Water Scarcity and Electricity Generation in South Africa

Part 1: Water use in the coal-to-electricity process

By Natalie Wassung

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Contents

Abstract

South Africa has a mean annual precipitation far lower than the global average. This is a fundamental constraint to development, especially when the country has already run out of surplus water and dilution capacity. To add further pressure, southern Africa's water resources are expected to decrease as a result of climate change. Despite the potential devastation, the country's response to climate change has been limited. South Africa's energy sector is dominated by coal power stations and is the country's primary emitter of carbon dioxide. Given the significantly higher water usage of coal-fired power plants compared to that of most renewable energy power plants, the transition to a clean energy infrastructure might be more successfully motivated by water scarcity than by the promise of reduced carbon emissions. This article analyses more critically the impact of coal-fired electricity generation on South Africa's water resources, by estimating a water-use figure that extends backwards from the power plant to include water used during extraction of the coal. This figure can then be compared to the water usage of alternative electricity generation options. It is then possible to estimate how much water could be saved by substituting these alternatives in place of additional coal-fired plants.

Key words: water scarcity; water use; electricity generation; coal power generation; coal mining

Opsomming

Suid-Afrika se gemiddelde jaarlikse neerslag is baie laer as die wêreldwye gemiddelde. Dit plaas 'n wesenlike beperking op ontwikkeling, veral aangesien die land se surplus water- en verdunningskapasiteit reeds uitgeput is. Om die saak verder te vererger, word verwag dat Suidelike Afrika se waterbronne gaan kleiner word as gevolg van klimaatsverandering. Ten spyte van die potensiële ramp, was die land se reaksie op klimaatsverandering tot dusver baie beperk. Steenkoolkragstasies, wat Suid-Afrika se energiesektor oorheers, is die land se primêre bron van koolstofdioksieduitlating. Gegewe die beduidend hoër waterverbruik van steenkoolkragstasies teenoor dié van die meeste kragstasies wat met hernubare energie werk, kan die verandering na 'n skoonenergie-infrastruktuur meer suksesvol gemotiveer word deur waterskaarste as deur die belofte van verminderde koolstofuitlatings. Hierdie artikel analiseer die impak van steenkoolgedrewe elektrisiteitsopwekking op Suid-Afrika se waterbronne meer krities deur te beraam hoeveel water verbruik word van die kragstasie terug tot by die ontginning van die steenkool. Hierdie syfer kan dan vergelyk word met die waterverbruik van alternatiewe kragopwekkingsopsies. Dit is dan moontlik om te beraam hoeveel water gespaar kan word deur hierdie alternatiewe op te rig in plaas van bykomende steenkoolkragstasies.

1 Background

In his 2010 State of the Nation address, President Zuma lamented that South Africa “is not a water-rich country” (Zuma 2010:12). This is no exaggeration. A semi-arid region, South Africa has a mean annual precipitation of 497mm per year, far lower than the global average of 860mm per year. This is a fundamental constraint to development, especially when the country has already run out of surplus water (Turton 2008). The subsequent loss of dilution capacity means that South Africa is also facing an escalating water quality crisis (Turton 2008).

To add further pressure, the IPCC’s 4th Assessment Report expressed a high level of certainty that southern Africa’s water resources would decrease as a result of climate change (IPCC 2007). Already, total precipitation in the region has declined between 1961 and 2000 (New et al 2006). By 2020, yields from rain-fed agriculture in the area could fall by up to 50% (IPCC 2007). These forecasts have serious implications for food security, socio-economic development and the survival of ecosystems.

Despite the potential devastation, and the knowledge that South Africa was the 13th highest carbon dioxide emitter out of 210 nations in 2006 (UNSD 2009), the country’s response to climate change has been limited. It has been suggested that the images used to explain global warming in southern Africa have been somewhat irrelevant, and the concept of carbon emissions too abstract to motivate urgent action, whereas water scarcity is a more local and tangible crisis (Wassung & Sebitosi 2010). Given the significantly higher water usage of coal-fired power plants compared to that of most renewable energy technologies (Carrillo & Frei 2009, UNESCO 2009), the transition to a clean energy infrastructure might be more successfully motivated by water scarcity than by the promise of reduced carbon emissions.

South Africa’s energy sector is the country’s primary emitter of carbon dioxide and other greenhouse gases (Winkler 2009). Dominating the sector are coal-fired power stations, which contribute approximately 90% towards South Africa’s electricity generation, due to the abundance of cheap coal, inefficient energy use and energy-intensive economy (Winkler 2009, EIA 2008, DME 2009). Power demand currently exceeds supply due to rapid industrialisation, solid economic growth and a mass-electrification programme (EIA 2008) and has led to power shortages and load shedding. Moves to increase supply are underway: three previously-mothballed power stations are being recommissioned, and two new power stations are being built (Eskom 2009b). The increasing number of coal-fired power stations and consequent extra mining activity thus deals a double blow – an even greater contribution to global warming, and further pressure on already-stressed water resources.

This article intends to analyse more critically the impact of coal-fired power on South Africa’s water resources, by estimating a water-use figure that extends backwards from the power plant to include water used during extraction of the coal. This figure can then be compared to water-use figures of alternative power generation options, in order to determine how much water could be saved by substituting these in place of coal-fired power.

2 Literature review

The increasing concern about climate change and subsequent re-examination of different power generation technologies has led to a growing amount of literature concerned with the 'energy-water nexus' (Feeley & Ramezan 2003, Hoffmann et al 2004, von Uexkûll 2004, Feeley et al 2008, King et al 2008, Carrillo & Frei 2009, Sovacool & Sovacool 2009). In summary, this is the recognition of a two-way flow of energy and water: thermal power generation requires water, and water supply services and treatment require energy. Thermal power generation requires freshwater predominantly for cooling, though different processes withdraw and consume different amounts (Hoffman et al 2004, King et al 2008, US DOE 2009). Critical analysis of the water use of thermal power generation is frequently motivated by concerns for water scarcity (Feeley et al 2008, Carillo & Frei 2009, Sovacool & Sovacool 2009) and acknowledges that thermal power generation is water intensive (Feeley & Ramezan 2003, Hoffman et al 2004, Sovacool & Sovacool 2009). The literature also recognises that if global warming continues as projected, conventional thermal power stations in drought-prone regions are going to become more of a liability (Larson et al 2007, King et al 2008). In addition to their greenhouse gas emissions, their water requirements will weigh even more heavily on water resources. This will lead to greater competition for water with other vital sectors such as agriculture, industry and domestic use (Feeley et al 2008). The problem is likely to be further exacerbated as more thermal power stations are going to be built to meet the dramatic increase in demand for energy (Eskom 2009b, MiningMx.com 2010, Engineering News 2010).

Of the papers that have been written on the energy-water nexus, several are from a US perspective, many of which were commissioned by the US Department of Energy. In general, the papers have a tendency to suggest ways of making thermal power stations more water efficient through technological advances or integrated water management, rather than recommend another option altogether – such as renewable energy (Feeley & Ramezan 2003, Hoffmann et al 2004, Feeley et al 2008). A few papers offer a compromise: investment in certain renewable energy technologies in addition to improved water efficiency for thermal power plants (Larson et al 2007, Sovacool & Sovacool 2009). While coal power generation in particular requires about 136 litres of water for every kWh generated[1] (Sovacool & Sovacool 2009), large-scale wind and solar energy plants require almost no water (Carrillo & Frei 2009, UNESCO 2009). Von Uexkûll comments: "In light of the global water crisis, it is most astonishing that this fact is not regularly brought forward in favour of renewable energy systems as opposed to nuclear and fossil energy sources" (von Uexkûll 2004:42). The same author was one of the few bold enough to suggest a complete move away from thermal power generation to certain renewable energy technologies (von Uexkûll 2004).

There is currently no literature on the South African energy-water nexus per se. In terms of legislation, the National Water Policy of 1997 and the National Water Act of 1998 progressively determine water use to encourage fair and sustainable socio-economic transformation and

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[1] This figure includes both water withdrawal and consumption.

development. The National Water Resource Strategy (NWRS) of 2004 describes how water resources will be "protected, used, developed, conserved, managed and controlled in accordance with the requirements of the policy and law" (DWAF 2004:i) and includes a short discussion of the water use and pollution associated with mining and power generation. A more specific enquiry into the water usage of coal power generation in South Africa also turned up zero exact results. The closest match was a number of papers concerned with the impact of coal mining on water resources (Vermeulen et al 2008), particularly the effects of inter-mine flow (Grobbelaar et al 2004), Acid Mine Drainage (Hobbs & Cobbing 2007, Cobbing 2008), and mine water pollution (Oelofse 2008). Other topics include the management of impacts (Hobbs et al 2008, Turton 2009), the water use in coal mining (Pulles, Boer & Nel 2001), and the reuse of coal-mine water for the irrigation of crops (Barnard et al 1998, Annandale et al 2007). The water use of coal mining and coal power generation in South Africa have been treated separately by the literature, though a recent paper on the non-point sources of water pollution that included both sectors (Heath et al 2009) could be the beginning of more integrated work on this topic. On the whole, the literature is heavily scientific and technical in nature, and is somewhat inaccessible to most decision makers.

The South African media, however, is already showing an awareness of the link between coal power generation and water use, and is taking state bodies to task. Recent news articles have voiced concern over the building of coal power stations in water scarce areas, such as Medupi, the 4800 MW plant currently being built in dry Lephalale, Limpopo province (African Energy News Review 2008, Blaine 2009, Boyi 2009).

Though literature on the water usage of coal power generation in South Africa is lacking, there is certainly a strong motivation to further investigate it: water scarcity. It is widely acknowledged from scientists to politicians that South Africa is a water-scarce country, and that water allocation and use must be done with efficiency and effectiveness in mind (DWAF 2004, Turton 2008, Ashton et al 2008, Zuma 2010). It is also recognised that climate change is highly likely to make the South African water situation worse (Schulze 2005, De Wit & Stankiewicz 2006, IPCC 2007).

The challenge, it seems, is not an inability to justify such research, but that access to pertinent information is restricted by company policy or suspicion. Professionals and academics involved in water research have had difficulty in the past trying to access reliable, accurate and comparable water use statistics, particularly from the mining, power generation and industrial sectors. In their 2009 paper for the Water Research Commission, Heath et al report a general industry resistance to providing information because it could affect future applications for water use and wastewater discharge (Heath et al 2009). This is likely to be a strong reason for the absence of literature on the water-energy nexus in South Africa.

3 South Africa's freshwater scarcity

South Africa is a water-scarce country. It receives an annual average of only 497mm of rain, well below the global average of 860mm per year (Turton 2008). The National Water Resource Strategy cites the available yield of freshwater in South Africa as 13 227 million m^3 (DWAF 2004). In 2000, water demand was approximately 12 871 million m^3, which means that 98% of the freshwater supply was used (Water Wheel 2009). This is an extremely high allocation figure, giving little leeway for times of drought or future economic growth and development. Turton points out that the lack of surplus water also means that South Africa has lost its capacity to dilute pollutants, and will require increasingly higher standards of water treatment that will require more expensive technologies (Turton 2008).

Exacerbating the problem of water scarcity is global warming. In turn, the lack of water results in the decimation of vegetation, worsening the drought effect of global warming through reduced infiltration and increased runoff. Sub-Saharan Africa is projected to experience an increasing number and intensity of droughts as global climate warms, placing further pressure on an already water-stressed region. It is estimated that rainfall could decline as much as 10% by 2050 (De Wit & Stankiewicz 2006). In South Africa specifically, global warming is expected to cause significant losses in the little runoff that does occur. The Western Cape, particularly around Cape Town, could lose over half of perennial supply, while northern and eastern regions could suffer medium to large losses in water supply (Schulze 2005, De Wit & Stankiewicz 2006). Groundwater recharge could be impacted upon even more severely than surface water sources, but is less predictable.

The National Water Resource Strategy recognises climate change's potential to significantly affect the availability of water in South Africa. There is evidence that fundamental patterns of the water cycle may already be changing, and further variation in rainfall could occur (DWAF 2004). While the impacts of climate change on water resources will not be uniform across South Africa (some areas could actually benefit), it is safe to say that changes in rainfall will be intensified by the existing hydrological system, i.e. dry areas are likely to become even drier (Schulze 2005). The response of the National Water Resource Strategy to the potential impacts of climate change is to include its consideration in catchment management strategies, and to monitor the situation (DWAF 2004). In the face of potentially great hardship, this is a strikingly passive reaction.

South Africa is a net importer of water (Eskom 2009a). Out of the nineteen water management areas in South Africa, five were already experiencing water shortages in 2000, and ten areas broke even. Only four areas enjoyed a surplus of water (The Water Wheel 2009). The Department of Water Affairs has projected that water demand will exceed supply by 2025, even by its most conservative scenario (The Water Wheel 2009). The province of Gauteng may suffer water shortages as soon as 2013, though this may be eased in 2019 by importing more water from Lesotho in the next phase of the Lesotho Highlands Water Project (The Water Wheel 2009). At time of writing, President Zuma was in talks with Prime Mininster Phakalitha Mosisili of Lesotho to finalise the Agreement on Phase II of the Project – Africa's largest water transfer scheme (AllAfrica.com 2010).

