SOUTH AFRICA'S DIMINISHING COAL RESERVES

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ABSTRACT

South Africa's coal reserves have been significantly reduced since 2003 and a re-assessment based on the complete statistical history of production from southern Africa has indicated that the present remaining reserve for the entire subcontinent comprises only about 15 billion tonnes or gigatonnes (Gt). South African coal geologists should therefore be mindful of experience in Britain, where reserves were grossly overestimated by conventional techniques and remained a large multiple of future production until very shortly before the effective collapse of the industry in the 1980s. The southern African historical analysis has shown that an impressive leap in coal production occurred between 1975 and 1985, from about 69 million tonnes per year (Mt/yr) to 179 Mt/yr. By 1989, the cumulative production had reached 4 Gt. Despite this doubling since to just over 8 Gt, the underlying pattern has been one of faltering growth. Hubbertarian analysis predicts a peak in production rate of about 284 Mt/yr in 2020, at which stage approximately half (12 Gt) of the total resource (23 Gt) will be exhausted. The Waterberg Coalfield (Ellisras Basin) in South Africa may be a remaining large resource, but structural complexity, finely interbedded coal-shale strata at large depths, low grades, high ash content and water scarcity are likely to inhibit its major development. Given South Africa's heavy dependence on coal for power generation and electricity supply, an anticipated peak production in 2020 will cause problems for future economic growth.

INTRODUCTION

A recent release of the BP Statistical Review of World Energy 2008[1] contains an item on coal reserves that is of particular interest – South Africa's coal reserve has been reduced by nearly 18 Gt, from 48 Gt in the previous annual review to 30 Gt in the 2008 edition.

Resource assessments in the 1980s by the South African Geological Survey[2,3], now the Council for Geosciences, provided the basis of the previous BP figure and the US Department of Energy estimate in 2008 that South Africa has the world's sixth largest recoverable coal reserves at 49 Gt.[4] In the early 2000s, however, following the issue in March 2000 of the first version of a new codification of mineral resource and reserve reporting by the South African Mineral Resource Committee (the 'SAMREC Code')[5], the Minerals Bureau (subsequently the Mineral Economics Directorate of the government Department of Minerals and Energy or DME), began a re-assessment of the coal resource and reserve estimates.[6]

Between 2003 and 2004, the DME substantially reduced South Africa's coal reserve from about 50 Gt to about 31 Gt,[6] lowering it (albeit temporarily) even further to 26 Gt in 2005. The 'official authoritative reference work on the Republic of South Africa', the South African Yearbook 2007/2008,[7] provides a coal reserve for 2006 of 31 Gt,[7] for eighth rank in the world, whereas editions prior to 2004/2005 provided coal reserve estimates of 55 Gt.

The most recent DME review[8] for 2007 cites the BP Statistical Review for its country rankings of world coal reserves, except for South Africa, for which the higher BP figure is replaced by a new estimate of 28 Gt.[8] In its explanatory notes, following SAMREC principles,[5] the DME observes that a mineral reserve refers to:

> [T]*he economically mineable material derived from a measured and indicated mineral resource. It includes diluting materials and allows for losses that are expected to occur when the material is mined. Appropriate assessment to a minimum of pre-feasibility study for a project or a Life of Mine Plan for an operation, must have been carried out, including consideration of, and modification by, realistically assumed mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors.*[8]

The BP global review 2008[1] thus provides belated recognition of the South African re-assessment since 2003. A question remains, however, about the completeness and rigour of the current re-assessment. Rutledge[9] has recently provided an estimate of only 23 Gt for the full recoverable cumulative coal resource in the African continent (effectively South Africa, Botswana and Zimbabwe), of which about 8 Gt was already consumed by production to end-2007. The implication that the present remaining reserve of African coal is only about 15 Gt deserves closer scrutiny.

