COAL-THE "DIRTY" FUEL?

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ABSTRACT

The world depends upon coal for much of its energy, yet coal had developed a reputation for being "dirty" and polluting. The reputation seems undeserved; coal can be, and often is, burned cleanly. There are concerns about various emissions, particularly sulphur and nitrogen oxides and mercury, but the impact of these emissions seems overstated, so that statutory control levels are set to unnecessarily low levels.

The global political desire to reduce the quantity of coal burned in order to lower the anthropogenic contribution of carbon dioxide does not conform to the plans of many developing nations to employ ever more coal to generate energy cheaply and from their own resources. While many OECD nations are actively reducing their coal use. developing nations, particularly at present those in SE Asia and probably in future much of Africa, will grow their coal consumption.

This raises the question as to whether it is better to develop economically than to be a good global citizen and reduce greenhouse gas emissions. Answering this question requires assessing the risks of future climate change. It is argued that changes thus far observed make the risks associated with climate change small, so that it is perfectly justifiable to build more coal-fired power stations.

1. INTRODUCTION

Coal is one of the three primary sources of energy on earth. In 2015, we consumed over 4 300 million tonnes of oil, 3 800 million tonnes oil equivalent [mtoe] coal, 3 100 mtoe gas, nearly 900mtoe hydropower, about 580mtoe nuclear power and 360mtoe other renewable energies[1]. Thus coal totalled almost exactly 30% of the primary energy available.

As such, coal is a virtually irreplaceable resource. We could imagine a world without coal, a world with 30% less energy, but it would be a nightmare of a world, with starvation re-appearing, mass migrations as people sought warmth in winter, and the re-emergence of diseases long forgotten.

Yet there is a mantra oft repeated. "Dirty coal!" shrieks the Sierra Club [2]. "Dirty coal – clean future" claims the Atlantic magazine [3]. A single Huffington Post webpage has over 40 reports devoted to "Dirty coal"[4]. "Coal is cheap, plentiful and dirty -- as cheap as dirt, as plentiful as dirt, and as dirty as dirt," says the Union of Concerned Scientists[5]. The reputation has a long history. In 1798 Count Rumford complained "*nothing surely was ever more dirty, inelegant, and disgusting than a common coal fire.*" [6]. Indeed, it often seems that one cannot talk about coal without preceding it with the "dirty" epithet.

So there is a huge gap between the perception of coal as being something we should not want and our considerable reliance on this apparently unwanted material. In this paper, therefore, the gap is explored, in the hope that the benefits which coal brings may be better understood and its dirty reputation in some measure cleaned.

2. COAL USE

The global use of coal is shown in Fig.1

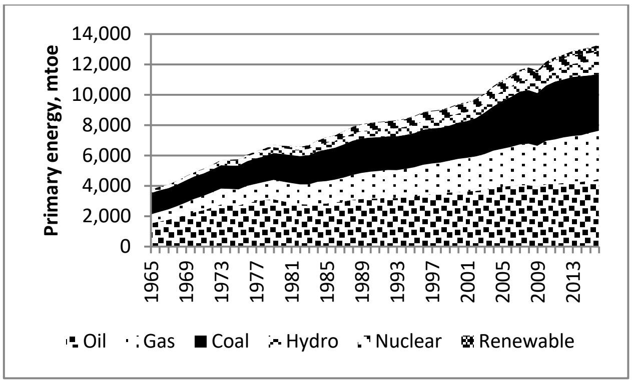

Figure 1. Primary energy sources, 1965-2016 [1]

Since 2000, use of coal by OECD nations has fallen by about 150Mt, primarily due to the use of greater quantities of natural gas. In contrast, in non-OECD nations, coal use has more than doubled, from 1250Mt in 2000 to nearly 2900Mt in 2015.

