment management agencies, water user associations and water services authorities – which are primarily at municipal level (DWAF, 2003).

The NWRS of 2004 is still the most up-to-date document from DWA for this topic, although a draft NWRS 2 has recently been gazetted (September 2012). The estimated future water demand of the power-generation sector, included coal-fired power stations and hydro-power schemes, is recognised in the 2004 strategy, as is the water demand for mining. The NWRS 2 will have to include the impacts on the water sector by the IRP2010 and future iterations of it.

3.2 Mining sector

Since 1994, mining, water, environmental and waste legislation have all undergone significant revisions to align them with the Constitution and other legislation. Today, the legislation protecting environmental and water resources is sound and comprehensive, but not very effective in its implementation. The three main Acts applicable to all mining activities are:

- the National Water Act (Act 36 of 1998) – administered by the DWA;
- the Minerals and Petroleum Resources Development Act (Act 28 of 2002) – administered by the DMR; and
- the National Environmental Management Act (NEMA) (Act 8 of 2004), enforced by the Department of Environmental Affairs(DEA).

These Acts enshrine the 'polluter pays' principle and require environmental impact assessments and environmental management plans for any activities that affect the environment.

Unfortunately there is a discrepancy between the sound laws governing mining in South Africa and the visible 'coal rush' that is currently happening in the coal-rich areas of South Africa. The government is frequently criticised for its lack of ability to implement and police its own laws and policies and to prevent malpractice.

One hundred and twenty-five mines (including 11 of the 22 coal mines that supply Eskom) have been operating without a valid water licence since mid 2010. In Mpumalanga alone, 54 mines abstract freshwater and discharge used water without authorisation. Some mines, such as the Arnot Colliery in Mpumalanga, have not even attempted to apply for a licence, yet are allowed to continue operations (Morgan, 2010; Wassung, 2010). This lack of compliance has had dire consequences for water availability and quality, resulting in human rights violations, for example in the town of Carolina, where people have had no access to drinking quality water for most of 2012 due to contamination of the dam that supplies the town.

3.3 Power sector

Before 1994 planning for electricity generation was mainly executed within Eskom and was dominated by an 'energy supply' objective, which had to ensure adequate supply to match a growing demand. Universal access and affordability of electricity were the ambitious and important objectives of the government from 1994 onwards, implemented through the National Electrification Programme.

A broad-based process of discussion and participation resulted in the 1998 White Paper on Energy Policy of South Africa (EWP, 1998). Based on this White Paper, a number of Acts and amendments to existing Acts have been put in place, including the establishment of the necessary institutions that govern the electricity sector. In the EWP, a restructured and unbundled power sector was envisaged and the importance of renewable energy sources and energy efficiency technologies was recognised. The government committed itself in the EWP to ensure that decisions to construct new nuclear power stations are taken within the context of an integrated energy policy (IEP) planning process. A first IEP was published in 2003 by the then-Department of Minerals and Energy, but was not far-reaching enough and finally had no practical relevance. In 2004 the Government gazetted the White Paper on the Renewable Energy Policy of the Republic of South Africa, which sets a first clear target of 10,000GWh from renewable energy by 2013.

Due to lack of investment into new generation capacity and the electricity supply crisis (first mentioned in the Energy Outlook for South Africa in 2002 and as expected from 2008 onwards), some efforts have been made regarding energy efficiency, solar water heating and other measures to reduce electricity demand. Another clear sign that energy and electricity specifically climbed up the ladder of importance was the separation of energy from minerals and mining into two separate government departments, which was a longer process but concluded in 2009.

The first Integrated Resource Plan (IRP1), which outlined the new electricity generation plans until 2030, was published in late 2009 but quickly become redundant. The development of the IRP2 was kicked off in early 2010 and was finally promulgated in May 2011, after a long participative process.

The 1998 Energy White Paper recognises that overlaps exist with other related economic sectors, including water and mining. Energy policy documents recognise that South Africa is classified as a 'water stressed' country. It is understood that dry cooling technologies will reduce the water demand for electricity generation and it is also mentioned that renewable energy has a significantly lower need for water during operations. Water supply is not seen as a restriction to future energy supply plans. Mining is considered in the energy plans as a significant user of electricity and hence an important contributor to electricity demand, but there is no mention about the water needs and environment impacts of mining's energy needs.