APPLICATION OF THE HUBBERT FRAMEWORK TO AFRICAN COAL

In the introduction to his seminal paper on the future of fossil fuels, M. King Hubbert[10] drew an analogy between the voyages of geographical discovery in the 16th century and the evolution of our knowledge of petroleum in the 20th century:

> *Then, as now, a voyager starting out on a major expedition of discovery needed to equip himself with charts of two kinds. He needed the large-scale detailed charts for piloting along known shores, and the comprehensive charts of whole oceans, or of the known world, as a guide for his major navigations.*[10]

After a brief summary of progress to date, he remarked as follows:

> *To continue the navigation analogy, what we seem to have achieved is an abundance of detailed charts of local areas, with only an occasional attempt to construct, shall we say, a map of the whole world which, despite its inherent imperfections, is still necessary if we are to have even an approximate idea of where we are now,*
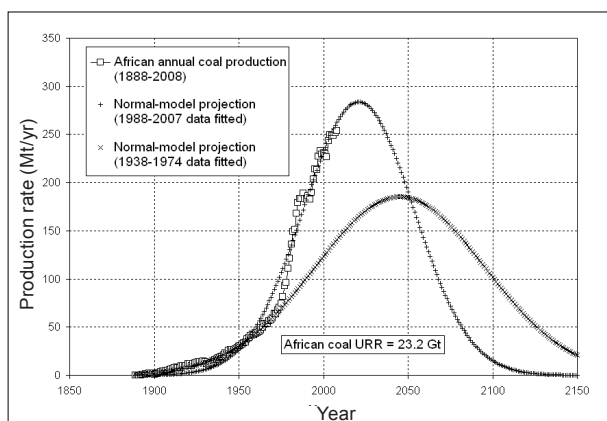
Source: Rutledge[9]
URR, ultimate recoverable resource

FIGURE 1
Annual production of African coal (i.e. South Africa, Botswana and Zimbabwe
production) with normal distribution models for early-stage (1938–1974)
and late-stage (1988–2007) data

*and where we are going. The object of this discourse will be to see
what can be done in this direction with the information presently
available.*[10]

Hubbert's distinctive achievement was to establish a general
intellectual framework for quantitatively analysing the
production history of exhaustible resources and providing
long-term forecasts of their future evolution, beginning with
the recognition that: 'No better record exists of the history of the
exploitation of the fossil fuels than the annual statistics of their
production'.[10]

In southern Africa, the production of the main fossil fuel – coal –
commenced in 1880 and a database of its annual and cumulative
production has been assembled from historical sources.[9] The
annual production curve shows an exponential growth from
less than 20 Mt/yr prior to World War II to over 250 Mt in 2007
(Figure 1). During the Great Depression, annual production
declined from 15 Mt in 1929 to 11 Mt in 1932, but otherwise
the pattern in the early years is generally one of uninterrupted
growth.

A marked increase in the rate of production occurred after
1974 in South Africa and subsequently dominated the African
production data when the apartheid regime was subjected
to international sanctions and boycott action. This external
pressure caused the state-owned petrochemical corporation,
Sasol, to build two large coal-to-liquid plants in 1980 and
1982. Construction of the 3600 MW Duvha Power Station by
the state-owned electricity supply commission, Eskom, began
in 1975, based on the largest opencast colliery in the southern
hemisphere. Beginning in 1982, Eskom also commenced
construction of the world's currently largest (4116 MW) coal-
fired power station at Kendal in Mpumalanga province. In the
course of just one decade, African annual coal production leaped
from 69 Mt in 1975 to 179 Mt in 1985.

By 1989 the cumulative production of African (predominantly
South African) coal had reached 4 Gt. During the two decades
since then, cumulative production has doubled again to just over
8 Gt (Figure 2). Despite this impressive doubling of cumulative
production, the underlying pattern has actually been one of
faltering growth; as can be seen in Figure 2, there were periods
of relative stagnation in production between 1986 and 1992 and
between 1997 and 2002.

The actual decline from 1986 to 2007 is best demonstrated in a
Deffeyes plot',[11] which shows the growth rate for cumulative
production (i.e. the ratio between production and cumulative
production expressed as a percentage) against cumulative
production (Figure 3). In 1985, the ratio peaked at 5.6%, having

risen spectacularly from 3.9% in 1975. By 1992 it had decreased
to 4.1% and, with brief intervals of reversal, has since declined
further to 3.4% in 2007.