The growth has occurred mainly in SE Asia. Since 2000, China has increased its consumption by 1200Mt, India by 240Mt, Indonesia by 70Mt and S Korea by 40Mt [1]. It seems likely to continue to grow – for instance, Pakistan used only 5Mt in 2015, but has under construction some 11GW of coal-fired power stations with a demand for over 40Mt coal by 2020. The International Energy Agency estimates OECD countries will grow their coal consumption to about 1400Mt by 2040 but non-OECD countries will grow to about 3000Mt by 2040 [7].

The Paris Accord [8] persuaded most nations to provide Nationally Determined Contributions[NDCs], the annual tonnage of carbon dioxide by which each nation felt it could reduce its emissions. When the NDCs were totalled, there was considerable disappointment that future

emissions would exceed the hypothetical amount needed to prevent global temperatures from rising more than 2^{o}C above pre-industrial levels.
It can only be concluded that, whatever coal's reputation may be, when there is a demand for cheap energy and a local coal resource in need of exploitation, exploitation is likely to occur regardless of concerns about future greenhouse gas emissions.

3. COAL MINING [9]

Most coal occurs in relatively flat seams, at varying depths below the surface. The seams are generally at least 1m high, although some coal occurs as thin (<10mm) wide seams separated by a few centimetres of sandstone or shale. When the coal is less than about 80m deep, it can usually be mined from surface.
There are two basic methods of mining from surface, strip mining and open cast. In strip mining, a long strip of the surface soil is first removed and stacked separately. Then the overburden is mined along the strip until the top of the coal seams is reached. The coal is mined, and the overburden replaced and then covered by the retained surface soil. Another strip is created parallel to the original one and so mining continues. The cycle may be varied, but the end result, when the mine is exhausted, should be a surface that is several metres lower than the original but otherwise undistinguishable.
In open cast mining, the overburden is dumped close to the mine, and a large hole created, accessed by haul roads cut into the walls of the pit. The pit may be deepened to access lower seams of coal. At the end of life, vegetation must be established on the overburden dumps to stabilize them, and the pit will probably fill with water which may be clean enough for recreation or agricultural use.
Open-cast mines can exceed 100m depth if the coal seams are sufficiently thick. However, at a certain point the coal:overburden ratio becomes so low that underground mining is more economical.
There are basically two methods of underground mining, room-and-pillar and longwall. In room-and-pillar mining, the roof is supported by pillars of coal that are left standing, while coal is mined from the area between the pillars. In longwall mining, the roof close to the face being mined is supported on strong, usually hydraulic, props. As mining proceeds, so the props are moved forwards and the roof behind the props is allowed to collapse.
Environmental impacts vary with the mining method employed. Strip mining can be low impact, as long as rehabilitation takes place at the end of the mine's life. Historically, rehabilitation was not enforced, with the result that there are now 5 900 abandoned mines in need of rehabilitation in South Africa alone, most of which are coal mines [10]. With proper rehabilitation, however, strip mining can leave an environment as good as the undisturbed surface.
All mining will have some impact on ground water. The primary risk is that of generating acid mine drainage (AMD). All coals contain some sulphur, much of which is usually in the form of iron sulphides. These can oxidize:

$$2FeS_2 + 7.5O_2 + H_2O \rightarrow Fe_2(SO_{4})_3 + H_2SO_4$$

and the ferric sulphate/sulphuric acid mix constitutes AMD. If the coal seam is below the local water table, then only a small quantity of AMD is likely to be generated because the only oxygen available is that soluble in water. If, however, the coal seam is above the local water table, then it will continuously be exposed to fresh oxygen and AMD generation will continue for a long time. AMD can be neutralised, but the process is relatively expensive. A cheaper process appears to have been identified [11].
A further possible environmental impact arises from the dumping of wastes. Not only can the dump be unsightly and a possible source of AMD, but is may contain sufficient combustible material to spontaneously overheat and burn.[12] Waste heaps can be covered with compacted soil, which will minimize water ingress, AMD formation and access to air, thus preventing combustion. It is costly to cover dumps in this way, and historically many such dumps were allowed to burn out, generating significant air pollution.
Fire is also one of the risks of underground and even some opencast situations. Their impact is very difficult to mitigate, and significant areas of land can be made unusable until the fires have burned out.
Most coals contain some methane gas, which can be released by mining. Methane is a powerful greenhouse gas. Moreover, unless underground ventilation is carefully controlled, methane concentrations can exceed explosive limits, which can then cause extensive damage. Most underground mines in South Africa have very low methane levels, probably because the coal was heated by post-depositional plutonism, but there are occasional pockets of gas that can present problems. Coal close to the surface, however, has a very low methane content, probably because any methane has diffused to atmosphere over the millions of years since it was formed. [13]
Coal dust in underground mines can also present an explosion hazard. It is controlled by spreading inert rock dust in those areas where coal dust can gather, so that the concentration of inerts in the dust is at least 80%.[14]
It can only be concluded that coal mining is an inherently dirty business. Much can be done to mitigate the impacts, but ultimately geology limits the practicability of potential mitigations.

5. COAL PROCESSING [15]

What is mined may not meet the needs of the customer. It may have too much ash or sulphur, for instance, or may be an inappropriate size. It is necessary in most cases to process the raw coal to produce a saleable product.
Most coal is processed by wet density separation. Rock has a density above 2t/m^3; the best quality high-volatile coal has a density of about 1.3t/m^3. Coarse coal is often processed in a suspension of fine magnetite; the product floats in a bath filled with such a suspension and is removed and washed to recover the magnetite. Finer coal is typically processed in a hydrocyclone, with the heavier rock particles forming a bed on which the coal "floats".
Sizing is carried out over vibrating screens. A typical product is a "Nut", +19-32mm. A particular environmental problem arises from the fine coal <0.1mm in size. This material is very difficult to dry, and tends to be disposed of in a "sludge pond". It is often inherently high grade, and the owners hope to find some way of making it saleable.

Disposal of the coal waste gives rise to impacts that are difficult to mitigate. Wastes containing as little as 20% organic matter have been known to self-combust. Once alight, such fires are very difficult to extinguish. Prevention requires compacting the waste to minimize ingress of oxygen, and then covering the dump with several metres of compacted inert soil.

Some waste may be lost into the bottom of the household fuel market, where it is burned very inefficiently in an *mbaula* or brazier. This is a primary source of air pollution in some townships close to coal mines and their waste dumps.

Whenever coal is handled, coal fines are generated because coal is inherently soft and breakable. For example, the ground where clean coal is dumped will become contaminated with fine coal and be useless for agriculture for many years. One of the few places where coal is handled without creating a nuisance is a power station fuelled by pulverized coal. There, the generated fines join the feed to the boilers and are burned.

6. COAL UTILIZATION

South Africa produces an average of 224 million tonnes of marketable coal annually, making it the fifth largest coal producing country in the world. 25% of our production is exported, making South Africa the third largest coal exporting country. The remainder of South Africa's coal production feeds the various local industries, with 53% (90 million tonnes) used for electricity generation. The key role played by our coal reserves in the economy is illustrated by the fact that Eskom is the 7th largest electricity generator in the world, and Sasol (44 million tonnes) the largest coal-to-chemicals producer. [16]

About 30 million tonnes are used in industry, both for heating and as a reductant in, for instance, the iron and steel industry.

About 1 million tonnes is sold for domestic heating [17]. This is a major source of air pollution. Indeed, Tsongwe *et al* [18] concluded that, even though there was an open fire inside a Soweto shack, the respirable fractions of the particulate aerosol were determined by the ambient outside pollution levels rather than by any activities with the home. The ambient air was polluted by particles from all the fires that were burning in the township, to such an extent that the sun was not visible on an otherwise clear day until after 10h00. Attempts to reduce the levels of pollution by top-lighting of braziers (*Basa njenga magogo*) did not succeed [19], but replacing coal with low-smoke fuel was quite effective [20]. Fine particle ($PM_{2.5}$) loadings as high as 0. 25mg/m^3 and PM_{10} loadings as high as 2.5mg/m^3 have been observed [18]. These levels may be contrasted with the National Ambient Air Quality Standards of 0.025mg/m^3 for $PM_{2.5}$ and 0.04mg/m^3 for PM_{10} annual average [21].