But it is questionable whether relying on the augmentation of supply, and particularly on imports, is a sustainable solution to water scarcity.

Firstly, there is only a fixed amount of freshwater available. Even if South Africa is able to increase its imports from equally water-scarce neighbours, and risk supply security in the face of regional disputes or disasters, this too is a fixed amount. While some may suggest desalination as a way of growing South Africa’s water supplies, this is still an extremely expensive technology and current water prices are highly unlikely to cover costs. Also, desalination is energy intensive, and as South Africa is already experiencing an energy crisis, other uses of energy will take preference while water could still be used more efficiently. Unless desalination plants are powered by renewable energy, the coal power stations used to deliver electricity to desalination plants will exacerbate water problems and increase carbon emissions, which in turn will worsen global warming, and increase the number of water shortages. Clearly, desalination powered by coal combustion is not a sustainable solution either.

Secondly, ‘getting more water’ is not going to suffice in the long term if water is not used efficiently in the present. Though the Department of Water Affairs has made some overtures in the direction of reducing domestic demand, little if anything has been done to manage the demand of the major water users, agriculture and industry. These major users are also responsible for most of the pollution of freshwater resources. Poor treatment of effluent from industry and domestic use is resulting in cyanobacterial blooms in most of the country’s rivers and reservoirs, which produce toxic microcystins (Turton 2008). Mining is leaving heavy metals and other pollutants in both surface and groundwater sources, even after the mine is closed (Oelofse 2008). These sectors are unlikely to initiate reform themselves, given the low price of water and general lack of transparency. While efficiency is a concern, the DWA is still busy trying to reduce the volume of water completely unaccounted for; currently this stands at 30% of national water supply (Roberts 2010). Yet, even efficiency cannot be improved indefinitely. Human beings, animals and plants each require a certain threshold of water to survive.

It should be mentioned that a growing population and a growing economy to support it are, by simple logic, going to strain fixed water resources eventually, even if distribution is fair and use is minimal. A truly sustainable solution to South Africa’s water scarcity would thus be to stabilise population and economic growth at a level that water resources can support. While the logic is simple, deriving the ‘magic number’ of people and an acceptable level of material welfare is not, and the implementation of such a controversial policy is fraught with difficulty.

However, there is a less controversial means to cope with water scarcity that has not yet been attempted. It is the lesser-known, yet vital partner of efficiency – effectiveness.

No link has yet been made to the sectors to which the Department of Water Affairs allocates water, that in some cases form a long and devastating chain of water use, and are also at the root of the climate change problem. A prime example, and the focus of this article, is the electricity sector, which relies on the mining industry for coal. Because electricity is seen as a high-value economic use of water, the allocation of water to Eskom's power stations is considered as being of strategic importance, and is an unquestionable priority. The DWA has gone as far as to recommend dry-cooling technology at new power plants 'where feasible' (DWAF 2004) – an efficiency solution, which alone is ultimately short-sighted and ineffective. But it has not demanded a transition to relatively 'water free' renewable energy technologies, a more effective and long-term solution, which would have a far greater impact on alleviating water scarcity in South Africa.

4 South Africa's electricity sector

The most important contributors to the South African economy are the mining and primary minerals industries (Mbendi.com 2010). The energy intensity of these industries has raised the country's electricity consumption to the equivalent of two-thirds of Africa's electricity use (EIA 2008). To support these economic sectors, the energy sector is given a preferential share of water resources, and is reported to account for 2% of national water consumption (SSA 2006, UNESCO 2006).

State-owned Eskom is one of the largest utilities in the world. It generates 95% of South Africa's electricity, as well as 45% of Africa's electricity (Eskom 2010b). Power is exported to Botswana, Lesotho, Mozambique, Namibia, Swaziland and Zimbabwe (EIA 2008). In the 2010 financial year, Eskom produced 232 812 GWh of electricity, 215 940 GWh of which was derived from coal power stations (Eskom 2010b). While Eskom does not have exclusive generation rights, it monopolises the supply of bulk electricity, and has a net maximum capacity of 40 870 MW (Eskom 2010b). South African municipalities add a capacity of approximately 2 400 MW, and private companies about 800 MW (DME 2009). Eskom also currently owns and operates the national transmission grid. However, recent media reports suggest that transmission might be unbundled from the utility and taken over by the Independent Systems and Market Operator, or ISMO, in the not-too-distant future (Creamer 2010b). This move would eliminate the conflict of interest between Eskom as generator and transmitter, as well as ease the problems stemming from Eskom as the only buyer of all co-generated and independent power (Creamer 2010b).

South Africa has eleven base load power stations, ten of which are coal fired and one a nuclear power station (Eskom 2010a). In addition, the country has six peak demand stations, two of which are hydroelectric, and four open cycle gas turbine plants (Eskom 2010a). Four hydroelectric power stations stabilise the distribution network in the southern region, and one relatively small wind farm completes Eskom's current electricity generation portfolio (Eskom 2010a). However, three previously-mothballed stations are being recommissioned, and three new stations are being built to cope with South Africa's rapidly increasing energy demand (Eskom 2009b). Eskom's New Build programme has attracted controversy in recent months due to its successful application for US$3.75 million from the World Bank, $3 million of which will go towards funding the construction of the Medupi coal power plant (Times Live 2010).

Details of Eskom's power stations are listed in Table 1 below:

Table 1: South Africa's electricity portfolio

	Name	Province	Technology	Capacity
Base load	Arnot	Mpumalanga	Coal	2100 MW
	Duvha	Mpumalanga	Coal	3600 MW
	Hendrina	Mpumalanga	Coal	2000 MW
	Kendal	Mpumalanga	Coal	4116 MW
	Koeberg	Western Cape	Nuclear	1930 MW
	Kriel	Mpumalanga	Coal	3000MW
	Lethabo	Free State	Coal	3708 MW
	Majuba	Mpumalanga	Coal	4110 MW
	Matimba	Limpopo	Coal	3990 MW
	Matla	Mpumalanga	Coal	3600 MW
	Tutuka	Mpumalanga	Coal	3654 MW
Peak Demand	Gariep	Free State	Hydroelectric	360 MW
	Vanderkloof	Northern Cape	Hydroelectric	240 MW
	Acacia	Western Cape	Open cycle gas turbine	171 MW
	Port Rex	Eastern Cape	Open cycle gas turbine	171 MW
	Ankerlig	Western Cape	Open cycle gas turbine	592 MW
	Gourikwa	Western Cape	Open cycle gas turbine	444 MW
Renewable Energy	Klipheuwel	Western Cape	Wind power	3.2 MW
Distribution	First Falls	Eastern Cape	Hydroelectric	6.4 MW
	Second Falls	Eastern Cape	Hydroelectric	11 MW
	Colley Wobbles	Eastern Cape	Hydroelectric	42 MW
	Ncora	Eastern Cape	Hydroelectric	2.4 MW
Return-to-service	Camden	Mpumalanga	Coal	1600 MW
	Grootvlei	Mpumalanga	Coal	1200 MW
	Komati	Mpumalanga	Coal	1000 MW
New Build	Medupi	Limpopo	Coal	4788 MW
	Kusile	Mpumalanga	Coal	4800MW
	Gas 1	(undecided)	Open cycle gas turbine	1036 MW

Due to South Africa's vast reserves, coal contributes approximately 88% towards South Africa's electricity supply (Eskom 2010b). Eskom's coal use is expected to continue or even accelerate over the next few years, as the three power stations are returned to service and two new ones built. Altogether, these five power plants could increase Eskom's coal use by over 50 million tons, if they use the average amount of coal burned by existing power stations in 2007 (EIA 2008).

Given coal's current and future dominance in electricity generation, it makes sense to further understand the industry and its common practices, in order to compare its water use to that of renewable energy sources in the following section.

4.1 Survey of the coal mining and power generation industries

4.1.1 Coal mining

Only mines that sell coal to Eskom for power generation purposes were considered here. Information was originally obtained from the Department of Minerals and Energy's directory of Operating and Developing Coal Mines in the Republic of South Africa (2009), but several details were missing or already out of date by April 2010. In such cases, the mine managers were contacted by phone and updated details obtained.

Table 2 below summarises the details of these mines and their practices:

Table 2: Details of mines supplying coal to Eskom

Producer	Colliery	Mine type	Preparation of coal for power generation	Power station supplied
Anglo American PLC	Kriel Colliery*	Both	Crushing	Kriel
	New Denmark Colliery	Underground	Crushing	Tutuka
	New Vaal Colliery*	Opencast	Crushing, screening and washing	Lethabo
Anglo & Exxaro (50:50)	Mafube Colliery	Opencast	Crushing	Arnot
BHP Billiton SA LTD	Middelburg Mine	Opencast	Washing	Duvha
	Khutala Colliery	Both	Crushing	Kendal
Eastside Coal Company	Eastside Coal Company	Opencast	Washing and separation	Hendrina
Exxaro Resources	Matla Colliery*	Underground	Crushing, screening, washing, separation	Matla, Majuba, Tutuka
	Arnot Colliery***	Underground	Washing	Arnot
	New Clydesdale Colliery*	Opencast	Washing and separation	Majuba & Duvha
	Grootgeluk Coal Mine*	Opencast	Crushing and washing	Matimba
	Leeupan Mine	Opencast	Washing	Majuba
	Glisa Colliery*	Both	Crushing and screening	Majuba, Tutuka, Camden, Komati
Eyethu Coal	Driefontein Colliery	Opencast	Washing @ Mooifontein Colliery	Duvha
Mashala Resources Pty LTD	Penumbra Mine	Opencast	Crushing and washing	Camden
Optimum Holding	Geluk Mine**	Underground	Crushing and washing	Hendrina
Sasol Mining (Pty) LTD	Optimum Colliery*	Opencast	Crushing, screening and washing	Hendrina
Umcebo Mining (Pty) LTD	Middelkraal Colliery*	Opencast	Washing and separation	Majuba
	Strathae Colliery	Opencast	Crushing, screening and washing	Camden
	Southstock Colliery	Underground	Washing and separation	Majuba & Tutuka
	Tweefontein	Both	Washing and separation	Majuba
Xstrata PLC	Umlabu*	Both	None	Camden

*Has applied for water licence, still being processed by DWA
** Has applied for water licence, but must still submit outstanding information
*** Has not applied for water licence

(National Assembly 2010)

Out of the 22 mines that supply Eskom with coal, 12 are opencast mines, five are underground, and five mines have both opencast and underground facilities (DME 2009). Opencast mines are thus the most usual type from which coal is extracted for power generation.

The most frequently used coal preparation is washing, which usually takes place at the mine. Washing separates impurities such as shale or stone from the coal through a flotation process; due to their greater density, the impurities sink to the bottom while the coal floats freely. This process makes it possible to extract a better quality of coal to meet the standard required by power plants. Washing is important as this is where the majority of water use occurs before the coal reaches the power plant.

Coal mines use water from several sources, including municipal or board water, river water, groundwater, rain water, and a combination of these (Pulles et al 2001). Besides washing, this 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 plant, irrigation of treated sewage, mine workings, slurry dam, and road wetting for dust suppression (Pulles et al 2001). Details of these processes, as well as the volume of water used and impact on water resources, are explained further in sections 5.1 and 5.2 below.

Although coal mining per se is not included as a water user of strategic importance in the National Water Resource Strategy 2004, the complete reliance of Eskom on South African coal mines to supply their power stations indirectly sees these mines as strategic water users. Faced with increasing water scarcity, some coal mines are recognising water as a critical resource that needs to be used and discharged in a sustainable manner (Holman 2008). This has led several mines to increase the amount of water reused or recycled, and treat underground mine water to potable standards to supplement local authorities' reservoirs. An example of this is the eMalahleni Water Reclamation Plant, which is supplied with underground mine water from three of Anglo Coal's mines and one of BHP Billiton's mines in the Witbank area (Holman 2008).

While water recycling is certainly an improvement in mine water management, it has recently come to light that 125 mines (including 11 out of the 22 coal mines that supply Eskom) are currently operating without a valid water licence (Morgan 2010, National Assembly 2010). In Mpumalanga alone, 54 mines abstract freshwater and discharge used water without authorisation – a drastic increase from last year's 13 mines (Morgan 2010). Some mines, such as the Arnot Colliery in Mpumalanga, have not even attempted to apply for a licence, yet are allowed to continue operations (National Assembly 2010). While more often the fault of the Department of Water Affairs rather than that of the coal mines, the lack of water licences and an effective licensing process pose a serious threat to the accountability of users and the protection of South Africa's scarce water resources.

The response of the Department of Water Affairs to the situation has been pitiful. When asked when it envisaged that all mines would operate with valid water licences, the DWA responded that it was "impossible to provide a target date" due to the participation required from the mines and legislative requirements of the Department of Mineral Resources, as well as the Department of Environmental Affairs (National Assembly 2010:1). The apparent fear of the government to demand participation and effect speedy licensing processes - both of which are supported by law - suggests a lack of capacity and/or a conflict of interest between state officials and the businesses they are supposed to monitor.