The IRPs were drafted without having the required IEP in place. DoE has launched the development of an IEP in early 2012 and it is hoped that a comprehensive plan will include all necessary considerations in relation to abstraction from and pollution of water resources, both in mining for energy and for power generation.

4. Key messages

1. Power generation from fossil fuels, nuclear and renewable resources all have adverse effects on our natural environment.
2. Renewable energy technologies such as solar and wind have little impact on water resources during operations.
3. Predicted impacts of climate change on electricity generation and on use of water resources by the energy sector are considerable.
4. Water supply is not currently seen as a restriction to future energy supply plans.
5. The policy frameworks that should be considered for the power sector – beside the energy sector itself – need to include those governing water and mining as well.
6. Mining for coal, uranium, REEs, copper and other minerals and metals are all part of the supply chain to build and operate power stations.
7. Water use in mining for 'energy' coal, uranium, REEs, copper, other minerals and metals adds a significant share to the total water use of the power sector.
8. The impacts of mining on groundwater and surface water and hence on human and wildlife habitats are severe and these impacts continue long after mines are closed.
9. South Africa's coal mines are mainly located in the north-east of the country and the majority of power stations have been built nearby. This concentration in one region of both coal mining and coal-fired power stations, with their accompanying huge demands on water supply and their high pollution potential for air and water, together pose severe threats to both human habitats and ecosystems.
10. The mining of uranium and rare earth elements is under development in South Africa and will increase the country's world market share in forthcoming years. It will also increase the local impact on humans and nature.
11. South Africa's rare earth element mines are located in the Northern Cape. As these mines go into operation in the next few years, it will be critical that all necessary measures are sufficiently prescribed by the authorities and implemented by companies to avoid significant pollution of surface water and groundwater, as has happened in China.
12. Carbon capture and storage would substantially increase water consumption if applied to power generation.

13. The continued and planned increased use of coal in the South African energy sector will have dire consequences for water resources, human habitats and ecosystems through water abstraction, water and air pollution around coal mines and CO_2 emissions.

14. The National Water Resources Strategy 2 will have to include the impacts on the water sector by the IRP2010 and future iterations of it.

15. IRP2010 was drafted without having the required IEP in place. DoE has now launched the development of an IEP in early 2012 and it is hoped that a sufficiently comprehensive IEP will include full consideration of water resource impacts, both in mining for energy and power generation.

5. Moving forward

The IRP2010 sustains the generation of electricity from coal for the next two decades and places South Africa on a mixed nuclear and renewable energy roadmap, yet current political signals appear to favour the nuclear option.

Renewable energy technologies such as solar and wind have relatively little impact on water resources during operations.

Most worryingly, predicted impacts of climate change on electricity generation and on conventional water resource use by the energy sector are considerable.

The demands of energy generation on increasingly limited water resources have to be far more seriously considered in our energy planning. The continued and planned increased use of coal in the energy sector effectively comes with a commitment to dire consequences on human habitats, especially due to water abstraction, water and air pollution around coal mines and coal-fired power stations and a massive contribution to climate change through CO_2 emissions.

6. References

Anglo American, 2011. Annual report. Accessible at http://www.angloamerican.com/investors/reports/2011rep.

Darwish, A, 2011. Immersion cooling of photovoltaic cells in highly concentrated solar beams. UNLV Theses/Dissertations/Professional Papers/Capstones. Paper 1081. Accessible at http://digitalscholarship.unlv.edu/thesesdissertations/1081.

Department of Energy (DoE), 2010. Integrated resource plan for electricity 2010–2030. Accessible at http://www.doe-irp.co.za/content/IRP2010_promulgated.pdf.

Department of Energy United States (DoE-US), 2008. Water requirements for existing and emerging thermoelectric plant technologies. DOE/NETL-402/080108 (August 2009 revision). Accessible at http://www.netl.doe.gov/energy-analyses/pubs/WaterRequirements.pdf.

DoE-US, 2009. Concentrating solar power commercial application study: Reducing water consumption of concentrating solar power generation. Report to Congress. Accessible at http://www.nrel.gov/csp/publications.html.

