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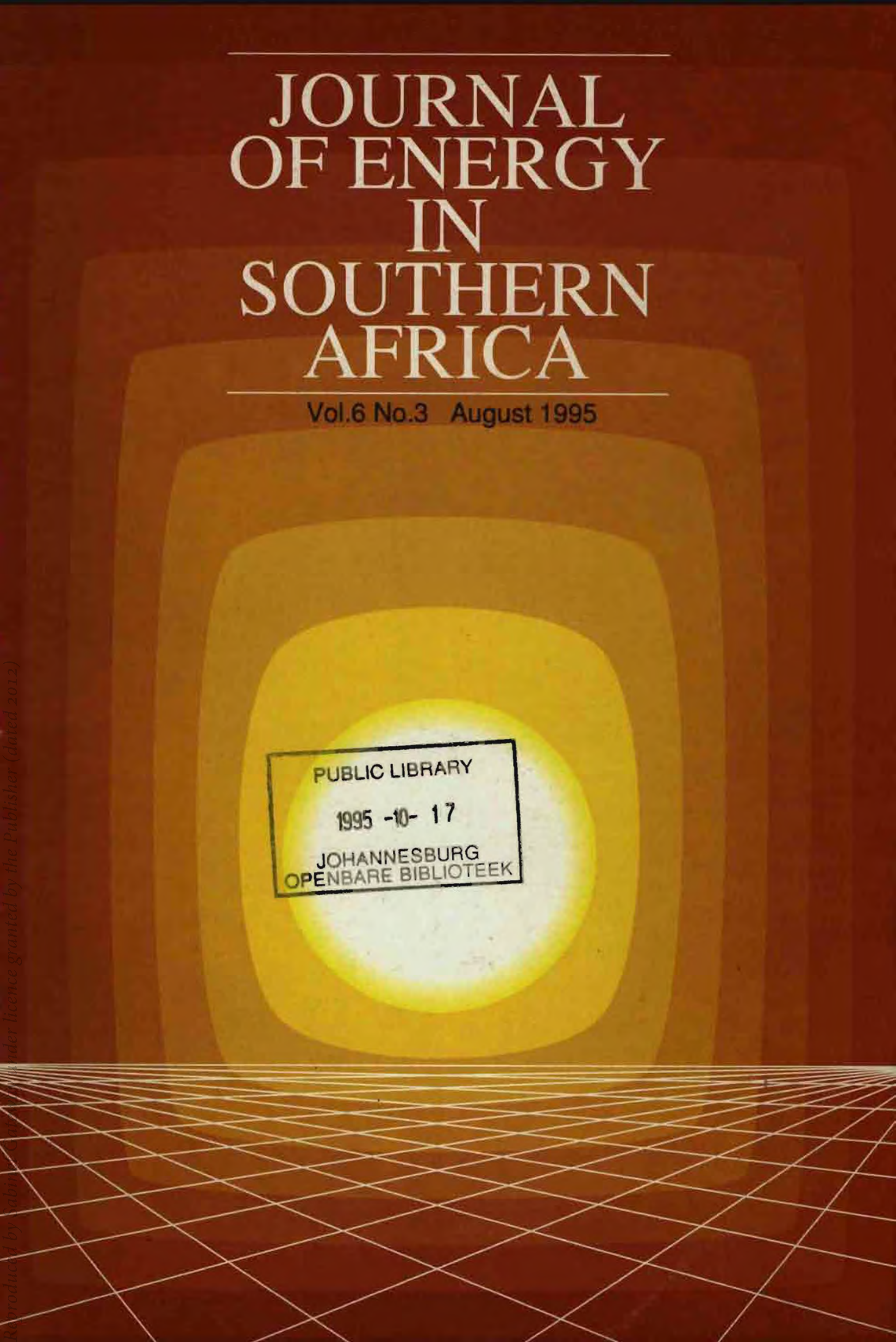