4.1.2. Coal power generation

Information about the coal power plants in South Africa was gleaned from Eskom's official website, recent Annual Reports, and water management plans as explained in water use licence applications. Where data was missing, Eskom's Media Desk was contacted, and answers were supplied via email. Details of the plants' cooling systems were confirmed through phone calls to the plants' managers.

Table 3 below provides details of the capacity, cooling technology and age of current and future coal power plants in South Africa.

Table 3: Current and future coal power plants in South Africa

	Name	Province	Capacity	Cooling	Fully online
Base load	Arnot	Mpumalanga	2100 MW	Wet, re-circulating	1975
	Duvha	Mpumalanga	3600 MW	Wet, re-circulating	1984
	Hendrina	Mpumalanga	2000 MW	Wet, re-circulating	1976
	Kendal	Mpumalanga	4116 MW	Indirect dry	1993
	Kriel	Mpumalanga	3000MW	Wet, re-circulating	1979
	Lethabo	Free State	3708 MW	Wet, re-circulating	1990
	Majuba	Mpumalanga	4110 MW	Wet, re-circulating & dry	2001
	Matimba	Limpopo	3990 MW	Direct dry	1994
	Matla	Mpumalanga	3600 MW	Wet, re-circulating	1983
	Tutuka	Mpumalanga	3654 MW	Wet, re-circulating	1990
Return-to-service	Camden	Mpumalanga	1600 MW	Wet, re-circulating	1973-90, 2006
	Grootvlei	Mpumalanga	1200 MW	Wet, re-circulating & dry	1976-90, 2010
	Komati	Mpumalanga	1000 MW	Wet, re-circulating	1968-90, 2012
New Build	Medupi	Limpopo	4788 MW	Direct dry	2015
	Kusile	Mpumalanga	4800 MW	Direct dry	2017

From the table above, it can be seen that the standard Eskom coal-fired power plant is located in Mpumalanga, has a capacity in the region of 3 400 MW, and uses a wet re-circulating process. Each plant makes use of cooling towers, whether a wet or dry cooling system is used. The average age of the plants is almost 27 years, with the oldest plant at about 42 years (Komati) and the youngest at 9 years (Majuba).

South African coal-fired power plants are purposely located close to coal mines in Mpumalanga, Limpopo and the Free State to avoid transporting thousands of tons of coal across the country. This means that fresh water, if not readily available, must be piped to these locations. Sources of water for power plants are the same as for coal mines. Water is used in the following processes: water purification, steam cycle in generating electricity, cooling, sluicing of ash, drainage, sewage treatment, and mine water recovery (Naidoo 2003). Details of these processes, the volume of water used, and the impact on water resources, are explained further in section 5.3 below.

Eskom is a strategic water user, and receives water through augmentation and inter-basin transfer schemes from the DWAF at a 99.5% level of assurance (DWAF 2004). Eskom is well aware of the potential of climate change to negatively impact water security and energy security for South Africa (Creamer 2010a). In the latest Eskom Annual Report, the utility comments:

> "..we will no longer be able to easily access relatively cheap and clean water... we must consider limited supplies and the implications of our water use and discharge on watersheds, ecosystems, and communities. The increase in demand for water together with deterioration in water quality will result in increases in the cost of water, requiring recovery from the electricity tariff." (Eskom 2010b:110)

The utility is already working on projects to minimise water use, such as using dry cooling methods in all new plants, and reusing water in existing plants. In 2009, 6 982ML of mine water was used at Tutuka and Lethabo power stations, and a system is being built to make use of about 6ML/day of mine water at Duvha power station (Eskom 2009a). Eskom has also looked at the potential for cooling by sea water for coastal stations. Several factors contribute to higher than necessary water usage at Eskom's power plants: the age and thermal efficiency of current plants; declining coal quality which requires burning more coal to produce the same amount of electricity; and declining raw water quality supplied to plants, which means that more clean water is needed to dilute the extra salt (Eskom 2009a, Eskom 2010b).

Though improving the thermal efficiency of existing power stations would decrease fresh water use, substantially diversifying the energy mix away from coal would have a far greater impact. This fact too is recognised by Eskom (Eskom 2009a, Pringle 2010, Creamer 2010a). However, in practice the utility is still very much focused on efficiency measures and on augmenting water supply, as can be seen in their plans to transfer water from the Crocodile-West Marico water management area to the Lephalale area, location of the new Medupi plant (Eskom 2009a, Eskom 2010b). Eskom's commitment to diversifying the energy mix has been heavily criticised by would-be independent power producers (IPPs), who have battled to conclude power purchase agreements with the utility (Van der Merwe 2010, Pringle 2010).

5 Thinking through water use in the coal-to-electricity process

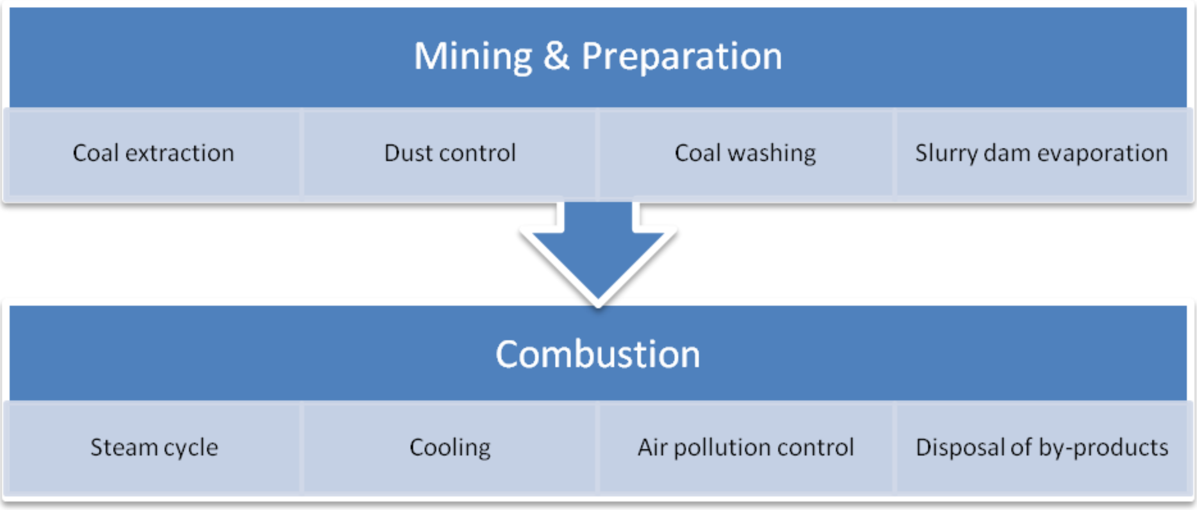
The primary goal of this adapted cradle-to-grave analysis is to investigate the volume of water required to produce electricity from coal. Therefore the analysis will include every step that requires water: the extraction and preparation of the coal from a mine, its combustion at a power plant, the measures taken to control dust and pollution at both locations, and the disposal of the coal combustion by-products.

This study is only concerned with the water use related to the fuel. It does not include the water used in the building or maintenance of the power station, nor in the manufacture or maintenance of mining or power generation machinery. Finally, though emissions to air and land also indirectly affect freshwater resources, they are almost physically impossible to quantify, and therefore only the direct use of and effects on freshwater resources will be considered.

The purpose of this analysis is to offer a figure that can be compared to the volume of water required to produce an equivalent amount of electricity from various renewable energy technologies.

The diagram below illustrates where water is used in the coal-to-electricity process:

Figure 1: Stages in the coal-to-electricity process in which water is used



As most coal mines in South Africa have their own beneficiation plant, coal mining and preparation will be explored together in one section.

5.1 Coal mining and preparation

Most frequently, coal mines that supply Eskom are opencast mines that use washing as a means to prepare coal for power generation purposes. While there are other methods of mining and preparation, these characteristics are discussed below in an effort to understand general practice. Information on these practices was gleaned from both primary and secondary sources.

Secondary sources frequently cited include the 2001 study by Pulles, Boer and Nel entitled *A Generic Water Balance for the South African Coal Mining Industry* for the Water Research Commission, and the 2005 book by Miller entitled *Coal Energy Systems*. A selection of mine managers, metallurgists, and suppliers of beneficiation equipment were contacted directly for data or estimates where hard data was missing. These primary sources were also used to confirm whether the 2001 or 2005 information was still correct.

5.1.1 Type of mine and mining method

Strip mining, a technique frequently used in opencast mines in South Africa, requires an average of about 160 litres of water to produce a ton of coal (Pulles et al 2001) and produces about 1.2 litres of liquid effluent per ton of coal (World Bank Group in Miller 2005). Surface mining can affect surface water sources by increasing runoff, reducing infiltration, and increasing sedimentation, which arise when vegetation is removed. The reduced infiltration means that groundwater recharge is decreased, which causes the availability of water to decline (Miller 2005). Salination of water sources can increase, which can render water unusable for drinking, irrigation or other activities. Acid Mine Drainage (AMD) can contaminate surface and groundwater, and can also occur in closed or abandoned mines (Miller 2005). AMD can be treated chemically or passively; certain passive treatments such as aerobic wetlands require water.

5.1.2 Dust control

Dust occurs as coal is hauled along roads, and is present on barren spoil surfaces as well as coal and soil stockpiles (Miller 2005). Dust from surface mines is a greater problem than in underground mines. According to the Pulles et al study in 2001, 11% of the 381 litres required for mining a ton of coal is used for road wetting and dust suppression, equivalent to about 42 litres per ton (Pulles et al 2001).

5.1.3 Coal washing

Before coal can be burnt at a power station, it needs to be cleaned of contaminants and processed to a particular quality standard or grade. This ensures more efficient use of the coal for power generation. Cleaning can also reduce the amount of sulphur in the coal, and thus cuts down the amount of pollution that may be released during combustion (Miller 2005). Although technology is being developed to clean coal using ‘dry’ methods, wet cleaning methods dominate, the discards of which result in a mix of water and fine coal that is disposed of in slurry dams. Estimates of water use for coal washing vary considerably, depending on the design of the plant and the number of washing stages: at the low end, approximately 38 litres of water are required to clean 1 ton of coal (Pulles et al 2001), while at the upper end, estimates of 150 litres per ton of coal have been given (Jacobs 2010).

5.1.4 Evaporation

Any water that comes into contact with disturbed areas on the mine is known as dirty water, and is either used by the beneficiation plant, or for dust control, pumped into slurry dams, or released into river systems. For all of these options, evaporation occurs. In total, water lost to evaporation amounts to about 229 litres per ton of coal mined (Pulles et al 2001).

In total then, the water directly used to mine 1 ton of coal can be calculated to be in the region of:
160 litres per ton (extraction) + 42 litres per ton (dust control) + 38 litres per ton (coal washing) + 229 litres per ton (evaporation) = 469 litres per ton. If upper end figures for coal washing are used, water use can rise to 581 litres per ton.

It is important to note, however, that several mines re-use and recycle part of their water. Recycling cuts down the mine's need to abstract expensive, treated water from the municipal system, as well as the need to discharge untreated mine water to the environment. This means that each mine will have a slightly different total water use figure, depending on the processes used and the proportion of water recycled.

For example, about 47% of the water used by Anglo Coal is recycled water, which leaves their fresh water consumption rate at approximately 181 litres per saleable ton of coal (Holman 2008). The figure of 181 litres is obviously much lower than the 469 litres of water per ton of coal estimated above, even taking into account a recycling figure of 47%. This is because the Anglo Coal figure describes the water use for primary activities, and does not include the water used for secondary activities such as coal cleaning (Holman 2008).

Coal cleaning or beneficiation plants have different water use figures depending on the design; some plants have filtration equipment to recover slurry, others recover water from tailings ponds, while old plants tend to pump water underground and do not recover it (Jacobs 2010).

Overall, recycling of water used in mining operations and in the beneficiation plant is estimated to be around 26% of the total volume of water used (Pulles et al 2001). The figure of 469 to 581 litres per ton can therefore be adjusted downwards to approximate 347 to 430 litres of fresh water per ton of coal ready for use at a coal-fired power plant.