The Deffeyes plot is important because it illustrates graphically
the rate of decline of a finite resource and also provides a statistical
method for extrapolation towards its ultimate exhaustion. In one
ideal model of cumulative growth, a linear relationship between
cumulative growth and cumulative production is an expression
of the S-shaped logistic curve, first elaborated by the statistician
Pierre Verhulst in 1838 in connection with population growth
studies. A straightforward linear extrapolation (Hubbert
linearisation) of the 1988–2007 data to 0% growth rate predicts
an ultimate recoverable resource (URR) of about 17 Mt only
(represented by the long dashed line in Figure 3).

Other bell-shaped distributions of production rate, such as the
Gaussian or normal distribution, first introduced by de Moivre
in 1733, can also generate an S-shaped growth pattern in a
cumulative plot (as seen in Figure 2). Real-world quantities are
often the balanced sum of many unobserved random events
and the central limit theorem provides a partial explanation
for the prevalence of the normal probability distribution. Thus,
provided there is reason to suspect the additive and independent
action of a large number of small effects on the observed rate of
coal production, it is reasonable to assume that rate observations
will be normally distributed in time.

The pre-boycott southern African coal data for 1938–1975
(Figure 3) are indeed well fitted by a normal distribution with
a 50-year standard deviation,[9] centred about a peak of 185 Mt in
the year 2045 and summing to 23 Gt URR (Figures 1 and 3). In
the Deffeyes plot (Figure 3), the projected normal curve fitted to
the 1938–1975 data is concave upward (flattening) below the 8 Gt
cumulative, is approximately linear in the 8 Gt – 16 Gt interval,
and becomes slightly convex upward (steepening) beyond 16 Gt.

A normal distribution fitted to the 1988–2007 production data
peaks at 184 Mt/yr in 2020 with a 33-year standard deviation
(Figures 1 and 3)[9] and projects to the same URR of 23 Gt
(Figure 3). The 1988–2007 growth-rate model predicts that the
southern African coal resource will be 90% exhausted (about
21 Gt cumulative) by 2062, whereas the model based on the
1938–1974 growth rates projects 90% exhaustion only in 2109 for
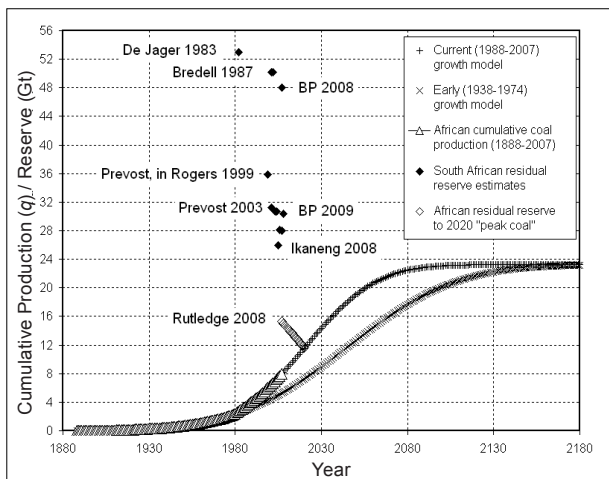the same URR. At present the subcontinent's coal is only 35%
exhausted.

PRECEDENT OF BRITISH COAL

For the two major fossil-fuel regions with substantial exhaustion,
namely US oil and British coal, Rutledge[9] shows that normal
and logistic curves fitted to the cumulative production for these
regions give reasonably stable projections for total production
or URR, past and future. For world coal, the sum of the fits for
regional ultimate production is 660 Gt, which is considerably less
than the 1100 Gt sum of cumulative production and reserves.