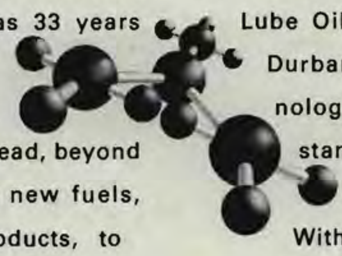

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JOURNAL OF ENERGY IN SOUTHERN AFRICA

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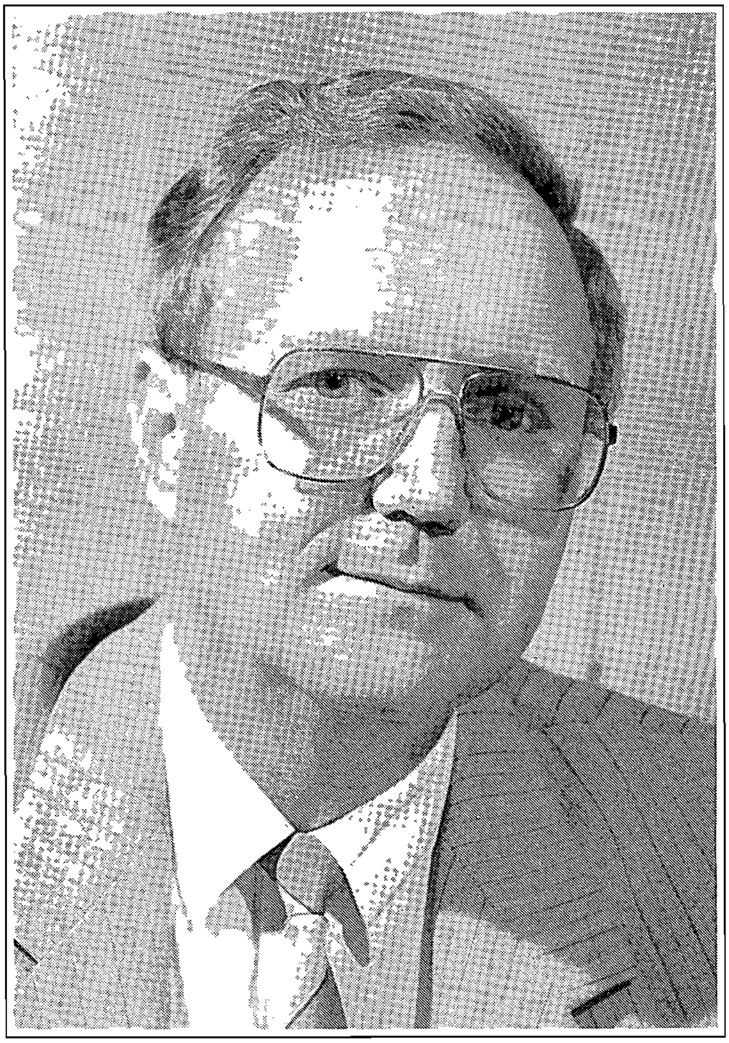
Profile: Waldo Stumpf

Chief Executive Officer, Atomic Energy Corporation of SA Ltd



Waldo Stumpf was born in Vryheid in 1942 and matriculated in 1959 at the Hoërskool Voortrekker in Pietermaritzburg. On completion of his army training, he entered the University of Pretoria in 1961 to study Metallurgical Engineering, with a bursary from the Atomic Energy Board. He was awarded his degree (cum laude) in 1964 and immediately started on his Ph.D. in metallurgy at the University of Sheffield in the U.K. The topic of his thesis was the heat treatment of ferritic chromium steels for which he was awarded his degree in 1968, as well as the Brunton medal by the Senate of the University for this work.

He returned to South Africa and started working for the Atomic Energy Board at Pelindaba on dispersion hardened Zirconium alloys before leaving for Germany in 1969 to join the Institut fur Materialforschung at the Karlsruhe Nuclear Research Centre as a visiting development engineer. This work entailed the development of advanced carbide nuclear fuels for the very extensive German fast breeder reactor programme. In 1971 he returned to Pelindaba and initiated a nuclear fuel development programme within the Department of Physical Metallurgy.