The generation of power by combustion of coal is, in contrast, remarkably "clean". There are repeated references to the external costs of power generation from coal combustion [e.g.22], but these claims have not been substantiated. For example, Fig.2 shows the average annual PM_{10} concentrations on the Eastern Highveld [23]. While it is true the statutory level is exceeded in many places, research shows that the source is partly dust from unpaved roads and smoke from domestic fires or burning coal waste as described in the previous section [23].

Most of the coal ash takes the form of lumpy material. It contains a small amount of carbon, but is essentially inert. A dump presents no significant impact, but it is better if vegetation is established, which can be done quite cheaply.

Some of the ash reports as fly-ash, of a size sufficiently small to be airborne. It is valuable as a cement additive, and so is captured. Most of the power stations are fitted with high-efficiency cloth filters, and are fully within environmental standards. Some of the older plants still employ electrostatic precipitators which are slowly being replaced, and have been granted exemption from licence conditions while they do so [24].

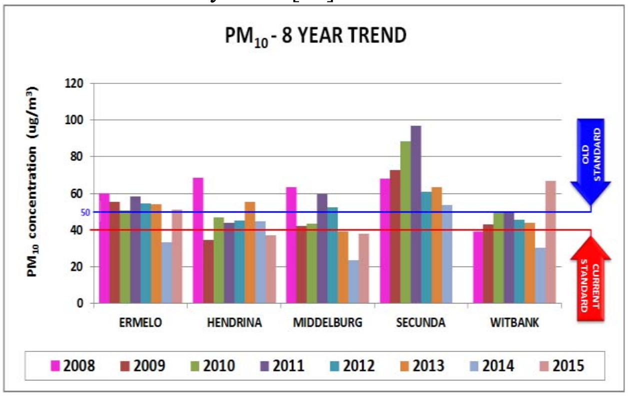

Fig.2 PM_{10} levels in the Eastern Highveld priority area [23]

Similarly sulphur dioxide levels are within standard levels, as shown in Fig.3.

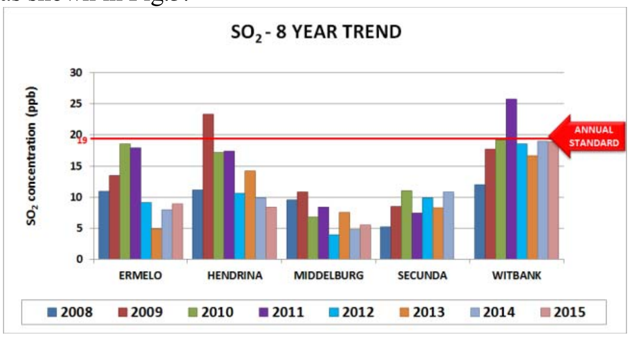

Fig.3 Annual average SO_2 levels in the Eastern Highveld [23]

The 19ppb level set as a standard is highly questionable. There is, for instance, evidence that 60ppb is the optimum level for plant growth under temperate conditions [25]. The state government in Hawaii recommends that the elderly and asthmatic should stay indoors and shut the windows when the volcanic SO_x levels exceed 10ppm, so 19ppb cannot be very hazardous to health.[26].

The highest average annual NO_2 concentration observed on the Eastern Highveld was just over 9ppm, well clear of the National Standard of 21ppm [27]. Again, it is very doubtful if this is a significant environmental impact.

Carbon dioxide emissions from the coal-fired power stations are of course significant (~220Mt) [28], and may have an environmental impact, but any such impact is very difficult to quantify as is discussed below.