Department of Water Affairs and Forestry (DWAF), 2004. National water resource strategy. Accessible at http://www.dwaf.gov.za/Documents/Policies/NWRS/Default.htm

Department of Water and Forestry (DWAF), 2003. Strategic framework for water services. Accessible at http://www.dwaf.gov.za/Documents/Policies/Strategic%20Framework%20approved.pdf.

Dersch, J; Richter, C, 2007. Water saving heat rejection for solar thermal power plants. Deutsches Zentrum fuer Luft- und Raumfahrt (DLR). Accessible at http://www.nrel.gov/csp/troughnet/pdfs/2007/dersch_dry_cooling.pdf.

Eskom, 2011. Annual report. Accessible at www.eskom.co.za.

Fearnside, PM, 2011. *Greenhouse gas emissions from hydroelectric dams in tropical forests*. New York: John Wiley & Sons Publishers.

Fig, D, 2005. *Uranium road: Questioning South Africa's nuclear direction*. Johannesburg: Jacana Media.

Gottlieb, B, 2010. Coal ash. The toxic threat to our health and environment. A report from Physicians for Social Responsibility and EarthJustice. Accessible at http://www.psr.org/assets/pdfs/coal-ash.pdf.

Greeff, L, 2011. The power of large dams. In Wilson, J (ed), *Water and climate change – an exploration for the concerned and curious*. Cape Town: Environmental Monitoring Group.

Gschneidner, A, 2011. Rare earth metals: Supply, demand, recycling, and substitution. Accessible at http://www.ccrhq.org/publications_docs/CCR_5.311-2.pdf.

Humphries, M, 2012. Rare earth elements: The global supply chain. Congressional Research Service (CRS), R41347. Accessible at http://www.fas.org/sgp/crs/natsec/R41347.pdf.

Hurst, C, 2010. China's rare earth elements industry: What can the West learn? Accessible at http://www.iags.org.

International Energy Agency (IEA), 2011a. Key world energy statistics. Accessible at http://www.iea.org/publications/.

International Energy Agency (IEA), 2011b. CO_2 emissions from fuel combustion: Highlights. Accessible at http://www.iea.org/publications/.

Interministerial Committee on Acid Mine Drainage (IMC), 2010. Mine water management in the Witwatersrand gold fields with special emphasis on acid mine drainage. Accessible at http://www.dwaf.gov.za/Documents/ACIDReport.pdf

International Rivers, 2008. Dirty hydro: Dams and greenhouse gas emissions. Factsheet. Accessible at http://www.internationalrivers.org.

Lima, IBT et al, 2008. Methane emissions from large dams as renewable energy sources: A developing nation perspective. Accessible at http://ecologia.icb.ufmg.br/~rpcoelho/Congressos/DGL2008/Reservoirs%20GHG%20emiissions/Global%20change%202008%20ok.pdf.

Massachusetts Institute of Technology (MIT), 2010. The future of the nuclear fuel cycle: An interdisciplanry MIT study. Accessible at http://web.mit.edu/mitei/docs/spotlights/nuclear-fuel-cycle.pdf.

Mielke, E, Diaz Anadon, Laura, and Narayanamurti, V, 2010. *Water consumption of energy resource extraction, processing, and conversion*. Energy Technology Innovation Policy (ETIP) Discussion Paper No. 2010-15. Harvard: Belfer Center for Science and International Affairs, Harvard Kennedy School.

Morgan, G. 2010. More than 100 mines operating without water licences. Accessible at http://www.da.org.za/newsroom.htm?action=view-news-item&id=8416

Torcellini, P; Long, N and Judkoff, R, 2003. Consumptive water use for U.S. power production. National Renewable Energy Laboratory. Golden, Colorado. NREL/TP-550-33905. Accessible at http://www.nrel.gov/docs/fy04osti/33905.pdf

OECD, 1994. The economics of the nuclear fuel cycle. Accessible at http://www.oecd-nea.org/ndd/reports/efc/

Phylipsen, G.J.M.; Alsema, E.A., 1995. *Environmental life-cycle assessment of multicrystalline silicon solar cell modules*. Utrecht: Department of Science, Technology and Society, Utrecht University.

Project 90x2030, 2012. Website. Accessible at www.90x2030.org.za.

Pulles, W, Boer, R and Nel, S. 2001. A generic water balance for the South African coal mining industry. Water Research Commission Report No. 801/1/01. Accessible at http://www.wrc.org.za.