In 1975, he was seconded to the Uranium Enrichment Corporation to initiate a programme on the development of a unique process utilised in the manufacture of the separation element for both the Y plant and Z plant, that is, the pilot enrichment plant and the later semi-commercial enrichment plant. In 1978, he returned to the Nuclear Development Corporation (the former Atomic Energy Board) to manage the planning and construction of a Zircaloy cladding tube manufacturing plant for the fuel element fabrication project, BEVA.

In July 1985, Dr Stumpf was promoted to General Manager of the BEVA project, and in October 1987 to Executive General Manager and member of the Atomic Energy Corporation's (AEC) Management Board with responsibility for fuel fabrication and conversion services. On 1 January 1990 he was promoted to Chief Executive Officer of the AEC and Chairman of the Management Board. In this capacity he was assigned the responsibility by the former State President F W de Klerk, firstly, to manage the dismantlement of South Africa's nuclear weapons programme and secondly, to advise the government on South Africa's accession to the Non-proliferation Treaty, which took place on 10 July 1991, and its entering into a Comprehensive Safeguards Agreement with the International Atomic Energy Agency (IAEA).

Dr Stumpf also introduced a strategic redirection of the AEC in 1990 through the AEC 2000 PLUS PLAN. This has resulted in the AEC reducing its state dependence for operational activities, since 1990, by 71% in real terms through large-scale redirection of the AEC towards commercial projects.

Waldo Stumpf has also published widely on a wide range of topics, such as the strategic redirection of organisations, nuclear non-proliferation, environmental management, the role of technology in the creation of wealth, nuclear power and nuclear technology, global warming and energy options for South Africa. He is honorary president of the South African Institution of Nuclear Engineers, past president of the Pretoria Toast Masters Club, and is also Professor of Metallurgical Engineering at the University of Pretoria on a part-time basis, where he has, since 1968, been teaching a regular post-graduate course on phase transformations in solid systems. He is a member of the S A Akademie vir Wetenskap en Kuns, the S A Institute of Mining and Metallurgy and the Engineering Council of S A. For recreation, he is a keen birdwatcher and is a member of the Northern Transvaal Ornithological Society.

He is married to Hettie and they have two sons (one is an industrial chemist, the other an actuary) and a daughter (a medical student).

Profile: Joggie Heuser

Chief Executive, Soekor

Marthunis Joachim (Joggie) Heuser began working at Soekor as an Administrative Officer on 1 April 1967 and exactly 25 years later, on 1 April 1992, he was appointed Chief Executive of Soekor. A totally different career for a man who's main ambition in life was originally, to become a pilot!

Joggie was born on 5 May 1938 in Bloemfontein. After matriculating in 1955 from the Kroonstad High School, he completed his national service in the South African Air Force. Thereafter he joined what was then known as the Office of the Controller and Auditor-General. He also enrolled at the University of Pretoria as an extra-mural student, obtaining his B.Comm.(Accounting) degree in 1960. He was put in charge of the auditing of the financial records of various state departments. During 1966 he was trained by the Public Service Commission as a work study officer and in this capacity undertook several projects for the Office of the Controller and Auditor-General.

When Joggie Heuser joined Soekor in 1967, he was involved in all the aspects of the company's administration. Coming from outside the specialised field of oil exploration, he had to develop expertise and an understanding of the terminology.

In those early days Soekor was involved in onshore exploration, which included the acquisition of seismic data and the drilling of boreholes onshore. Part of Joggie's responsibility was moving the rigs to different locations and negotiating access diplomatically to properties of landowners who were not always co-operative.

Joggie also had to handle any claims against Soekor for possible damage caused by the company's activities. For this purpose he established the Legal and Contracts Department, and in 1973 he was appointed Head: Contracts Division. In this capacity he travelled the world to negotiate the best possible contracts for Soekor in the very competitive world of the international oil business. These travels were not without incident. For example, in 1977 in Amsterdam, Joggie had the frightening experience of being trapped on the fourth floor of a hotel during a fire. He managed to escape by climbing down the drainpipe. The hotel was razed to the ground in about two hours and several people lost their lives.