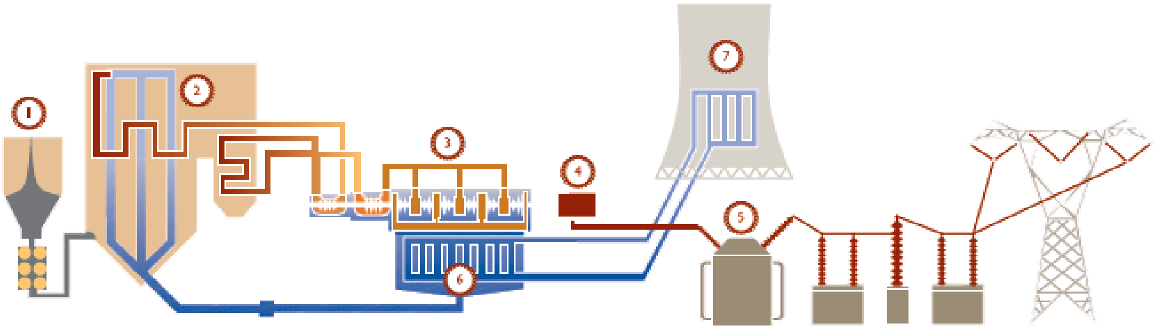
5.2 Coal combustion at power plant

All Eskom power stations have to submit an integrated water and waste management plan every two years to comply with the Department of Water Affairs. Each plan is site specific and is taken seriously. Unfortunately, these plans are highly confidential and not accessible to the general public (Hendricks 2010). However, the 2003 Duvha Power Station Water Use Licence Application was available online, and assurance has been given that little has changed in the latest reports (Hendricks 2010). Given that the standard Eskom coal-fired power plant is roughly 27 years old, approximately 3 400 MW, located in Mpumalanga, and uses a wet, re-circulating cooling process (from 4.1.2 above) the Duvha plant, which is 25 years old, 3 600 MW, located in Mpumalanga and uses wet, re-circulating cooling, is a suitable representative for coal-fired power stations in South Africa.

This section uses the figures given in the Duvha Water Use Licence Application as a means to estimate the water use of individual processes during the combustion of coal. As such, the figures are intended to be used as a benchmark to aid understanding, rather than for the calculation of a highly accurate water balance.

The majority of water is used in two processes in coal power plants, namely the internal steam cycle and the cooling process. Water is also used in certain air pollution control measures, and is consumed via evaporation from slurry dams which contain coal-combustion by-products.

Figure 2: Diagram of the coal combustion process at a power plant



1 – Fuel; 2 – Boiler; 3 – Steam turbines; 4 – Generator; 5 – Transmission; 6 & 7 – Cooling systems

Source: Eskom poster, 2008

5.2.1 The internal steam cycle

In the internal steam cycle of a coal power plant, demineralised water is piped above a boiler (2) where the coal is burnt, and the heat turns the water to steam. The steam then turns a turbine (3) to generate electricity (4). As the steam passes through the turbine it is fed into a condenser (6), which transforms the steam back into water. Duvha power station in Mpumalanga reports the use of 2 megalitres of water per day in the steam cycle (Naidoo 2003). Using the 21 383 GWh production estimate by Duvha in 2003, this is roughly equivalent to a rate of 0.034 litres per kWh of electricity produced.

5.2.2 The cooling process

All thermoelectric power plants, including coal-fired plants, require cooling of the power-generating machinery. This is because the machinery does not operate as efficiently when temperatures increase beyond a certain point, and components can be damaged by extreme heat. Cooling is also necessary to condense the steam after it has passed through the turbine (as explained in 5.2.1 above), and eject the excess heat to the environment. Cooling can be achieved by water - the most common method for South African power stations - or by air, or a combination.

There are two ways of cooling with water: once-through (also known as open-loop) or re-circulating (closed-loop). Once-through cooling withdraws water for one use only before returning most of it to the source, although a significant amount of the water withdrawn is lost to evaporation (US DOE 2009). In the re-circulating process, water is usually withdrawn from an available source and then sprayed down cooling towers (7), which make use of evaporation within the chimneys to cool the water. Compared to re-circulation, once-through cooling is more energy efficient and lower in infrastructure and operational costs; however the ejected water is warmer than ambient water, which can kill fish and damage aquatic ecosystems. The amount of heat ejected is related to the thermal efficiency of the power plant: the higher its thermal efficiency, the lower the water usage. Re-circulated cooling requires less water withdrawal because the water is recycled through the use of cooling towers or evaporation ponds, but water consumption is higher due to evaporation in the process. (King et al 2008:283-4)

Cooling with air (dry cooling) requires the use of industrial fans, and is a less energy-efficient solution. Capital costs are also higher, and more land is necessary to house the additional machinery needed. (King et al 2008:283-4). Currently only four coal-fired power plants in South Africa use dry cooling (or a combination of wet and dry) due to their location in water-scarce areas.

Table 4 below compares the different rates of water withdrawal and consumption by the different cooling processes for fossil-fuel fired power plants:

Table 4: A comparison of water withdrawal and consumption by cooling method

Cooling method	**Water withdrawal (Litres/kWh)**	**Water consumption (Litres/kWh)**
Wet, once-through	76 – 189	1.1
Wet, re-circulating (cooling tower)	1.9 – 2.3	1.8
Wet, re-circulating (evaporation pond)	1.1 – 2.3	1 – 1.9
Dry	Negligible	Negligible

Source: Adapted from King et al 2009.

Duvha uses approximately 125 megalitres per day in a wet, re-circulating cooling system (Naidoo 2003). This is equivalent to a rate of about 2.13 litres per kWh. This figure is significantly higher than the water consumption figures given in the table above; however, the table only compares fresh water use and excludes dirty or reused water from calculations. Duvha uses a combination of raw water and dirty storm water in its cooling process (Naidoo 2003).

5.2.3 Air pollution control

Certain pollution control techniques use water to control ash or the sulphur released in the flue gas. The ash that is removed from the power station is back-stacked into the mine or stacked on dumps. While ash is stacked, water is sprayed onto the ash pile to control the dust until it can be covered with layers of topsoil and planted with grass. In Duvha's case, the power plant typically uses 53 megalitres per day for their ashing system (Naidoo 2003). This is equivalent to about 0.9 litres per kWh. Water for the ash control process is sourced from water treatment effluents, dirty storm water and cooling water blow-downs (Naidoo 2003).

Sulphur compounds emitted to the atmosphere by power plants can be deposed as acid rain, which leads to the acidification of water sources and destruction of fish populations (Miller 2005). A process known as 'scrubbing' is effective at reducing this air pollution from coal power plant emissions. However, scrubbers do not destroy the pollution, they merely concentrate it to be more manageable - and transfer the pollution problem to water sources. Wet scrubbers also use a lot of water: between 3 ML and 7 ML of water per day (Mirant.com 2010). Though South Africa does not yet use scrubbers or flue-gas desulphurization, the technique will be used in new power plants Kusile and Medupi (SouthAfrica.info 2008, Njobeni 2010).

5.2.4 Disposal of coal combustion by-products

Coal combustion by-products such as fly ash, bottom ash, boiler slag and flue-gas desulphurization material contain toxic elements or pollutants, which can contaminate groundwater and surface water sources (Miller 2005). While some of these by-products are used in other industry applications such as in the production of cement (Eskom 2008), the remainder are left out in slurry dams. In 2010 for example, Eskom produced 36.01 Mt of ash, but only sold 2 Mt and recycled 5.6%, disposing of 33.89 Mt on dams and ash dumps (Eskom 2010b). Again, due to the size of slurry dams and location in dry regions, much water is lost to evaporation. Duvha reports an evaporation loss of 484.571 megalitres per year from the Low Level Ash Water Return Dam and the Emergency Pan (Naidoo 2003). This is roughly equivalent to 0.022 litres per kWh of electricity produced.

In total, water use in the average coal power plant can be estimated to be in the region of:
0.034 ℓ/kWh (internal steam cycle) + 2.13 ℓ/kWh (cooling) + 0.9 ℓ/kWh (air pollution control) + 0.022 ℓ/kWh (disposal of by-products) = 3.086 ℓ/kWh.

However, as is the case for coal mines and preparation plants, coal power plants also reuse or recycle a proportion of their water. In 2010, Eskom reports that water used to generate electricity equated to an average of 1.34 ℓ/kWh, a figure that excludes rain water and reused mine water (Eskom 2010b). Therefore, while about 3.086 ℓ of water is required per kWh, only 1.34 ℓ is cleaned water, and the balance of 1.746 ℓ must consist of rain water and reused water. As rain water is part of fresh water, the absence of a rain water figure makes it difficult to calculate a more accurate fresh water use figure. For the purposes of this study then, fresh water use by coal power plants must be estimated to be upwards of 1.34 ℓ/kWh but below 3.086 ℓ/kWh.

5.3. Water use of coal from 'cradle to grave'

From the investigation carried out in 5.1 above, the volume of fresh water used to mine and clean a ton of coal for power generation purposes is estimated at between 347 ℓ and 430 ℓ. According to Eskom, 0.56 kg of coal is required to produce 1 kWh of electricity (Eskom 2009). This means that between 0.194 ℓ and 0.240 ℓ of fresh water is required during the mining and coal cleaning stages to produce 1 kWh of electricity.

Adding to these figures the 1.34 ℓ to 3.086 ℓ specifically required by coal power plants to produce 1 kWh, the total amount of freshwater required over the 'cradle to grave' lifecycle of coal used for electricity generation can be estimated as being between 1.534 ℓ/kWh and 3.326 ℓ/kWh.

In reality, these figures are even higher. Water use relating to labour (drinking and ablution water) is an essential component in the extracting, cleaning, burning and disposal of coal, but as an indirect requirement it is beyond the scope of this study. Also, if the water needed to restore surface and groundwater sources to their original state (after the ejection of wastewater and seepage) was included, this would also significantly raise water use figures. This dilution component of water use has been omitted from the study as the figures differ widely, depending on the severity and extent of the pollution (which differs between coal mines and between power stations), and on variable rainfall figures.

Eskom's total electricity sales in 2010 equated to 218 591 GWh, of which 88% was sourced from coal (Eskom 2010b). This means that coal-fired electricity contributed approximately 192 360 GWh to electricity supply last year. Using the higher (but still conservative) freshwater use figure of 3.326 ℓ/kWh derived above, it can be deduced that approximately 639 790 ML of freshwater was used to generate electricity from coal in 2010. Yet, the electricity sector is frequently said to consume only 2% of national water supply (SSA 2006, UNESCO 2006) which translates to 1.76% of national water supply going to coal electricity generation. This statistic is misleading, as it clearly does not include the water used during coal extraction, processing, pollution control and the disposal of by-products – without which no electricity could be produced. If available freshwater yield in South Africa is estimated at about 13 227 000 ML per annum (DWAF 2004), the full coal power generation process actually requires around 4.84% of national water supply - more than double the original statistic.

6 Evaluating the water-saving impact of alternative power generation

From the calculations above, saving one kWh of electricity derived from coal corresponds to a saving of up to 3.326 litres of water – more, if labour and restoration uses are included. This ratio has serious implications when choosing energy projects. By substituting certain renewable energy systems for coal power plants, much water can be saved and diverted to sectors where it is urgently needed.

Wind, tidal and wave energy systems use zero water to derive their fuel, and no water is required in the production of electricity (Gerbens-Leens, Hoekstra & Van der Meer 2008, Jacobson 2009). Solar PV plants require around 0.14 ℓ/kWh, which is used for cleaning (Jacobson 2009). Solar thermal plants, particularly parabolic trough and central tower receiver plants use between 2.8 to 2.94 ℓ/kWh for cooling and cleaning, still lower than electricity from coal. Parabolic dish CSP plants do not have thermal storage, and their power conversion unit is air cooled, so they only require around 0.14 ℓ/kWh for cleaning of mirrors (Jacobson 2009). Even though some solar CSP plants require cooling, they still avoid the negative impact of coal mines and power plants on water resources when discharge water is contaminated by heavy metals or other toxic substances. However, not all renewable energies are made equal. Hydroelectric power is much more water-intensive than other electricity generators. Hydro power consumes water through evaporation and seepage from dams, estimated at between 5 – 29 ℓ/kWh (Gerbens-Leens et al 2008, Jacobson 2009), which is far higher than the water used to produce the equivalent amount of electricity from coal.

Table 5 below illustrates the potential water savings of substituting 1 kWh of coal electricity with 1 kWh of electricity from various renewable energy sources.

Table 5: Litres of water saved by substituting 1 kWh of coal electricity

Renewable energy substitute for coal electricity	Litres of water saved/kWh
Wind, tidal or wave energy	3.326
Solar PV	3.186
Solar CSP (Parabolic dish)	3.186
Solar CSP (Parabolic trough, central tower receiver)	0.386 – 0.526

In summary, substituting coal electricity with electricity from solar CSP, solar PV, wind, tidal or wave energy sources could save in the region of 0.386 ℓ/kWh to 3.326 ℓ/kWh. This is equivalent to a water saving of 12% to 100% per kWh depending on renewable energy substituted.

Exchanging large, centralized coal power plants for large renewable energy plants is by no means the only energy-related solution to South Africa's water scarcity. In fact, transitioning to decentralized, local electricity production and distribution may offer far more benefits than simply more effective and efficient water use. These and other electricity generation options and their water-saving impact will be explored in more detail in Part 2 of this article.

7 Conclusion

South Africa’s natural water scarcity is made all the more dire by high allocation figures, loss of dilution capacity, increasing drought impacts of global warming, and a lack of active response to these trends by government. The Department of Water Affairs has so far concentrated its efforts on augmenting supply and encouraging efficiency, but the latter is aimed at domestic and not industrial users, where the real damage is done. 152 mines are allowed to abstract and discharge water without a valid licence (including 11 out of the 22 coal mines that supply Eskom) - a distinct failure of the Department of Water Affairs to implement government policy. This is also a failure of the Department of Water Affairs, the Department of Mineral Resources, and the Department of Environmental Affairs to co-operate and co-ordinate. At the top of the list of failures, however, is the lack of effective allocation of water. This has been neglected, yet it must be efficiency’s main partner in order to achieve sustainable water use.