Røyne, A, 2005. Cooling devices for densely packed, high concentration PV arrays. Accessible at http://folk.uio.no/anjaroy/PVCooling.pdf.

Sasol, 2009. Sustainable development report. Accessible at http://www.sasolsdr.investoreports.com/sasol_sdr_2009/.

South African Centre for Carbon Capture and Storage. www.sacccs.org.za/roadmap.

Tremblay, A, 2004. The issue of greenhouse gases from hydroelectric reservoirs: From boreal to tropical regions. Montreal. Accessible at http://www.hydroquebec.com.

Wassung, N, 2010. Water scarcity and electricity generation in South Africa. Masters' thesis, University of Stellenbosch.

Wilson, J (ed), 2011. *Water and climate change – an exploration for the concerned and curious*. Cape Town: Environmental Monitoring Group.

World Nuclear Association (WNA), 2011. World nuclear power reactors and uranium requirements. Accessible at http://www.world-nuclear.org/info/reactors.html

WWF-SA, 2011. Coal and water futures in South Africa: Report. Accessible at http://www.wwf.org.za/media_room/publications/

WEB references are presented in the footnotes. All visited in June/July 2012.

[1] 'Power sector' refers here to all aspects from mining to power generation. Distribution impacts have not been included.
[2] 'Renewable energy' here includes hydro power, solar thermal power, solar photovoltaic and on-shore wind farms.
[3] http://www.southafrica.co.za/about-south-africa/environment/energy-and-water/, 29 February 2012.
[4] The Western Cape Water Supply System (WCWSS) provides water to more than three million people. In 2008 the actual water usage from the WCWSS amounted to approximately 493 Mm^3/a. Some 32% of the water supplied by WCWSS is used by irrigators and 63% or 311 Mm^3/a is used for domestic and industrial purposes within the City of Cape Town. Western Cape Water Reconciliation Strategy, Newsletter 5, March 2009. Accessible at http://www.dwaf.gov.za/Documents/Other/WMA/19/WCWRSNewsletterMarch09.pdf

[5] http://www.eskom.co.za/c/article/240/water-management/

[6] http://mydocs.epri.com/docs/SummerSeminar11/Presentations/04-04_Lennon_Eskom_Dry_Cooling_v3.pdf
[7] The EIA documentation for Kusile's ash disposal facility explains that an area of over 30km^2 will be filled up to 60m high with the ashes generated through Kusile's operation during its lifetime of 60 years.
[8] http://www.mcclatchydc.com/2010/08/26/99728/study-of-coal-ash-sites-finds.html
[9] http://earthjustice.org/blog/2010-september/new-report-coal-ash-linked-cancer-and-other-maladies
[10] http://www.abc.net.au/unleashed/42476.html
[11] http://www.ornl.gov/info/ornlreview/rev26-34/text/colmain.html
[12] http://www.world-nuclear.org/info/inf111.html
[13] http://www.world-nuclear.org/info/inf23.html
[14] http://www.radwaste.co.za/vaalputs.htm
[15] http://www.projectsiq.co.za/uranium-mining-in-africa.htm, http://mg.co.za/article/2012-08-03-00-nuclear-frontrunner-arevas-toxic-political-dealings/
[16] http://www.ucsusa.org/nuclear_power/nuclear_power_technology/how-nuclear-power-works.html
[17] http://www.wise-uranium.org/uwai.html
[18] http://www.nnr.co.za/wp-content/uploads/2011/07/PSIF-Minutes-11-March-2010-Koeberg.doc
[19] http://www.unep.org/dams/
[20] http://www.wwindea.org/home/index.php
[21] http://www.businesslive.co.za/southafrica/sa_markets/2012/05/05/sa-prepares-to-dig-up-precious-rare-earth-minerals, http://www.frontierrareearths.com/, http://www.gwmg.ca/html/projects/mining/index.cfm
[22] http://www.unhchr.ch/tbs/doc.nsf/0/a5458d1d1bbd713fc1256cc400389e94/
[23] http://www.dwaf.gov.za/dir_ws/fbw/
[24] This figure does not take into account the number of households disconnected (due to inability to pay and/or technical failures) shortly after technical installation.