In 1982 he was appointed Company Secretary, a portfolio which was extended to include Administrative Manager, and in 1988, General Manager: Administration. In 1992, Joggie was appointed Chief Executive and Chairman of the Technical Board Committee.

During his 28 years with Soekor, he has been involved with all aspects of the oil and gas exploration business. Other than pure oil exploration activities, he was also involved in the commissioning and operation of the Mossgas offshore production platform until October 1993, when this responsibility was transferred to Mossgas. As a result of his experience with Soekor, Joggie has a profound knowledge of upstream oil and gas activities, and has been involved in all the company's commercial aspects.

Since becoming Chief Executive of Soekor, Joggie has managed the company firmly and efficiently, and is greatly respected by his colleagues and subordinates. Under his leadership, the company has been able to concentrate on its core business, namely, exploration and production. This has enabled Soekor to be on the verge of developing South Africa's first offshore oilfield. This oilfield could come into production by the middle of 1996, pending government sanctioning of the project.

Joggie has built up good relations locally and abroad. He is well known and respected in oil circles throughout Africa and abroad, and has presented papers at international oil and gas seminars and congresses.

At home, he is a capable handyman. He enjoys the "great outdoors" and is very fond of animals. He often hunts, but only with a camera. He married Marie (née Roberts) in 1961 and they have two children. His daughter, Renee, is a lawyer and his son, Johan, is a computer programmer.

Uranium resources in South Africa: A review of geology and economics

*L C AINSLIE, *R G HEARD and *B B HAMBLETON-JONES

South African uranium resources are hosted dominantly by quartz-pebble conglomerates with associated gold mineralisation, with the rest being found in sandstones and coal in the Karoo Supergroup. South Africa's known uranium resources, as at 1 January 1993, stand at 297 900 tonnes U, but in terms of economic viability in the current market situation they are substantially lower.

Uranium production in South Africa is at present inextricably linked to the gold mining industry, which is in a parlous state, with many mines facing closure if a sustained rise in the gold price does not come about in the near future. Gold production is falling steadily because of the state of the gold market, and uranium is an inevitable casualty.

The dependence of the uranium industry on the unpredictable and volatile gold market is unsatisfactory, and alternative sources of uranium are being sought. Attention has been focused on the Karoo Supergroup which is the only other potentially viable source of uranium outside the Witwatersrand Basin. Factors which were re-examined are the influences of stratigraphy, source areas, tectonics and volcanism on the distribution of uranium.

Uranium mineralisation in the Namaqualand Metamorphic Complex, which has associated monazite ores, is briefly mentioned.

Keywords: uranium; resources; geology; economics

Introduction

Uranium exploration in South Africa commenced in the late 1940s when a world-wide investigation of uranium resources focused attention on the uranium content of the Witwatersrand quartz-pebble conglomerates.

South African uranium production commenced in 1952 when a uranium plant was commissioned at the West Rand Consolidated Mine which exploited the quartz-pebble conglomerates of the Witwatersrand Supergroup. This was closely followed by the commissioning of four more uranium plants at various centres in 1953. Production accelerated until 1959 when 26 mines around the Witwatersrand Basin were feeding 17 uranium plants for a total annual production of 4 954 tonnes U. Production subsequently declined to 2 262 tonnes U in 1965.

Until the early 1970s uranium exploration in South Africa was confined to the Witwatersrand Basin and always played a subordinate role to gold.

In 1971 the Palabora Mining Company became the first non-Witwatersrand uranium producer in South Africa. It produces uranium as a by-product to copper at its open pit mining operation in the Northern Province.

The world oil crisis in the 1970s stimulated interest in uranium as an energy source and caused the uranium price to soar to a peak of \$43,25/lb. U_3O_8 in 1979(11). This stimulated an intensification of exploration activities aimed at uranium as a primary product and resulted in the opening of a mine aimed primarily at uranium production, namely the Beisa Mine in the Free State Goldfields in 1982. Uranium exploration was, for the first time, extended outside the Witwatersrand Basin. The Karoo Basin was the scene of high levels of exploration activity during the 1970s with 10 local and international companies participating. A total of 1 575 kilometres of drilling was completed and resources of about 100 000 tonnes U in all cost categories were identified.