The 19th century Hubbert of British coal was the economist
William Stanley Jevons[12], who – in contrast to some 21st century
economists *vis-à-vis* contemporary earth science – was clearly
respectful of geological opinion:

*Geologists of eminence, acquainted with the contents of our strata,
and accustomed, in the study of their great science, to look over
long periods of time with judgment and enlightenment, were
long ago painfully struck by the essentially limited nature of our
main wealth. And though others have been found to reassure the
public, roundly asserting that all anticipations of exhaustion are
groundless and absurd, and 'may be deferred for an indefinite
period,' yet misgivings have constantly recurred to those really
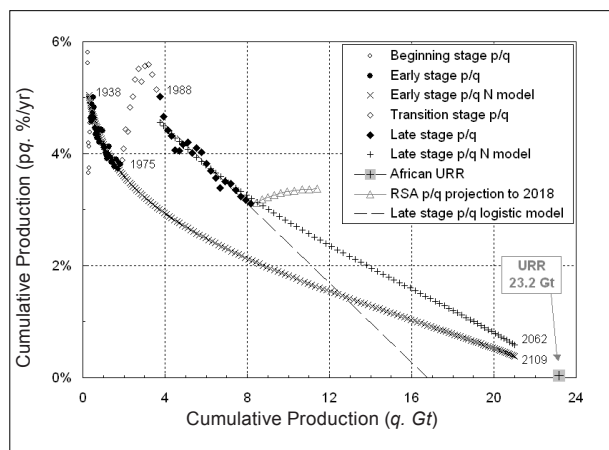examining the question.*[12]

Already in the mid-1860s, when there were more than 3000
British coal mines, Jevons correctly predicted that even
though the reserves-to-production ratio was about 1000
years, exponential growth would exhaust reserves in the 20th
century.[12] In fact, British coal production peaked at 292 Mt/yr

FIGURE 2
Cumulative production (*q*) curve for African coal with early-stage (1938−1974) and current or late-stage (1988−2007) growth models based on the same ultimate recoverable resource of 23.2 Gt

Source: Rutledge[9]

FIGURE 3
Deffeyes plot showing the ratio (*p/q*) of annual rate of production (*p*, %/year) to cumulative production (*q*, tonnes) plotted against cumulative production for the four stages of African coal production with the Hubbert linearisation trend line indicating a lower ultimate recoverable resource (URR) of < 17 Gt

Source: Rutledge[9] and BP[1]

in 1913 and declined to only 19 Mt/yr by 2006.[13] A Deffeyes plot for production from 1854 to 2006 using Hubbert linearisation[13] shows a strong trend line with the very first point in 1854 near the line, projecting to a British URR of 27 Gt.

British reserve estimates made at different times prior to 1970 are in the order of 100 Gt. Compared to a plot of remaining production,[13] these estimates are absurdly high, only collapsing near the end of the production cycle. Thus, rather than reserves being an indicator of future production, it appears that the trend of past production is a more reliable predictor of reserves, which were grossly overestimated by conventional techniques throughout most of the production history. This experience in Britain, where until relatively recently reserves were a large multiple of future production, should serve as a salutary warning to South African coal geologists.

SOUTH AFRICA'S PROBLEMATIC COAL RESERVES

In 1999, the President of the South African Institute of Mining and Metallurgy, M.H. Rogers,[14] noted that the 'reserve and resource estimates as they are known at present are not adequate for informed projections on the future of the coal industry', having then recently been downgraded from 55 Gt to 40 Gt. A

DME-commissioned reappraisal of coal resources and reserves, taking

> [C]ognisance of new technologies, the new reserve and resource definitions now being developed by SAMREC and [considering] quantity, quality, location, sterilization and for the first time 'above ground reserves' or coal discards [was] expected to be published in 2002. [14]

The 2007 Survey of Energy Resources of the World Energy Council[15] still tabulates 'proved recoverable reserves' at 48 Gt. It refers, however, to an ongoing re-assessment that, if correct, could reduce this figure to 31 Gt, noting as follows:

> The South African Department of Minerals and Energy has initiated a comprehensive survey to re-evaluate the reserve but no report has yet been issued. No information is available as to the progress of the study. What is clear is that South African reserves require an urgent and comprehensive re-evaluation.[15]