Currently, coal power plants generate about 88% of available electricity in South Africa. As they are responsible for significantly higher water usage compared to most renewable energy technologies, water scarcity concerns (in addition to reduced carbon emissions) could further motivate a transition to a clean energy infrastructure. To best express how much water could be saved by substituting certain renewable energy systems for coal power plants, it was necessary to investigate the volume of water required to produce electricity from coal. The investigation covered each step that requires water: extraction and preparation of the coal, combustion, control of dust and pollution at both mine and power plant, and disposal of coal by-products. As such the study was limited to the water use directly related to the fuel, and excluded the water used to build the plants as well as manufacture and maintain the machinery.

Information was obtained from published studies, draft water management plans, media reports, and informal phone interviews with industry experts. It was estimated that the total amount of freshwater required over the ‘cradle to grave’ lifecycle of coal used for electricity generation can be estimated as being between 1.534 ℓ/kWh and 3.326 ℓ/kWh. This means that coal electricity generation alone (including coal extraction, processing, pollution control and disposal of by-products) uses around 4.84% of national water supply, rather than the frequently-quoted 2% which only takes into account coal combustion at a power plant. The underestimation of this figure illustrates the ominous nature of the South African water-energy situation. In reality, these figures are even higher if the water used by mine and power plant labour and water-resource restoration was included. Yet, by substituting coal-fired electricity with electricity from solar CSP, solar PV, wind, tidal or wave energy sources, a minimum of 0.386 litres to 3.326 litres could be saved for every kilowatt hour generated.

Substituting large, centralized coal power plants for large renewable energy plants is not the only energy-related solution to South Africa’s water scarcity, nor is it possibly the best. Transitioning to decentralized, local and renewable electricity production and distribution may offer far more benefits. These and other electricity generation options will be explored in more detail in Part 2 of this article.

Unfortunately, this study was limited by a lack of transparency regarding water management plans and water licences. It is unclear how the disclosure of water use and water-related practices could result in any long-term negative consequence to mining or utility companies. If anything, the competition that would result from such transparency would encourage them to use water more effectively and efficiently – if supported by appropriate legislation and enforcement – and would reduce operating costs. It does not seem justified to allow such confidentiality when it disempowers the public, effectively eliminating their ability to hold industry accountable for its water use. Furthermore, it is contradictory to declare that “no part of the water resources of South Africa will be regarded as private property” and call water resources “a public commodity” yet restrict access to pertinent information in the manner of private ownership (DWAF 2003:1). The first steps towards effective and efficient water use - even before the sustainable allocation of resources - are transparency and accountability.

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Nomenclature

AMD	Acid Mine Drainage
DME	Department of Minerals and Energy (South Africa)
DWAF	Department of Water Affairs and Forestry (South Africa) – now the Department of Water Affairs (DWA)
EIA	Energy Information Administration
GWh	Gigawatt hour
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
ISMO	Independent Systems and Market Operator
kWh	kilowatt hour
m^3	cubic metres
ML	Megalitres
Mt	Megatons
MW	Megawatts
MWh	Megawatt hour
NWRS	National Water Resource Strategy (South Africa)
SSA	Statistics South Africa
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNSD	United Nations Statistics Division

List of tables and figures

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Water Scarcity and Electricity Generation in South Africa

Part 2: Water conservation through coal-electricity alternatives

By Natalie Wassung

This article is presented in partial fulfilment of the requirements for the Master of Philosophy degree in Sustainable Development from the School of Public Management and Planning, University of Stellenbosch.

Contents

Abstract

South Africa is a water-stressed country. Yet it is powered almost completely by coal-fired electricity which, together with coal mining, uses large quantities of water. Add to this the increasing drought effect of global warming, and water insecurity is by far the biggest threat to the country's sustainability. The logical solution might seem to be building large-scale renewable energy plants to replace existing coal power plants. But wholesale implementation of this option would most likely encounter a myriad of social, technical, financial and political obstacles. However, much water can be saved from cheaper investment alternatives, such as energy conservation, energy efficiency and renewable energy micro-generation. The advantages and challenges of these options are explored, followed by discussion of what needs to be in place for successful implementation. The paper then evaluates the current system of water allocation and discusses its shortcomings, before envisioning what a sustainable allocation model might look like. Using this model and incorporating the energy-saving options would liberate water to be used in other vital sectors of the economy. They would help to return dilution capacity and improve water quality, restore valuable aquatic ecosystems, and provide more drinking and sanitation water for society's desperate.

Key words: coal-fired electricity; energy conservation; energy efficiency; energy education; smart meters; smart grid; distributed generation; micro-generation; sustainable water allocation

Opsomming

Suid-Afrika se waterbronne verkeer onder geweldige druk. En tog word die land se krag hoofsaaklik deur steenkool opgewek, 'n proses wat, saam met steenkoolontginning, geweldige hoeveelhede water verbruik. Voeg hierby die toenemende droogte-effek van aardverwarming, en wateronsekerheid is verreweg die grootste bedreiging vir volhoubaarheid in die land. Dit lyk dalk of die logiese oplossing is om op groot skaal bestaande steenkoolkragstasies te vervang met kragstasies wat met hernubare energie werk. Grootskaalse implementering van hierdie opsie sal egter heel waarskynlik oneindige sosiale, tegniese, finansiële en politieke teenstand ondervind. Baie water kan egter bespaar word deur goedkoper beleggingsalternatiewe, soos energiebehoud, doeltreffende aanwending van energie en mikro-opwekking deur middel van hernubare energie. Die voordele en uitdagings van hierdie opsies word ondersoek, gevolg deur 'n bespreking van wat nodig is vir suksesvolle implementering. Die artikel evalueer die huidige stelsel van watertoewysing, bespreek die tekortkominge van dié stelsel en skets dan 'n moontlike volhoubare toewysingsmodel. Die gebruik van hierdie model saam met die energiebesparende opsies sal water beskikbaar stel om in ander lewensbelangrike sektore van die ekonomie gebruik te word. Dit sal help om die verdunningskapasiteit te herstel en die watergehalte te verbeter, waardevolle waterekosisteme te herstel en om meer drink- en sanitasiewater aan 'n desperate samelewing te voorsien.

1 Introduction

South Africa is a water-stressed country. The national economy is based on mining and is highly energy intensive. It is powered almost completely by coal-fired electricity, which uses large quantities of water and thereby exacerbates the water scarcity problem. Added to this the increasing drought effect of global warming, and water insecurity is by far the biggest threat to the country's sustainability.

So far, South Africa has dealt with the symptoms of water scarcity and the energy crisis, not the deeper causes. This means we often suffer unintended consequences, as problems tend to become more complex over time (Turton 2008). We try to solve water scarcity problems by building dams and inter-basin transfer schemes, and in time we create the perfect conditions for toxic Cyanobacteria to flourish (Turton 2008). We deal with the energy crisis by building more coal power plants (Eskom 2009), worsening global warming. While there are alternatives to coal-fired electricity, there are no substitutes for water. It is thus imperative that water be used sustainably, and as efficiently and effectively as possible. The link between energy and water can no longer be ignored.

Part 1 of this two-article series critically examined the South African coal-to-electricity process, and determined that water use could be estimated at between 1.5 litres per kilowatt hour (ℓ/kWh) and 3.3 ℓ/kWh of electricity produced. These figures are directly related to the extraction and combustion of the fuel. They do not include the water used to construct the required equipment or infrastructure, or supplied to the labour force, or to restore water resources through dilution. Compared to renewable energy technologies such as wind and solar, coal electricity generation is highly water intensive.

The logical solution seems to be building large-scale wind or solar power plants to join or replace existing coal power plants. However, this might not be the only or even the best response. Though large-scale renewable power plants should certainly be part of the solution, much water can be saved from simpler, cheaper investment alternatives.

This paper explores two types of these investment alternatives. The first are energy-related solutions to water scarcity, while the second is the effective allocation of water through an improved water budget philosophy. The energy-related solutions include the often-overlooked energy conservation, energy efficiency and renewable energy micro-generation. To be most effective, all three of these solutions should be pursued together, as reducing electricity usage makes it more possible for micro-generation to supply the amount of electricity we need. This paper explores these options in greater depth, outlining some of the advantages and challenges they present, and discussing what still needs to be put into place in South Africa for these solutions to be implemented successfully. Then the paper evaluates the current system of water allocation and discusses its problems, before envisioning what a sustainable allocation system might look like.

Incorporating these options would liberate water to be used in other vital sectors of the economy. They would help to return dilution capacity and improve water quality, restore valuable aquatic ecosystems, and provide more drinking and sanitation water for society's desperate.

2 Energy-related solutions to water scarcity

Given the high water use figures of coal-fired electricity, reducing energy consumption is imperative if South Africa is to manage scarce water resources sustainably. This can be done through conservation and efficiency measures, as well as replacing a significant portion of coal-fired electricity with electricity from renewable energy sources.

Investments in these initiatives have the simultaneous benefit of saving energy (and related carbon emissions) as well as water. They also defer the high capital investment required to build new coal power plants.

2.1 Energy conservation and efficiency

South Africa has already set two targets related to energy efficiency: a reduction in energy demand of 12% by 2015, and a long-term goal to save 4 255 MW over twenty years (Eskom 2006). To help achieve these targets, Eskom's Demand Side Management (DSM) programme was begun in earnest in 2002 (Eskom 2006).

With the assistance of the Department of Energy and the National Energy Regulator (NERSA), the programme aims to reduce electricity use during peak periods, install energy-efficient technology, and optimise industrial processes (Eskom 2006). In addition, Eskom is using awareness campaigns to develop energy-saving habits in customers (Eskom 2010a).

Specifically, the current DSM programme includes:

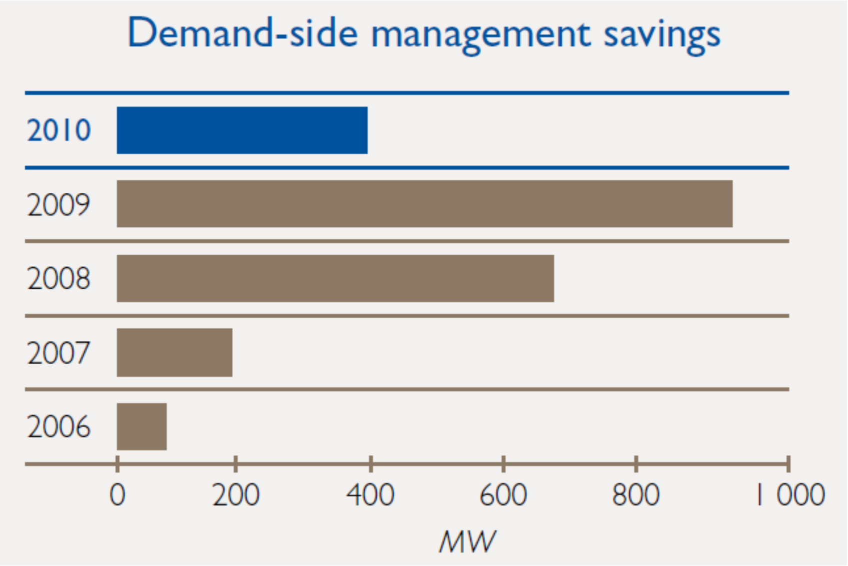
- the weekly broadcasting of the Power Alert meter on national television, which targets household consumer behaviour
- projects to reduce demand in the industrial and commercial sectors
- hot water load management in municipal environments
- a mass rollout of Compact Fluorescent Lightbulbs (CFLs)
- a rebate scheme for solar water heaters, and
- efforts to improve the efficiency of industrial electric motors and pumps.

(Eskom 2010a)

Eskom estimates a potential to reduce 8% to 15% of electricity use within the next decade through energy efficiency initiatives (Eskom 2010a).