In addition to intensified exploration activities, the South African uranium producers responded to the increased demand for uranium by almost trebling production to 6 143 tonnes U in 1980.

Many decades of mining activities had generated vast tailings deposits around the Witwatersrand Basin which contained substantial reserves of gold and uranium. The boom in the uranium market lead to the establishment of dump reprocessing plants at Welkom (Joint Metallurgical Scheme - 1977), in the East Rand (ERGO - 1978), and at Klerksdorp (Chemwes - 1979).

The collapse of the uranium market in the early 1980s had serious repercussions in the South African uranium industry which has resulted in the closure of 14 uranium plants since 1980. The spot market uranium price fell from over \$40/lb. U_3O_8 in the late 1970s to less than \$10/lb. U_3O_8 in 1989, where it has languished ever since. At the end of 1994 only four mines were producing uranium from five plants.

Uranium resources

In terms of the tonnage contained in various deposit types in South Africa, this country is effectively placed fourth after Australia, Niger and Canada, and holds nearly 10% of the known world's resources, outside those of centrally planned economies (WOCA) resources(13). Some 60% of these resources are contained in the quartz-pebble conglomerates of the Witwatersrand Basin, with most of the rest being found in the sandstones and coal measures of the Karoo Supergroup. A very minor proportion is contributed by the Phalaborwa Alkaline Complex. Table 1 summarises the uranium resources in the Reasonably Assured Resource (RAR) and Estimated Additional Resource - I (EAR-I) categories recoverable at costs less than \$130/kg U.

RESOURCE CATEGORY	COST CATEGORY	
	<\$80/kg U	<\$130/kg U
RAR	146 600	240 800
EAR-I	34 700	57 100
TOTAL	181 300	297 900

Table 1: South African uranium resources (as at 1 January 1993)

Table 2 illustrates the different deposit types in which these resources occur, and Figure 1 shows the distribution of the various deposit types found in South Africa. These resources are presented according to the International Atomic Energy Agency (IAEA) system. Thus each cost category contains all the

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* Atomic Energy Corporation of South Africa Ltd, P O Box 582, Pretoria 0001, South Africa

TYPE OF DEPOSIT	RECOVERABLE RESOURCES (1 000 tonnes U)		NO. OF PRODUCTION CENTRES	
	RAR	EAR-1	Existing & Committed	Planned & Prospective
1. Quartz-pebble conglomerates	145	34	3	–
2. Tailings dumps	22	–	–	–
3. Sandstone	23	8	–	–
4. Coal-hosted	48	9	–	–
5. Surficial	1	–	–	–
6. Carbonatites	2	5	1	–
7. Marine phosphates	–	–	–	–
8. Granites	–	–	–	–

Table 2: RAR and EAR-1 (<$130/kg U) distribution by geologic type (as at 1 January 1993)