The analysis presented above indicates a southern African URR of only 23 Gt (compared to that shown in Figure 3), of which approximately 8 Gt has already been extracted to 2008 (Figure 2). The remainder or residual reserve for southern Africa is thus only 15 Gt, or about half the current unofficial estimate for South Africa alone. The central Karoo Basin, covering South Africa and Lesotho, has been the traditional centre of coal production for over a century. In 1999, the Witbank, Highveld, Ermelo and Sasolburg-Vereeniging Coalfields, which are close to major South African industrial centres and are favourably located with respect to the Richards Bay coal line and harbour, still contained the bulk of the mineable reserves.[14] The focus of significant exploration attention has now moved to the peripheral basins of Karoo age in the northern part of South Africa, Mozambique, Botswana, Zimbabwe and Namibia.

In South Africa, the Waterberg Coalfield,[16] formerly estimated at about 14 Gt[3,14] but re-assessed prior to 1999 to be 6 Gt,[14] was regarded as the 'remaining large, virtually unmined, resource […] [but] remote from port access and most of the country's industries'[14]. It currently contains only one active colliery, the open-cast Grootegeluk Mine, which was initiated in 1974–1975, officially opened in April 1981, and became fully operational in March 1982. Eskom's air-cooled Matimba Power Station (3990 MW) was constructed near the mine, and was officially opened in November 1989.

According to Jeffrey,[16] the Grootegeluk Mine had reserves of 442 Mt and a total resource of 3 Gt in 2005. In 2007, for the Waterberg Coalfield (geologically the Ellisras Basin) as a whole, Prevost[17] gave an estimate of 11% out of a total reserve of about 28 Gt for South Africa, which amounts to about 3 Gt. The Grootegeluk Mine will be the sole supplier of coal to Eskom's new power station, Medupi, which is due for completion in 2015.

The Ellisras Basin is still considered extremely important to South Africa because, according to some informal estimates, it may contain more than 50% of South Africa's remaining coal reserves. It is, however, relatively underexplored compared to the Witbank and Highveld Coalfields, and characterised by complex structural geology. A recent airborne geophysical survey has shown that the basin has undergone much more structural disturbance than was previously suspected.[18] A large number of faults occur throughout the basin and subdivide the deposit into distinct blocks. Many faults lack significant magnetic signatures and further ground-based geophysical surveys may be necessary to detect them and thus infer displacement of deeper coal layers.

Because of this structural complexity, the large depths (250 m – 400 m) in most parts of the basin, and the width (about 60 m) and finely interbedded nature of the Grootegeluk Formation, insurmountable problems regarding roof support and spontaneous combustion of the remaining strata preclude selective conventional underground mining. Furthermore, the generally low grade of the coals, high ash content and low yields

are a significant stumbling block to major development of the Waterberg Coalfield and cast doubt on its financial feasibility.[16]

Mining, beneficiation and processing require large volumes of water, but both surface and groundwater are scarce in this area. It is also unlikely that there is a sufficient shallow groundwater resource to increase the existing supply and a potential deep aquifer is unexplored. Any mining development will have to have adequate security of water supply, ensure that the scarce groundwater resource is well protected and that pollution of aquifers does not occur. Even the less conventional extractive technologies, such as underground coal gasification, may be severely limited by the lack of an adequate water resource.[16]

In order to surmount the water-supply constraints, the Department of Water Affairs is promoting the Mokolo and Crocodile River (West) Augmentation Project, the second phase of which involves the construction of a large-diameter pipeline from the Crocodile River near Thabazimbi in the Limpopo province to convey water to the Lephalale area at a planned full capacity of 169 billion litres per annum by 2025.[19] Whether this transfer scheme is ecologically sustainable in the longer term remains to be answered during the upcoming stage of Environmental Impact Assessment. Whether it is economically viable in view of the continuing large uncertainty regarding quantification of the coal resource in the region, may be even more pertinent at this stage.