Sasol and the iron and steel and cement industries account for about 40Mt [28] of carbon dioxide. These other industries generally have low particulate, SO_x and NO_x

emissions, although fertilizer operations are a source of NO_x, which cannot truly be laid at dirty coal's door
"South Africa's long-term emissions trajectory is to aspire to peak in the 2020 - 2025 period at between 500 and 550 Mt Carbon Dioxide Equivalent (CO2-eq), to remain at that emissions level until 2035, and for emissions to decline to a range of between 200 and 400 Mt CO2-eq in 2050."[29]. To achieve this, it is intended to phase out much of the coal-fired power generation, to introduce significant renewable energy generating capacity, and to replace much of the need for continuous supply with nearly 10GW of nuclear power and large quantities of natural gas[30].
It will be necessary to invest huge sums in the planned new generation plant. Such investment would be justified if the costs of continuing with business-as-usual were likely to be excessive. This naturally depends on the costs likely to be incurred because of carbon-dioxide-driven climate change. These costs have been much discussed, but the estimates [e.g.31] remain controversial. A re-evaluation of the environmental risks seems necessary.

7. ENVIRONMENTAL RISKS OF EXCESSIVE CARBON DIOXIDE

The underlying hypothesis is that global warming is occurring because the levels of carbon dioxide and other infra-red scattering gases are increasing in the atmosphere. The scattered infra-red has less chance of escaping to space, but is trapped with the earth system and so causes an increase in temperature.
There are a number of problems with this hypothesis. Firstly, there is some natural variation in the earth's temperature, estimated for 8 000 years of the Holocene, to be about $\pm 2^{o}C$ over a century [32]. The increase observed since 1900CE is $<1^{o}C$, so the question arises as to how much of the observed increase is natural and how much caused by growing CO_2. Secondly, the warming that is observed is insignificant when compared to the diurnal and seasonal changes that occur, as Fig.4 illustrates.

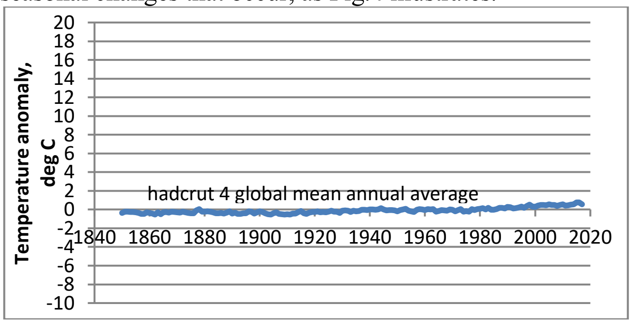

Fig.4. Global temperature anomaly since 1850, compared to typical annual temperature range of $\pm 30^{o}C$
Thirdly, there has been a rapid increase in the carbon dioxide concentration in this millennium, yet the temperature has been essentially static:

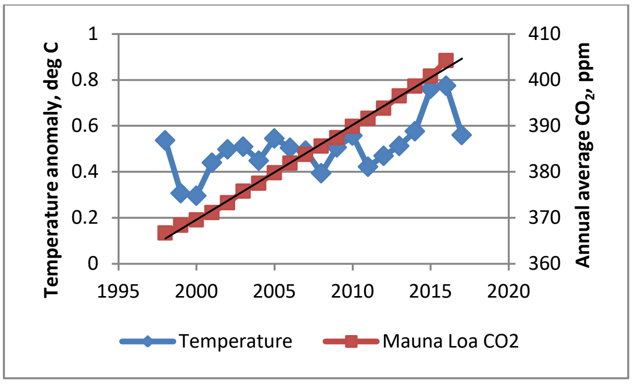

Fig.5 Comparison of recent temperatures and CO_2

This last observation is important because the gap between the global temperatures predicted by all the models of global circulation and that observed in the atmosphere by both balloons and satellites is growing:

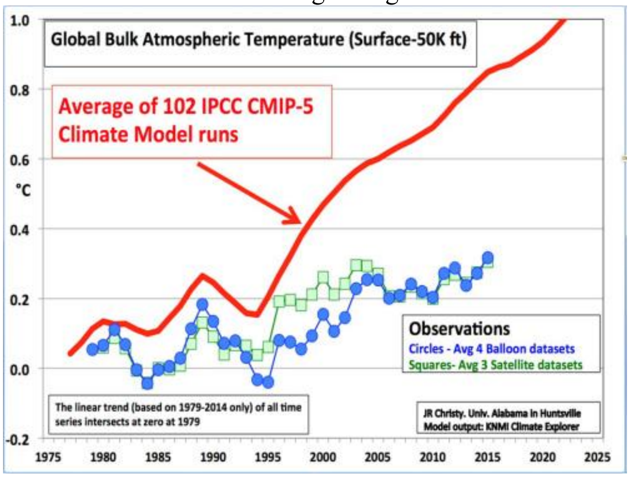

Fig.6 Divergence of climate model predictions and measurements of actual global temperatures.
So it is reasonable to assume that the risk of catastrophic global warming is low. NB, this does **not** mean that there is a significant risk of catastrophic warming; it merely accepts that there is some warming and suggests that future warming is unlikely to be as catastrophic as predicted by the (apparently flawed) models.
Thus, for instance, it seems unlikely that there will be a significant increase in the frequency or severity of high-intensity storms. It is very difficult to determine an increase in frequency. Assume, for example, that a severe event is one that is outside the 95% probability band. Then in 200 time periods, you would only expect 10 such events, 5 of which would be high and 5 low. Statistics soon tell you that the estimate of 5 is associated with an error of ±2, i.e, you would expect somewhere between 3 and 8 events on either the high or the low side of the 200-event record. This is illustrated by the 250-year record of rainfall over England and Wales [33], which happens to be very close to normally distributed:

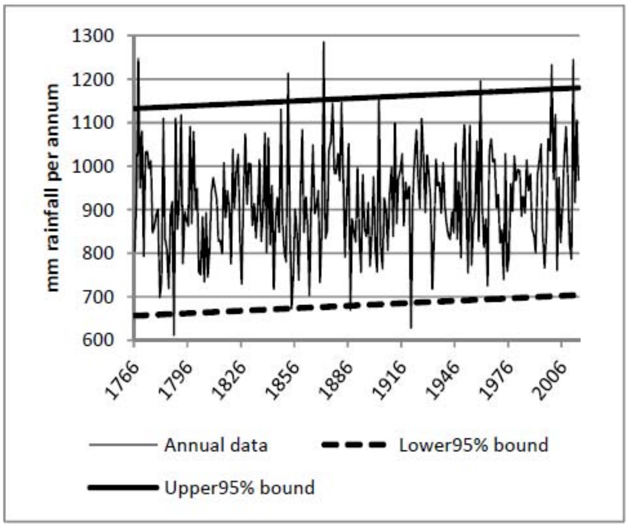

Fig.7 250-year record of rainfall over England and Wales, showing 5% extreme events.

In 250 years, one would have expected 12.5 extreme events if the likelihood were 5%. In fact there were 7 high events and only 4 low events, 11 in total. The chances of detecting a change in the rate of extreme events (as so defined) is essentially nil.

This is a very general finding. The IPCC produced a Special Report on the subject [34] and found:

- "It is **very likely** that there has been an overall decrease in the number of cold days and nights, and an overall increase in the number of warm days and nights, at the global scale" which you might expect in a warmer world!
- "There is **medium confidence** that the length or number of warm spells or heat waves has increased since the middle of the 20th century"
- "There is **low confidence** that any observed long-term increases in tropical cyclone activity are robust"
- "There is **low confidence** in observed trends in small-scale phenomena such as tornadoes and hail"
- "There is **medium confidence** that since the 1950s some regions of the world have experienced a trend to more intense and longer droughts, but in some regions droughts have become less frequent, less intense, or shorter"
- "There is limited to medium evidence available to assess climate-driven observed changes in the magnitude and frequency of floods. Furthermore, there is **low agreement** in this evidence, and thus overall **low confidence** at the global scale regarding even the sign of these changes."
- "It is **likely** that there has been an increase in extreme coastal high water related to increases in mean sea level"

An assessment of cyclone damage found that, when you accounted for the increase in population, the density of buildings and inflation, the peak damage was in the 1920's and had been falling ever since [35].