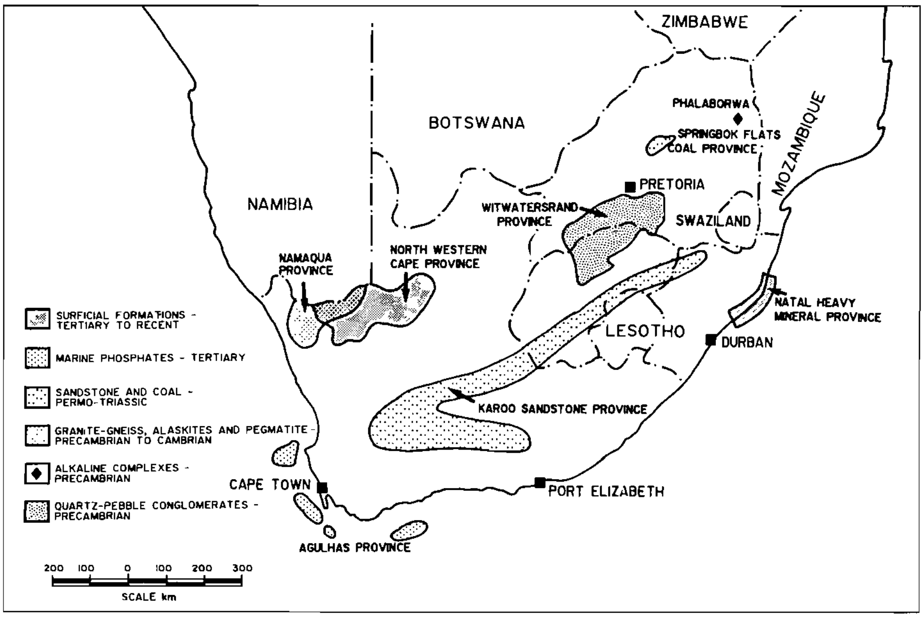

Figure 1: Uranium provinces of South Africa

resources in the lower cost categories, and these are termed the known uranium resources. The IAEA system is described in their biennial publication entitled *Uranium Resources Production and Demand*, the so-called Red Book(13).

South Africa's total known resources as at 1 January 1993 are 297 900 tonnes U. This represents a relatively small drop of 12,7% from the resources reported as at 1 January 1991, but the reduction amounts to a substantial 45,2% when compared with the resources reported at 1 January 1989.

The cost categorisation of resources recoverable at costs less than $130/kg U has been used to maintain conformity with historical reporting procedures, but this obviously has little economic validity in the current state of the uranium market. Only a proportion of these resources are economically viable at present. At the present spot market price of about $20/kg U only about 42 000 tonnes U could be mined profitably. Even at the average long-term contract price of about $40/kg U only 71 000 tonnes U are viable.

In South Africa a number of factors influence the magnitude of uranium resources, the primary ones being the uranium grade, gold price, the dollar/rand exchange rate, and the influence of the national inflation rate on mining and extraction costs. The influence of uranium grade is obvious - the higher the grade the lower the cost/kg U of extracting it. Suffice to say that a large proportion of South African resources are low-grade and would not be viable except for the associated gold mineralisation. Uranium has an ubiquitous, although variable association with gold in the quartz-pebble conglomerates of the Witwatersrand Basin, and is produced as a by-product of the gold. Where the gold grades are economic the uranium can be extracted at relatively low cost, because the mining and milling costs are borne by the gold revenue, and the uranium extraction costs consist only of the metallurgical costs. However, if the gold is not economic, the extraction costs for the uranium become proportionately higher because of the extra mining and milling components. Thus if the gold price falls and parts of the gold reserve become uneconomic, then the associated uranium resources consequently move into higher cost categories, and may not be mined at all.

The viability of gold mineralisation in South Africa is primarily dependent on the working costs of mining, and on the dollar/rand exchange rate, because the gold price is denominated in dollars. The inter-relationship of these factors is shown in Figure 2. It can be seen that the dollar price of gold dropped from the highs of over $600/oz. achieved in 1980, and since 1984 has traded below $400/oz., except for 1987 and 1988(1). From 1987 it dropped steadily to a low of $343/oz. for 1992, and since then it has slowly risen to an average price of $384/oz. For the reasons stated above this would have resulted in a negative effect on South Africa's uranium resources, but this was ameliorated by a rise in the dollar/rand exchange rate which resulted in the rand gold price rising steadily from 1981 to 1988. This was reflected by a concomitant increase in the uranium resources for that period. From 1988 to 1992 the rand gold price has remained relatively static, but in 1993 and 1994 a rapid fall in the value of the rand relative to the dollar has seen a dramatic increase in the rand price of gold. A similar but less dramatic rise in working costs has largely prevented a substantial increase in the profitability of the Witwatersrand gold mines. The rise in rand gold price and working costs has meant that the uranium resources will benefit little from the fall in the rand relative to the dollar.