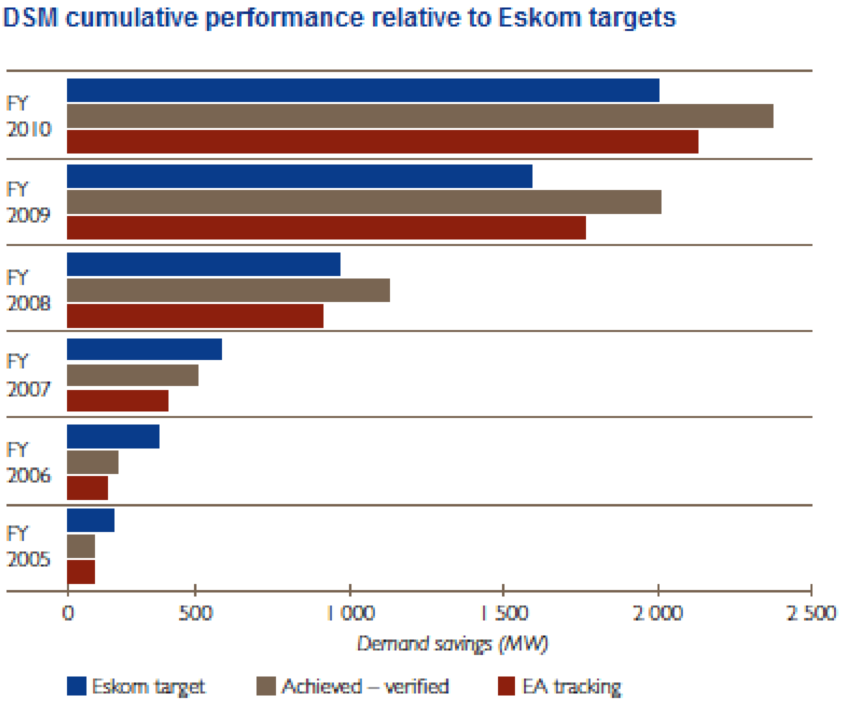
The impact of the DSM programme so far can be seen in Figure 1 and Figure 2 below:

Figure 1. Annual DSM electricity savings



Source: Eskom Annual Report 2010

Figure 2. DSM cumulative performance (excluding savings from Power Alert meter)



Source: http://www.eskom.co.za/annreport10/cnb_demand.htm

According to Eskom, 372 MW of electricity were saved in the 2010 financial year through the current DSM programme (Eskom 2010a). This is equivalent to a saving of approximately 3 259 GWh, about 1.39% of the 232 812 GWh annually produced (Eskom 2010a). This is a far cry from the 8% to 15% electricity saving anticipated by the utility. Additional investment options are therefore needed for the full savings potential to be realised.

This section explores three different investment options in regard to energy conservation and efficiency, over and above what Eskom and the Department of Energy are already promoting. These options include energy education, the roll out of smart meters, the implementation of the smart grid, and the decentralisation of electricity generation. To be most effective, these investments should be made concurrently. Also, they should not replace the current DSM programme, but rather augment its impact. Importantly, these options need to be seen as alternative ways of investing in water resources.

2.1.1 Energy education

The literature explored for this section was unanimous in conveying that energy education helped to reduce energy consumption (Garg & Kandpal 1996, Dias et al 2004, Darby 2006, Zografakis et al 2008). However, specific case studies were hard to find, due to the many different types of energy education assessed. In a paper by Dias et al (2004), the authors studied twelve different strategies for energy conservation in Brazil. They found that energy education programmes were the third most efficient way to save energy, and were the cheapest investment (Dias et al 2004). This is supported by Zografakis et al (2008), who suggest that energy literacy is a more effective investment than advanced technological solutions. Dias et al (2004) estimated that educational, marketing and institutional activities towards energy saving cost in the region of US$0.01 for each kWh saved. Bringing that figure up to date using a total average US inflation rate of 15.67% since 2003 (InflationData.com 2010) and using an exchange rate of R8 to the US dollar, an investment into energy conservation could cost approximately R0.09 per kWh saved. Given the upcoming 25% year-on-year electricity tariff increases (expected for the next 3 years at least) (Nersa 2010) and the water security scenario depicted earlier, energy education would evidently be a worthwhile investment.

Although Dias et al (2004) suggest that simply raising electricity prices could replace energy education where concepts are considered too difficult, this is unlikely to be a sustainable solution in South Africa. Electricity was amongst the cheapest in the world until the power supply crisis of 2008, when Eskom was allowed to start raising electricity prices significantly, between 14.2% and 31.3% annually (Mybroadband 2008, I-Net Bridge 2009, Nersa 2010). The public has been strongly resistant to the price hikes (SAPA 2009a, SAPA 2009b, Williams & Roberts 2010), and in the past riots have broken out when people feel that service delivery is lacking (Turton 2008). Also, studies have shown that people adapt to higher prices in the long term (Dias et al 2004). Energy education - supported by higher electricity prices - is therefore necessary for lasting energy conservation.

Efficient ways of communicating energy knowledge are necessary to change individual attitudes and promote values (Dias et al 2004). Zografakis et al (2008) note that energy awareness is formulated during childhood; children can act as educational agents and opinion leaders at home, and grow up to be environmentally-aware citizens. The authors showed that energy awareness and energy-efficient behaviour is best promoted by repetition throughout a child's school years, and should be supplemented by more general energy-information initiatives for adults (Zografakis et al 2008). Eskom's DSM programme targets school-goers as well as adults in various capacities through: residential, commercial and industrial programmes; public education; schools programme; and various stakeholder activities (Eskom 2008). However, the lack of teachers informed about energy conservation has been cited as a major barrier to school-based education programmes (Garg & Kandpal 1996, Zografakis et al 2008). In addition, there is often a lack of suitable learning material and teaching support, particularly in developing countries (Garg & Kandpal 1996, Dias et al 2004).

Most energy education is offered at the postgraduate level in universities (Garg & Kandpal 1996). Energy education has only recently been included in primary school education in South Africa, when some school-goers learn about electricity and renewable energy from the age of about 5 (De Abreu 2010, Butcher 2010). However, knowledge is fragmented and differs between private and public schools – some do not include it at all (De Abreu 2010, Butcher 2010). Hands-on approaches such as laboratory classes, field trips, energy-efficient measures at school, simple installations of renewables, energy audits and monitoring of the school's energy consumption are effective learning tools that should be included as part of the education programme (Managenergy 2004 in Zografakis et al 2008.)

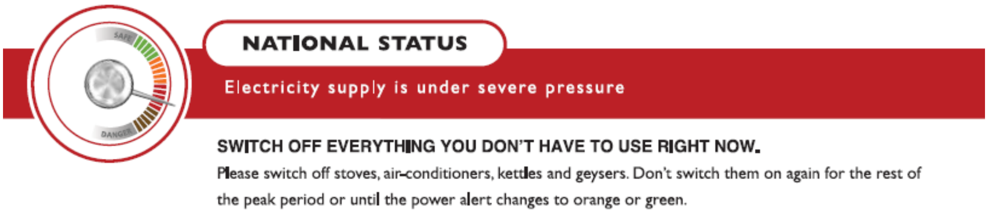
Eskom's DSM programme for "participating institutions" provides some teachers and learners with resource packs and energy audit guides (Eskom 2006). While these efforts are a start, much more could and should be done to increase national energy conservation. "Participating institutions" should become the norm rather than the exception. Teachers need to be informed about energy efficiency, and involved with energy efficiency consultants in developing a more focused curriculum.

Public education for adults is trickier to accomplish beyond the usual marketing and public relations campaigns, yet their participation in energy conservation is essential.

The South African public have shown themselves to be fairly responsive to the raising of energy awareness, in the few forms it has been offered. For example, approximately one million households participated in the voluntary Earth Hour initiative in 2010, where lights were switched off for one hour across the world. South Africa saved an estimated 420 MW of electricity in the process (Prinsloo 2010a).

Also, response to Eskom's power alert meter broadcast on television during the week has reportedly been significant (Simbalism 2010, Dalgleish 2010). The alert visually communicates to viewers how close the power stations are to maximum capacity or blackouts (see Figure 3 below). When the needle points to the red or brown area, customers know to urgently switch off unused lighting or electrical appliances. For the 2010 financial year, Eskom reported demand savings of 88 459 MWh attributable to the power alert meter (Eskom 2010b). However, these must be taken within the context of the 2008/9 global economic recession and may not reflect genuine energy savings.

Figure 3. Eskom's power alert meter



NATIONAL STATUS

Electricity supply is under severe pressure

SWITCH OFF EVERYTHING YOU DON'T HAVE TO USE RIGHT NOW.

Please switch off stoves, air-conditioners, kettles and geysers. Don't switch them on again for the rest of the peak period or until the power alert changes to orange or green.

Source: Eskom 2008

Given the potential of these smaller energy efficiency initiatives, it is likely that further energy education would serve to increase the number of households responsive to DSM programmes.

2.1.2 Smart meters and the smart grid

It is difficult to significantly reduce one's electricity consumption without knowing how much electricity is being used. Although South African households and businesses receive bills or pre-pay for electricity, these do not provide specific information about electricity pricing at a particular time or about which appliances are drawing power.

Advanced Metering Infrastructure (AMI), more commonly known as smart meters, provide this type of information to the consumer as well as to the electricity utility (Renewable Energy Focus 2009a). The improved detail of energy information can help the utility to reduce power outages, and service can be restored more quickly. The consumer is able to manage electricity consumption and take advantage of lower electricity prices to run non-essential appliances, while reducing electricity demand particularly at times of peak prices (Neenan & Hemphill 2008). This management can take place either on site at the home or factory, or remotely via a website. It is interesting to note that simply providing electricity-use information sees consumers adjusting their level and time of consumption, independent of price differences (Neenan & Hemphill 2008). Feedback information can thus be an effective tool for energy literacy (Darby 2008) and energy efficiency.

Smart meters are already being used in several countries and regions. In the United States, 4.7% of meters installed are 'smart' (Renewable Energy Focus 2009a). Europe is cited as having 39 million units installed at the end of 2008 (Berg Insight 2009). Australia is currently rolling out 2.6 million units in the province of Victoria (ABC News 2010). Every meter in Malta will be 'smart' by 2012 (Timesofmalta.com 2009), and the United Kingdom is installing 26 million smart electricity meters, one in every household by the end of 2020 (Moylan 2009).

Smart meters that include demand response components and demand control functions can cost between US $200 and $525 per unit (Renewable Energy Focus 2009b). This is roughly equivalent to R1 500 to R4 000 per meter. The electricity savings derived from the use of smart meters varies according to source. Estimates range from 2% to 3% of a consumer's annual energy use (Moylan 2009), to between 4% and 12% (Behr 2010), to between 5% and 15% (Darby 2006).

In 2010, the industrial and mining sectors together consumed 87 549 GWh of electricity (Eskom 2010a). Using the minimum savings estimate of 2% and the maximum of 15% associated with the installation of smart meters, a saving of 1 751 GWh to 13 132 GWh per year could be achieved. With 88% of total electricity generation derived from coal, and related water-use figures of between 1.534 ℓ/kWh and 3.326 ℓ/kWh, the installation of smart meters could lead to a saving of between 2 364 ML and 38 437 ML of fresh water per year.

Where residential users are concerned, 10 350 GWh of electricity were used in 2010 (Eskom 2010a). Installing smart meters throughout the sector could save 207 GWh to 1 553 GWh per year, and 279 ML to 4 544 ML of water per year.

Though the exact payback period will differ depending on the cost of the smart meter and the cost of supplying electricity, the literature agrees that this investment will financially benefit utilities in the long term (Renewable Energy Focus 2009b). Together, sufficient quantities of these type of efficiency savings could mean that generating capacity is ‘freed up’ to meet growing demand, and Eskom is able to avoid the high capital investment (and negative ecological effects) of building of a new power plant.

Smart meters are just one of the elements of the smart grid system. The smart grid controls electricity transmission and distribution, communication and applications. It acts as type of bridge that links people and electricity provision through technology, ensuring the adequate flow of electricity and matching demand and supply (Schuler 2010). This means that electricity wastage is minimised, and efficiency is increased. The smart grid offers consumers the opportunity to respond to different electricity prices, which incentivises customers to reduce electricity use at peak times (Renewable Energy Focus 2009b). Grid optimisation can be achieved, which means that the system is more reliable and operates efficiently while protecting electricity assets. The smart grid enables distributed generation and can act as a virtual storage of excess electricity – a very useful function where intermittent renewable energy sources are concerned (Renewable Energy Focus 2009a).

Without compromising on human comfort levels, implementing a smart grid could save 5% to 10% of electricity generated (Renewable Energy Focus 2009a). A saving of up to 21 859 GWh could be achieved, as well as saving of 63 980 ML of freshwater per year where coal-fired electricity is concerned (Eskom 2010a). Again, this could defer the need to build new power plants to match growing electricity demand.

The challenges of smart meters and the smart grid are few and solvable. There is concern for security, as customers may not want to share information about their electricity use for safety reasons (for example, criminals could use it to predict when residents will be away). Authentication methods could therefore be used to ensure privacy and truthfulness of information for both customer and utility, e.g. through email confirmation (Renewable Energy Focus 2009b). Maintaining the grid as a large-scale, distributed computer system with real-time requirements could be a significant obstacle, but not an insurmountable one. However, pilot projects need to be at least city-sized in order to be economically viable (Renewable Energy Focus 2009a). Equipment and software standardisation that allows interoperability are also needed (Alanne & Saari 2004, Bouffard & Kirschen 2008).

Finally, the smart grid will only be able to realise its full potential if there is price differentiation or price-responsive demand rather than fixed rates for electricity. Demand response programmes should avoid the use of administrative customer baselines, which simply pay consumers for reducing their electricity usage at peak periods, as they create an incentive to under-consume (Chao 2010). Rather they should take the form of a subscription with a contract-based baseline, as this will avoid price distortion and provide efficient incentives, while still offering customers a choice (Chao 2010).