It does not matter which putative impending disaster you study, in every case the evidence for climate change being the root cause is weak at best, and totally absent most of the time. No, the polar bears are not disappearing; no, the coral recovers from bleaching; no, malaria is not spread by a warmer climate; no, sea level is not rising faster than ever. Yes, glaciers are melting, as you might expect in a warmer world, but they have melted then regrown before.

It can only be concluded that the risks of future impacts, and therefore the costs of future impacts, are **very likely** to be low. We may continue to burn fossil fuels with impunity.

And this is not surprising; the world has been warming for at least 150 years, and we would have expected the effects of a warmer world to show themselves by now. Yes, we can see the effects on temperature and on ice, but this is implicit in a warmer world. But extra rain, awful droughts, furious cyclones, raging floods, a ravaged biosphere – there is no solid evidence in spite of a lot of searching.

8. CONCLUSION

It can only be concluded that coal is inherently dirty stuff. Mining it is a dirty business; processing it for sale produces mucky wastes; transporting it, even dumping it, leaves a trail of black dirt. With care and mitigation, the impacts can be minimized, but there will always be some impact.

But when it comes to using the coal, as long as it is burned efficiently, then the environmental impacts are low. There is massive air pollution from domestic coal fires, but these are highly inefficient – about 20% of the energy in the coal goes up the chimney as smoke, and coal smoke is a high-energy fuel! But power stations, burning over 100 times more coal than the whole of the domestic sector, produce only a fraction of the total particulate load. In many places, the domestic pollution dominates by a large margin.

South Africa's present energy plans [30] call for some additional coal-fired power stations. These are needed because:

1. Many of the existing coal-fired power stations are nearing the end of their economic life, and
2. Some power sources are needed which are guaranteed to operate 24h per day to ensure power supply when renewable energy sources cannot provide sufficient energy.

With efficient combustion, the environmental impact of additional coal-fired power stations will be low, and ultimately contribute to a cleaner environment, particularly if the cost of electricity can be contained to the point where the poor can afford to discard their coal stoves, and cook and heat their homes electrically.

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10. BIBLIOGRAPHY

[1] BP Statistical Review of World Energy June 2017. http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html Accessed June 2017.

[2] Sierra Club http://content.sierraclub.org/coal/dirty-coal Accessed March 2017.

[3]Atlantic Magazine https://www.theatlantic.com/magazine/archive/2010/12/dirty-coal-clean-future/308307/ Accessed April 2017.