A combination of unfavourable geological, hydrometeorological, technical and socio-economic factors appears to militate against the existence of large recoverable reserves in the Waterberg Coalfield. Conservative estimates that place the reserve within the 3 Gt – 6 Gt range,[14,16,17] i.e. 20% – 40% of the remaining 15 Gt reserve for southern Africa (Figure 3),[9] are likely to be vindicated in future over those estimates which put it in the 10 Gt – 14 Gt range.[3]

IMPLICATIONS OF DECLINING PEAK COAL PRODUCTION RATES

The current application of the Hubbert method to southern African coal forecasts a peak in production rate at about 284 Mt/yr in 2020 (Figure 1),[9] at which stage approximately half (12 Gt) of the economically recoverable resource (about 23 Gt) will be exhausted. Thereafter, the annual production rate will decline. It is notable that the 1976–1987 transitional interval of the production history produced no addition to the URR, but merely sharpened the normal distribution (the standard deviation was reduced to 33 years from 50 years) and brought forward the model date of peak coal production from 2045 to 2020.

Since 2003 official estimates for South Africa have dramatically reduced its coal reserves from ~48 Gt to ~30 Gt (Figure 2). The current analysis[9] suggests that a further reduction to a value of less than 15 Gt may be anticipated in a re-assessment based on strict SAMREC definitions.[5] How will such a severe reduction in the South African reserve base affect the economy of the country?

In South Africa, the approach to 'peak coal', i.e. the date at which annual production reaches a culmination or zenith, was implicitly recognised by Prevost[6] in a prescient 2003 review:

The South African coal industry is rapidly approaching a stage of stagnation, mainly due to a lack of re-investment by the main producers. Our industry has therefore recently not been able to raise its production. On the contrary, we are steadily decreasing output and exports … The year 2020 is the 'target' date by when we will know if the local coal industry will survive or not. Around this time, most of the large collieries with an output of more than 10 million tons per year will close down or their reserves will be near exhaustion. If by then the industry has not been re-structured to generate more small mines with lesser output, it will be too late.[6]

Given South Africa's heavy dependence on coal for power generation and electricity supply, the economic situation appears to be heading rapidly towards a state of severe permanent crisis, which will be exacerbated by the anticipated low level of coal production at peak in 2020.

Emissions from energy supply and use (exclusive of transport emissions) account for over 70% of South Africa's total greenhouse gas (GHG) emissions. Since July 2008, official government policy dictates that 'GHG emissions must peak, plateau and decline […]. This means it must stop growing at the latest by 2020–2025, stabilise for up to ten years and then decline in absolute terms'[20]. The predicted appearance of southern African peak coal in 2020 (Figure 1) is therefore good news for climate change adaptation. In terms of the normal model prediction, and solely due to the natural limits of the resource, coal production will decline to the present-day rate of 250 Mt/yr by 2037 and will decrease below 200 Mt/yr by 2050. By 2062–2063, when the resource is 90% exhausted (Figure 3), the production rate will be 125 Mt/yr, the level last seen between 1980 and 1981.

However, this good news for the global and local environment is potentially shocking news for future economic development. Most of the industrial world's institutions – its social organisation, legal system and financial structures – have evolved during the late 19th and 20th centuries, all in an atmosphere of continued exponential growth fuelled mainly by fossil carbon and hydrocarbon resources. The world, including southern Africa, is now entering a stage where the restraints on the phenomenon of exponential growth have become obvious for all to see in the form of overcrowding, resource exhaustion and environmental degradation, but its exponential-growth culture is ill-adapted to deal with the problems of nongrowth.

In 1977, Hubbert[21] himself wrote:

In the face of this impending cultural crisis, if a major catastrophic solution is to be avoided, it is imperative that the predicament the world has reached be understood. Only with such prior understanding are rational actions compatible with the facts likely to be undertaken. Therein lies the challenge to geologists. The knowledge essential to competent intellectual leadership in the impending difficult situation is preeminently geological – a knowledge of the earth's history and evolution of its organisms, a knowledge of the earth's mineral and energy resources.[21]

ACKNOWLEDGEMENTS

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