In South Africa, the Department of Energy has proposed the Standard Offer Programme (SOP), which would enable electricity consumers to claim a rebate in respect of the amount of energy they had saved from the electricity system (Van der Merwe 2010). Overseen by the DoE, Eskom funds will be given to approved energy efficiency projects, and in 2010 the project developers will receive payment of R0.54/kWh saved, based on the avoided cost of electricity supply resulting from the project (Van der Merwe 2010). This figure is to be updated annually, with estimates of R0.51/kWh for 2011 and R0.57 for 2012 (Van der Merwe 2010). Although a rebate for energy conservation is a giant leap forward in achieving efficiency goals, there is a need to replace the fixed rate with peak- and off-peak prices to reduce demand and shift electricity load profiles. In order for demand response programmes to work, however, new laws would be required that would allow real time tariffs which are dependent on power demand.

Eskom is in the process of launching the first phase of its AMI project in South Africa. 10 000 customers whose electricity consumption is over 1 000 kWh per month will have an advanced smart meter installed (Eskom 2010b). If successful, phase 2 will go ahead with an additional 110 000 qualifying customers (Eskom 2010b). Eskom's first phase translates to a minimum saving range of between 2 GWh and 18 GWh, and a coal-related water saving of between 3 ML and 53 ML per year. Phase 2 could bring a minimum additional saving of between 22 GWh and 198 GWh, and a water saving of 33 ML to 528 ML per year. The smart grid is likely to be more of a medium- to long-term plan, as the widespread installation of smart meters would first need to be achieved.

Though the AMI project is certainly a positive development, the focus on residential electricity use seems somewhat misdirected in light of the potential savings from the mining and industrial sectors. For a more effective investment, this paper recommends that smart meters be rolled out in these sectors before targeting residential users.

2.1.3 Distributed generation

South Africa has a considerably centralised energy distribution system. Most coal-fired electricity is generated in the Mpumalanga and Limpopo provinces where the coal deposits are located, and is transmitted country wide. By the time the electricity reaches distant provinces such as the Western Cape, much of it has been lost in transmission. Moving towards decentralised or distributed generation means that efficiency losses due to transmission are minimised, as generation and consumption of electricity occur in close proximity to one another (Bouffard & Kirschen 2008, Wolfe 2008, Bayod-Rújula 2009). Losses due to theft through illegal electricity connections, which amounted to between 4 100 GWh and 5 850 GWh in 2008/9 financial year, could also be reduced (Reuters 2010a). Like energy education and smart metering, distributed generation is also a cost-effective and efficient way of conserving energy (Bouffard & Kirschen 2008).

Distributed generation supports smaller-scale power plants and renewable energy installations. This means reducing the risk and capital associated with large-scale build projects that take many years to complete (Bouffard & Kirschen 2008). In addition, the relative independence of distributed generation means that, as a whole, the country's electricity supply is more resilient to power outages, intermittency, or external threats such as natural disasters (Alanne & Saari 2004, Bayod-Rújula 2009). Localised energy storage can temporarily bridge the gap between the production and consumption of electricity (Bouffard & Kirschen 2008). Distributed generation also provides new product and service opportunities, and stimulates competition in the electricity market (Bayod-Rújula 2009).

In the South Africa context, distributed generation is only possible and desirable through localised renewable energy installations. There is little point exacerbating the water and carbon emission problem by building distributed coal power plants, which would in any case be too far from the source of coal to be economically viable. For the electricity system to be flexible enough to incorporate different energy sources, however, a new network design is necessary that will allow the bi-directional flow of electricity (Bouffard & Kirschen 2008, Bayod-Rújula 2009). Distributed generation is made viable in South Africa due to the abundant solar resource across the country, as well as wind resources along the coastline.

South Africa's cities and towns are spread over a wide area, which means that geographically the country is well suited to distributed generation (Alanne & Saari 2004). Many areas are also remote and connection to the national electricity grid is impractical. These areas can benefit from distributed generation, and it is also easier to find smaller sites for renewable energy systems than the large sites needed for centralised generation (Bayod-Rújula 2009). South Africa has already begun to make advances in this direction by making the electricity generation function and the transmission function independent entities, though both will likely remain owned by the state (Creamer 2010a).

In addition to these advantages, the number of jobs increases in a decentralised generation system (Alanne & Saari 2004). This corresponds to the primary goal of the National Planning Commission to increase employment (Creamer 2010b). However, industry is aware that there is a severe shortage of skills necessary to fully transition to a low-carbon economy (Creamer 2010b). Education is therefore essential. Also, a viable market environment and adequate networks are necessary if distributed generation is to succeed in the long term (Woodman & Baker 2008).

Finally, successful micro-experiments are already taking place. For example, solar panels are running eight traffic light intersections in Johannesburg, with approval to expand to 400 intersections (Venter 2010). Persuading government officials to attempt distributed generation on a larger scale will be easier after seeing the micro-experiments' success. It is unlikely that South Africa's entire electricity system could be decentralised, however, at least not in the short to medium term, due to the high cost and nature of some emerging technologies, e.g. concentrated solar power (Bouffard & Kirschen 2008).

2.2 Renewable energy technology

Besides conserving energy through reduced demand and energy efficiency measures, water can also be saved through a move away from coal-fired electricity to renewable energy sources. This section explores the renewable energy technologies suitable for South Africa and summarises their water-saving capacity, as well as the potential for micro-generation.

2.2.1 Renewable energy technologies appropriate for South Africa

In the first article in this series, it was established that wind, wave or tidal energy could save approximately 3.3 ℓ/kWh if they replaced coal-fired electricity. Solar PV and solar CSP (parabolic dish) could save about 3.2 ℓ/kWh, while solar CSP that makes use of parabolic troughs or a central tower receiver could save between 0.4 and 0.5 ℓ/kWh. Investments in renewable energy should be made according to the resources available in South Africa, in addition to their water-saving capacity. The country enjoys considerable solar resource potential, with moderate to good wind potential. Wave energy potential is also significant, but because of its early stage of technology development, costs are prohibitive, at least for the short- to medium-term (DME 2003). It makes sense then to direct investment towards solar and wind energy development.

The White Paper on Renewable Energy estimates a wind energy availability figure of 64 000 GWh to 198 000 GWh per year, assuming a 30% conversion efficiency and a capacity factor of 25% (DME 2003a, DME 2003b). On average, 22 GWh of electricity is produced via wind power[1]. This means that South Africa is able to improve its water savings by a further 213 000 ML to 658 000 ML per year, if the full potential of wind power was realised.

Where solar energy is concerned, photovoltaic applications could range from 0.15 GW to 10 GW per year or more, if India or Germany's cumulative installed capacities are used as a guideline (Eluvangal 2010, EnergyPortal 2010). In 2009, solar PV contributed 6 200 GWh of electricity in Germany (BMU 2010). In 2007, total installed capacity of solar PV in South Africa was estimated at 0.012 GW (Agores 2008). If South Africa's solar PV industry expanded to generate the same amount of electricity as Germany – replacing the equivalent amount from coal - this could result in a water saving of 20 000 ML per year.

Solar thermal potential is estimated at 36 217 GWh per year (DME 2003b), but at time of writing no solar CSP plants have yet been built. This means that 115 387 ML of water could be saved per year through the use of parabolic dish installations, or in the region of 14 000 ML per year for parabolic trough systems, should solar CSP approach the upper limit of contribution. For these large-scale renewable energy plants, significant investment in transmission lines would be needed in order to distribute the electricity from the areas of high solar radiation to cities and towns (Pegels 2010).

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[1] Based on the following: Darling wind phase I 5.2MW + Klipheuwel 3.2MW + Coega 1.8MW. Assumed capacity factor of 25%.

From these calculations, the most effective water saving investment could be made in wind energy development, though a diversified approach that includes all four systems is likely to be optimal, given the significant solar resources in South Africa.

Though these figures above serve to illustrate the significant potential of renewable energy to contribute to South Africa's electricity supply and save water, realistically achievable targets are much lower. Declining technology costs do however mean that the potential for renewable energy increases in the future (Winkler 2009). After 2020, Winkler estimates that renewables will be competitive with other technologies, and could offer approximately 17 000 GWh to national electricity supply (Winkler 2009). By 2025, renewables could contribute about 37 000 GWh or 11% in terms of grid capacity contribution (Winkler 2009). This is equivalent to a 10% reduction in the percentage of electricity generated from coal power plants from their current contribution, and a freshwater saving of around 111 875 ML per year.

Besides the water and electricity saving benefits, increasing renewable energy supply will result in growth in the manufacturing and service industry. This is likely to lead to an increase in related employment opportunities, particularly if the infrastructure and equipment is made locally. Local production is an obvious opportunity given South Africa's abundant metals, minerals and other necessary raw materials. If successful, local production offers significant potential for export.

To increase the uptake of these technologies to replace coal power generation and supply growing demand for electricity, greater energy education, a system conducive to distributed generation, and a functioning energy market are needed. Energy education has already been discussed, and the local energy market will be analysed in the sections that follow. The government is well aware of the potential of renewable energy to supplement the electricity supply through distributed generation (DME 2003). However, this is at odds with current practice. One of the fundamental barriers to the development of renewable energy in South Africa is that the government continues to seek predominantly large-scale energy solutions to suit the existing centralised energy supply system. Micro-generation has been seen merely as a way to reduce domestic energy demand, rather than as contributing to a potentially powerful and cost-effective energy supply system.

2.2.2 Micro-generation

Distributed generation and micro-generation often go hand-in-hand. Micro-generation is, by default, distributed generation. This is because the energy system is usually on site and is designed to fully or partially electrify an individual house or a factory, for example.

As is the case for distributed generation, micro-generation suffers from lower transmission losses than a centralised energy system, making it more energy-efficient. In addition, units can be installed in small spaces, such as on buildings, which make them a more flexible option. It is easy to scale up this type of technology as the units are able to function independently. Micro-generation is best suited to renewable energy systems. This means that much water can be saved as the building of more coal-power plants can be deferred indefinitely.

Unlike large-scale, centralised power plants, micro-generation requires consumers to actively install systems on the property. This in turn requires a fairly advanced degree of energy education and acceptance of the technology (Sauter & Watson 2006). However, there are different ways of deploying micro-generation depending on the interest and acceptance of the consumer. A ‘plug and play’ model, in which the customer owns the micro-generation unit, requires a high level of acceptance (Sauter & Watson 2006). In the ‘company control’ model, a company owns and installs many units in an area, which become a type of power plant. This model requires more passive acceptance from the consumer (Sauter & Watson 2006). In the ‘community micro-grid’ model, the community shares the costs and rewards of installing micro-generation units, as well as the responsibility to balance the grid (Sauter & Watson 2006). Given the capital costs to install micro-generation units, the general lack of energy education, and the tendency to shift responsibility to the government, South Africa may be best suited to the ‘company control’ model.

Micro-generation is beginning to be used in a variety of applications. For example, it is used to power the traffic lights at certain intersections in Johannesburg with solar energy (Venter 2010), to provide electricity to the Diepsloot skills centre in Johannesburg, also through solar PV and battery storage (Holman 2010), and to power a survey transmitter for Xstrata Zinc through solar PV and wind energy (Fletcher 2007). With successful projects in place, it should be easier to convince stakeholders to scale up the use of micro-generation in South Africa.

Some of the most intensive users of energy are mining companies and smelters. These industries also tend to produce significant quantities of waste heat. Companies like Freepower Limited in the UK have taken the initiative and are delivering micro-generation systems that use the wasted heat to turn a turbine and produce electricity, for use on site (ReFocus 2005). These systems are straightforward and cost effective, and can be set up and ready in a few hours (ReFocus 2005). Waste-heat-to-electricity systems also provide customers with the opportunity to sell unused electricity back to the grid. The benefits of using waste heat have not gone unnoticed by South African mines and smelters: Exxaro is currently investigating co-generation options, as well as several other clean energy projects ranging from 7 MW to 90 MW (Reuters 2010b).

To encourage an increase in the use of micro-generation and renewable energy in general, policy changes are needed to improve the energy market. These are discussed in the following section.

2.3 Policy support

In 2003, the South African government published a White Paper on Renewable Energy. In it the Department of Minerals and Energy (DME) stated its target of obtaining 10 000 GWh of consumed electricity from renewable energy sources by 2013 (DME 2003b). In 2009 NERSA announced feed-in tariffs for Independent Power Producers (IPPs) of wind, concentrated solar power, landfill gas and mini-hydro schemes in REFIT I, and later for solar PV in REFIT II (Nersa 2009a & 2009b). While these are specific applications, energy policy in general is focused on creating economic growth, competitiveness, social development and localisation. The government also recognises that the cost of failure and of externalities should be included in energy project costs (Prinsloo 2010b).

These goals suggest a government receptive to energy efficiency programmes and the promotion of renewable energy. Yet despite the presence of admirable policy, there has been less than admirable implementation. In addition, some policy instruments are still needed or need to be improved.