What has had a marked influence on these resources has been the steady and substantial rise in industry average working costs(2). Since 1988 these have risen by 59,5% while the gold price has remained static in dollar terms, which has had a strongly adverse effect on the uranium resources, by moving the known resources into higher cost categories. A contributory factor was the closing profitability gap for the gold mining industry as a whole which has severely constrained exploration expenditure, thus limiting the addition of newly discovered resources. There are indications that this gap may be widening, which might lead to a mild resurgence in gold exploration.

The uranium industry in South Africa is at present totally reliant on the well-being of the gold mining industry for its survival. A number of gold mines have been threatened with closure in recent years. The cessation of gold recovery operations at a mine would automatically increase the cost of extracting its uranium resources by a substantial amount. Stilfontein and Bracken mines were the first major mines to announce their closure and others may well follow. Many are curtailing operations in order to maintain profitability. Various scenarios have been presented with regard to the future of the gold mines. In 1991, assuming a flat gold price of R950/oz. and considering 47 mines, it was predicted that within three years, one third of the mines would probably close, a further third would have serious difficulties in remaining profitable, while only six of the remaining third would be profitable without having to institute substantial steps to assure their viability(5). In retrospect this prediction was overly pessimistic, but the survival of the mines has only been achieved by the implementation of severe measures and many are still confronted with the possibility of closure.

Figures 3 and 4 show the situation with regard to gold mining costs for 1993 and 1994(2). From Figure 3 it can be seen that at a gold price of R1 175/oz., which was the average price for 1993, four mines operated at a loss in 1993. In 1994 the average gold price was R1 363/oz., and six mines operated at a loss (Figure 4). This is an improvement on the situation in 1992 when twelve mines operated a loss, but there is still reason for concern.

The immediate threat of closure has subsided for many mines because of the rise in the rand gold price, but a significant improvement in the dollar gold price is needed to relieve the pressure on the more marginal mines, and to generate more confidence in their long-term future. If this can be achieved it can be expected that South Africa's uranium resources will increase.

The parlous state of the gold industry and its influence on the future of the uranium industry make it important that other sources of uranium be sought to provide a stable local supply where its viability will not be influenced by the vagaries of a volatile gold market. The most obvious area for investigation is the Karoo Basin and this will be dealt with later.