[4]http://www.huffingtonpost.com/topic/dirty-coal Accessed April 2017.
[5]http://www.ucsusa.org/clean_energy/coalvswind/brief_coal.html#.WS2WVcYlHIU Accessed April 2017.
[6]http://www.science20.com/chatter_box/dirty_coal_and_boring_science Accessed April 2017
[7]International Energy Agency, *International energy outlook 2016*. IEA, Paris, Report Number: DOE/EIA-0484(2016)
[8]UN Treaty Collection, "7. d Paris Agreement" https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-d&chapter=27&clang=_en Accessed May 2017
[9]Osborne, D. ed."The coal handbook" *Woodhead Publishing*, 2013. ISBN 9780857094223
[10]van Druten, E.S. and Bekker, M.C. "Towards an inclusive model to address unsuccessful mine closures in South Africa". *J.S.A. Institute of Mining and Metallurgy,* Vol.117, No.5, pp485-490 (2017)
[11] Bewsey, J.A." The KNEW process - recovery of acid mines water profitably"*Water Research Commission*, Report WRN111413 (2016)
[12] Moroeng, O.M. "Spontaneous combustion of coal – a South African perspective." MSc thesis, Geology, University of Pretoria, (2015)
[13 Lloyd, P. and Cook, A. "Methane release from South African coal mines" *J SA Institute of Mining and Metallurgy*, Vol.105 pp 483-490 (2005)
[14] Department of Mineral Resources. "Prevention of Flammable Gas and Coal Dust Explosions in Collieries."Report Ref. DME16/3/2/1-A1 (2002)
[15] Leonard, J.P. "Coal preparation", Society for Mining Metallurgy & Exploration, New York (1991) ISBN 13: 9780895202581
[16]http://www.eskom.co.za/AboutElectricity/ElectricityTechnologies/Pages/Coal_Power.aspx
[17] Qase N, Lloyd PJD & van Zyl H "Intervention potential for low-smoke fuels in the distribution chain," Report to Department of Minerals & Energy, October 2000
[18]Tsongwe, H.T., Kgamphe, J.S., Annegarn, H.J. and Sellschop,J.P.F. "Indoor-outdoor air particulate study in a Soweto home." *Clean Air Journal ISSN 0379-4709*, pp6-13 (1989)
[19] Nuwarinda, H. "Air pollution study of a Highveld township during a *Basa Njengo Magogo* roll-out." MSc Thesis, University of Johannesburg, Nov.2007
[20] Asamoah J.K., Lloyd P.J., Hoets P. &Grobelaar C.J. "South Africa's low smoke fuel programme. Preliminary results of the macro-scale experiment in Qalabotjha*." J Energy in SA*. Vol. 9 (2) pp64-7 (1998)
[21] Department of Environmental Affairs "National ambient air quality standards." Government Gazette No.32816, 24 Dec.2009,
[22] Greenpeace "The true cost of coal - The monstrous price of South Africa's coal addiction." http://www.greenpeace.org/africa/en/News/news/The-True-Cost-of-Coal/ Accessed May 2017
[23] Parliamentary Portfolio Committee on Environmental Affairs "Nationally Determined Contribution & Air Quality" 13 June 2017. https://pmg.org.za/committee-meeting/24598/ Accessed June 2017
[24]Fin 24 "Eskom gets reprieve from emission caps" http://www.fin24.com/Economy/Eskom-gets-reprieve-from-emission-caps-20150224 Accessed May 2017
[25] Olsen, R.A. "Absorption of sulphur dioxide from the atmosphere by cotton plants." *Soil Science* Vol.84, pp.107-112 (1957)
[26] Hawaii Government "Safety precautions necessary during high vog levels" (2009). www.hawaii.gov/gov/vog. Accessed April 2009
[27] Lourens, A.S., Beukes, J.P. *et al* "Spatial and temporal assessment of gaseous pollutants in the Highveld of South Africa". *SA Journal of Science*, Vol.107, pp1-8 (2011)
[28] Department of Environmental Affairs. "South Africa's Second National Communication under the United Nations Framework Convention on Climate Change." DEA, Republic of South Africa, Pretoria (2011)
[29] Department of Environmental Affairs, "Opportunities for and Costs of Mitigation in South African Economy." DEA, Pretoria (2011)
[30] Department of Energy. " Integrated resource plan update; Assumptions, base case results and observations. Revision 1" DoE, Pretoria, (2016)
[31] Stern, N. "The economics of climate change". Report to UK Government, (2006)
[32] Lloyd, P.J. "An estimate of the centennial variability of global temperatures." *Energy & Environment*,Vol. 26(3), pp. 417–424 2015. DOI: 10.1260/0958-305X.26.3.417
[33] UK Meteorological Office "Monthly England & Wales precipitation" http://www.metoffice.gov.uk/hadobs/hadukp/data/monthly/HadEWP_monthly_qc.txt Accessed January 2017
[34] IPCC,"Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation." Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., *et al* (eds.)]. Cambridge University Press, Cambridge, UK. (2012)
[35] Pielke, R.A.Jnr "The Rightful Place of Science: Disasters and Climate Change" Consortium for Science, Policy & Outcomes (2014) ISBN 978-0692297513

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Presenter: The paper is presented by Philip Lloyd.