In the case of energy efficiency, the recently increased electricity prices should help to inspire consumers to conserve electricity. Eskom's Standard Offer Programme will incentivise energy service companies to encourage similar behaviour through payment for electricity savings achieved (Van der Merwe 2010). However, electricity suppliers still need to be able to sell at differentiated prices, not a fixed tariff, to incentivise consumers to demand less electricity during peak times. In turn, differentiated pricing will not be fully effective without a mass rollout of smart meters, whose price feedback allows consumers to adjust their electricity consumption.

Where renewable energy is concerned, a correctly-priced domestic or small-commercial feed-in tariff is needed to provide an incentive for households and businesses to install micro-generation units. In the case of large-scale renewable energy projects, the most frequent industry complaint is a lack of sufficient economic incentives, regulatory clarity and certainty, and co-ordinated government involvement (Reuters 2010c, Pegels 2010, Creamer 2010c). These add to market risk and higher lending costs for project development. To incentivise these IPPs beyond the existing feed-in tariffs, Eskom cannot continue to be both sole electricity buyer and main competitor. The Department of Energy has recognised the conflict of interest and is in the process of establishing an Independent Systems and Market Operator (ISMO) to arrange the buying of electricity from IPPs (Prinsloo 2010c). The rapid establishment of the ISMO is essential to the efficient growth of the renewable energy sector in South Africa.

3 Allocation solutions to water scarcity

In addition to the energy-related solutions to water scarcity identified above, the allocation of water to the energy sector itself needs to be reconsidered, in light of national sustainability goals. The following section outlines what sustainable water allocation should look like, how this is different to current practice, and what needs to change in order to achieve sustainable water allocation in South Africa.

3.1 Sustainable water allocation

Policy can positively affect water scarcity by equitably distributing water across population groups and sectors, encouraging efficiency through technology changes, and assisting in achieving allocative efficiency (Ohlsson 1999). As explained in the first article in this series, water-use efficiency on its own is not the solution to coping with scarcity: the effective allocation of water is imperative. The very definition of sustainability suggests an emphasis on demand management – doing better with what we have – rather than augmenting supply to meet our needs (Turton 1999). Sustainable allocation can therefore be thought of as an instrument of demand management.

In the past, *efficient* allocation of water was apparently misunderstood to mean *effective* allocation. The Department of Water Affairs would re-allocate water from heavy water users such as agriculture to 'more efficient' users in industry or commerce, as the latter are able to generate higher economic returns per litre of water used. Using this method, much water can be saved with a relatively small loss in income (Turton 1999). Turton (1999) suggests that this model of water allocation based on sectoral water efficiency (SWE) is effective - so long as it occurs at a rate at which the reallocation is politically acceptable. This he calls society's 'adaptive capacity'.

There are several problems with this approach to water allocation. Firstly, South Africa is an arid country with only 35% of the land area receiving enough rain to produce dryland crops. This means that some irrigation is essential (Otieno & Ochieng 2004). These rainfall areas are also spread out over the country, which means that water transfer to urban centres for industry requires extensive piping, and water losses are significant (Roberts 2010).

Secondly, 49% of the population live in rural areas and rely on agriculture for food production and employment. Continuing to allocate water away from agriculture is likely to cause significant social tension, due to the resultant job losses and the forced migration to over-stretched urban centres that is likely to follow (Turton 1999). It is unlikely that this reallocation would ever be politically acceptable for the majority of citizens. South Africa already suffers from an unemployment rate of 25.2% (Statistics South Africa 2010), and every other government policy aims towards job creation, not elimination. Reallocating water away from agriculture is therefore a direct contradiction of policy. Though the economic loss will be relatively lower, a higher number of people will be rendered helpless than those who will gain. In addition, the gains are likely to go to big business, not the poor, thereby worsening South Africa's already dire income inequality.

Thirdly, decreasing the size of the agricultural sector in this way makes importing more food necessary, which leaves the country vulnerable to oil price fluctuations and other external shocks. South Africa's food security is negatively impacted by this method of allocation, and this is felt particularly by the poor.

Farmers should certainly be taught and incentivised to make use of water-saving techniques such as drip irrigation. However, water allocation based purely on sectoral water efficiency (i.e. economic contribution) is clearly unsustainable. This allocative efficiency may bring short-term (economic) gains, but is likely to hinder rather than aid progress towards sustainability, and acts as a smokescreen that defers true reform.

What is required then is a fundamental re-allocation of water between different sectors of the economy, based on contribution to sustainability. This requires a thorough and integrated analysis of all the social, ecological and economic costs and benefits in a broad sense (Van der Zaag & Savenjie 2006).

This view is supported by legislation, though arguably not enforced. Section 24 of the South African Constitution gives an individual the right:

a. to an environment that is not harmful to their health or well-being; and
b. to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that
    i. prevent pollution and ecological degradation;

ii. promote conservation; and
iii. secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development. (Constitution 1996)

This type of allocation could be achieved by giving sustainability ratings for each water permit applicant, and allocation would then be prioritised according to the rating. This may seem 'idealistic' to the critical. But logically, sustainability can never be achieved by minimising negative impacts (Birkeland 2008, Braungart & McDonough 2009). In simple terms, you cannot become 'good' by being 'less bad' (Birkeland 2008). The system of water allocation has to be fundamentally changed.

3.2 Achieving sustainable water allocation in South Africa

3.2.1 Increase transparency and accountability for water use

As explained in Part 1 of this article series, transparency and accountability are the first steps towards effective and efficient water use before sustainable allocation can be made. The first concern is that applications for water permits (in which a prospective user must submit a water management plan) are kept confidential. This is clearly in conflict with Chapter 2 Paragraph 32 of the Bill of Rights:

> 32. Access to information
>
> (1) Everyone has the right of access to –
>
> (a) any information held by the state; and
>
> (b) any information that is held by another person and that is required for the exercise or protection of any rights.
>
> (2) National legislation must be enacted to give effect to this right, and may provide for reasonable measures to alleviate the administrative and financial burden on the state. (Constitution 1996)

Secondly, though this section of the Bill of Rights gives individuals the Right of Access to Information, the science community is frequently required to keep research classified as part of funding contracts with the private sector. This protects a company from any negative publicity should they be found to be harming people or the environment in some way (Turton 2009). Clearly, this is contrary to the spirit of the Right of Access to Information, and makes it impossible to hold companies and people accountable for their actions. Confidentiality contracts such as these should be illegal.

Thirdly, the government has historically been a facilitator rather than a regulator of industry (Turton 2009). The mining sector in particular has been allowed to prevent the state from regulating the industry, avoiding liability, and externalise social and environmental costs onto the rest of society (Turton 2009). The industry is a powerful lobbyist and fierce opponent, one which has gone to great lengths to dissolve former regulatory and interest groups who have evidence of possible misdemeanours (Turton 2009). This 'lack of oversight' is encouraged by government officials holding shares in private companies or serving on mining company boards (Nxumalo 2009, Letsoalo & Mataboge 2009). Government officials should not be allowed to have financial interest in the industries they are supposed to be regulating, as this represents a clear conflict of interest.

In summary, water use should not be allowed to be confidential. Users need to be held accountable for their actions as they affect the nation as a whole. Transparency and enforcing the integrity of government officials are key in achieving sustainable water allocation.

3.2.2 Increase water prices

The water price is an important signal of availability as well as cost of provision (Van der Zaag & Savenjie 2006). However, South Africa's water prices currently do not signal the situation of water scarcity, and as such do not encourage water conservation. Raising water prices will always be a controversial topic, usually under the guise of concern for the poor, but more likely due to general industry resistance to cost increases. In any case, the very poor in Cape Town, South Africa receive 6 000 litres of water free per month (City of Cape Town 2008), so raising water prices is unlikely to interfere with meeting basic water needs.

Another concern is that current water prices do not allow service providers to recover costs, and this problem is compounded by a significant rate of non-payment. At time of writing, local municipalities owed R1.2 billion to Water Boards – a situation described as "perilous" (Morgan 2010). In addition, the Water and Environmental Affairs Minister Buyelwa Sonjica estimated that R23 billion is needed to prevent the collapse of South Africa's sewerage systems (Ndaba 2010). Raising water prices will not only encourage conservation and efficiency, but will allow service providers to maintain aging infrastructure and repair the leaks that are causing 30% of water delivered to be wasted (Roberts 2010).

Admittedly the ability of the agricultural sector to cope with higher water prices is limited, and the higher prices will almost certainly be passed on to consumers. This has negative implications for food security. It is therefore necessary to allow some government intervention in this regard (Turton 1999, Van der Zaag & Savenjie 2006). Water price increases could be differentiated between sectors depending on broad-based contribution to South Africa's sustainability.

4 Conclusion

This paper has offered two types of investment options to prevent the excessive water usage of coal-fired electricity and the coal mining that supports it. The options deal with the deeper problems of water scarcity and the energy crisis, which are more frequently driven by demand than by supply. As such, they are better able to work towards the sustainable use of water and energy in South Africa.

The first are energy-related investment options, which include energy conservation and efficiency through energy education, smart meters and the smart grid, and distributed generation. The effectiveness of these options would appear to be underestimated, and as such are not being sufficiently advanced by the Department of Energy. Collectively, these efficiency savings could liberate generating capacity to meet the growing electricity demand. This would defer the high capital investment and ecological damage associated with building and operating new coal power plants.

Case studies have shown that education is not only the cheapest but potentially the most effective investment in energy conservation. The South African public has already shown itself significantly responsive to public energy-saving campaigns. This needs to be scaled up as well as implemented in every school curriculum, which currently lacks a coherent energy education component.

Installing smart meters just across the mining, industrial and residential sectors in South Africa could lead to electricity savings of up to 13 132 GWh per year, and freshwater savings of up to 38 437 ML per year. These savings are much larger than the impact of smart meters on residential electricity use, which could save up to 1 554 GWh and 4 544 ML of water per year. This indicates that Eskom’s plan to roll out smart meters in the residential sector may be misdirected, given the savings potential in the mining and industrial sectors.

The implementation of a smart grid could lead to savings of up to 21 895 GWh per annum, and a coal-related freshwater saving of 63 980 ML per annum. In order for smart meters and the smart grid to be successful, however, real-time tariffs need to be introduced.

Distributed generation would support renewable energy plants and micro-generation, create more jobs, allow the electrification of areas too remote to be connected to the national grid, reduce the electrical losses associated with transmission, and reduce the effect of power blackouts. However, distributed generation needs a new network design that allows the bi-directional flow of electricity.

Moving towards replacing coal power plants with solar and wind power is another solution that can contribute to significant water savings, given the low water use of these renewable energy technologies. It was determined that wind energy offers the most effective water saving investment, though a diversified mix that makes use of South Africa’s substantial solar resources is optimal. By 2025, the competitive cost of renewable energy technology means that it could contribute 11% of electricity supply, equivalent to 37 000 GWh and a related water saving of 111 875 ML per year. The potential for micro-generation should also be fully exploited and incentivised through a domestic feed-in tariff or alternatively through net metering.

For both of these energy-related solutions, improved policy support and effective implementation is needed. In particular, increased clarity and certainty of policy is required for the stakeholders in the industry to secure financial loans.

The second type of investment option is directly related to water, and involves designing and implementing a fundamentally different water allocation system. Water should no longer be allocated to sectors based simply on economic contribution. Rather, it should be allocated according to contribution to broad-based sustainability, which includes social and ecological aspects as well as economic. In order to achieve this, transparency and accountability must be improved by making water permit, usage, and research information easily available to the public. Water prices should increase in order to better signal the actual situation of scarcity, encourage conservation and efficiency. The higher prices will also help water boards to cover supply and maintenance costs. Some government intervention is required to protect agriculture from excessively high water prices as this would negatively impact the country's food security.

The current amount of water given to the coal mining and electricity industry is not a sustainable allocation decision. This is because both in the short term and in the long term, these industries contribute to water scarcity and other types of ecological degradation. Building more coal power plants and increasing coal mining to supply them will actually send South Africa into a water deficit, given that the country's total available resources have already been allocated to the maximum (Turton 2008). No additional water should therefore be set aside for coal mining or coal power plants.

A sustainable economy is built on sustainable energy use and sustainable resource use. The link between coal mining, coal-fired electricity and water can no longer be ignored if South Africa is to ensure a sustainable water supply for the future.

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Nomenclature

AMI	Advanced Metering Infrastructure
CFL	Compact Fluorescent Light
CSP	Concentrated Solar Power
DoE	Department of Energy
DME	Department of Minerals and Energy – now separate departments (see above)
DSM	Demand Side Management
DWAF	Department of Water Affairs and Forestry – now the Department of Water Affairs (DWA)
GWh	Gigawatt hour
IPP	Independent Power Producer
ISMO	Independent Systems and Market Operator
kWh	kilowatt hour
ML	Megalitre
MW	Megawatt
MWh	Megawatt hour
NERSA	National Energy Regulator
PV	Photovoltaic
RE	Renewable Energy
REFIT	Renewable Energy Feed-In Tariff
SOP	Standard Offer Programme

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