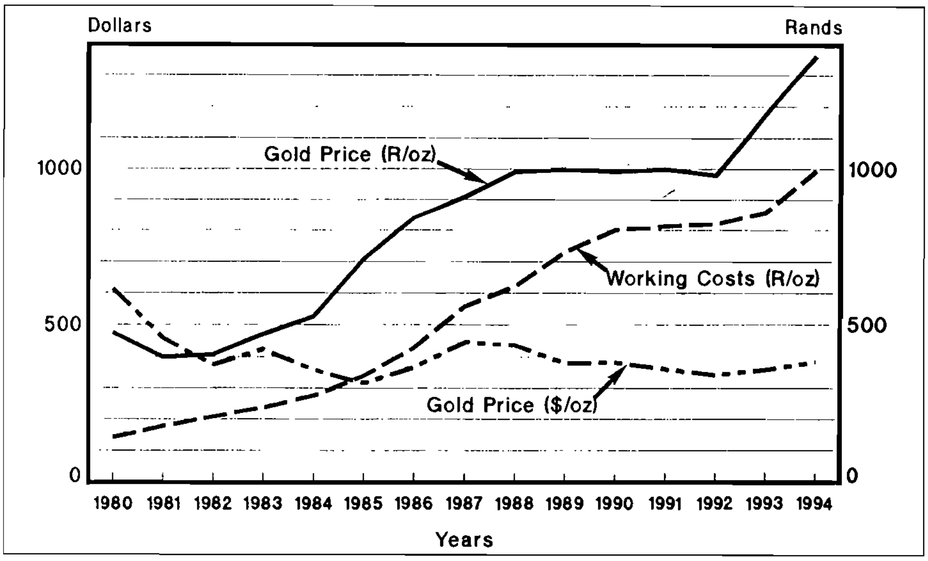

Figure 2: *South African gold mine working costs and gold price*

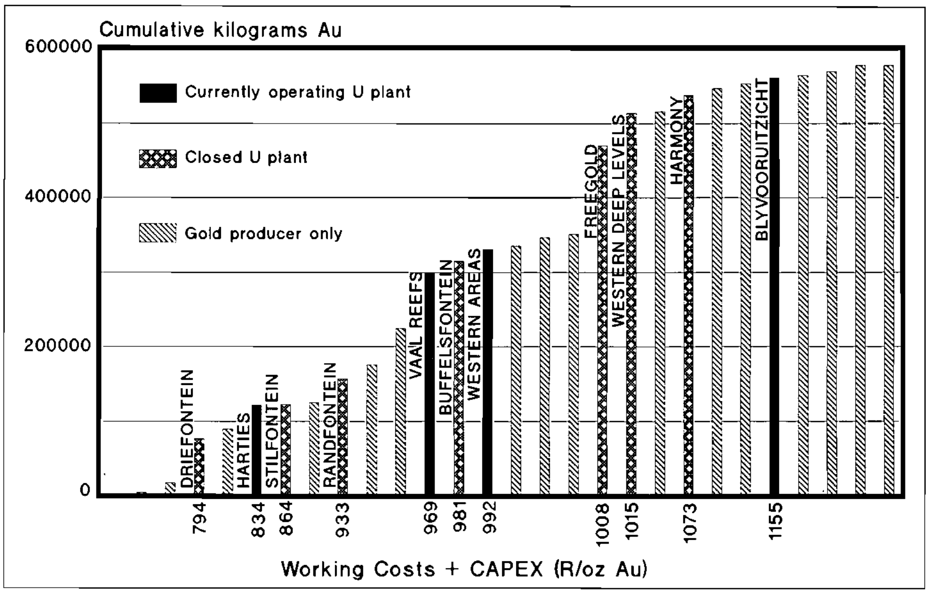

Figure 3: *South African gold production and working costs (+ capex) - 1993*

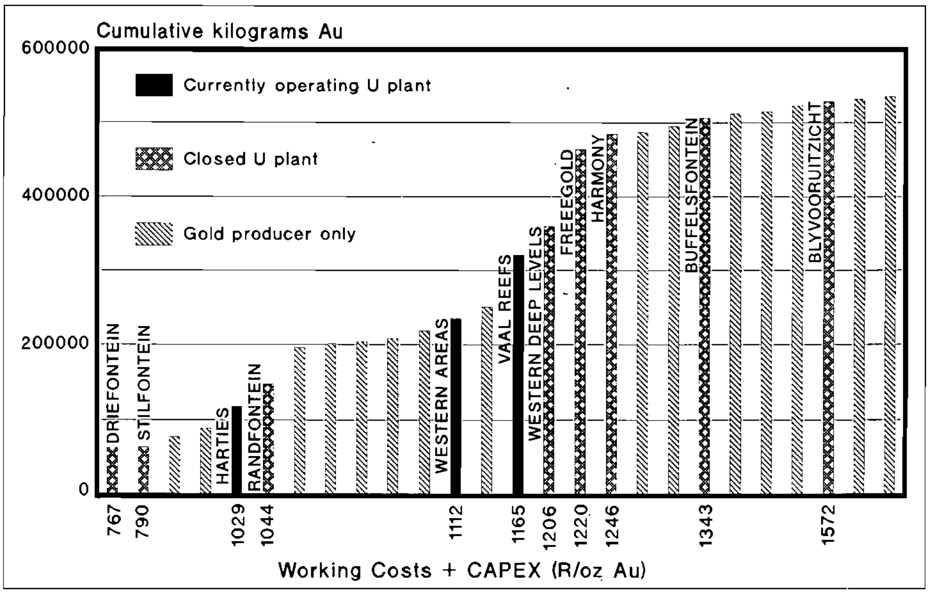

Figure 4: *South African gold production and working costs (+ capex) - 1994*

PRODUCERS	1993 PRODUCTION			1994 PRODUCTION			DIFFERENCE BETWEEN 1993 & 1994	
	U_3O_8 (t)	% of total	Rank	U_3O_8 (t)	% of total	Rank	$U3O_8$ (t)	% change
Hartebeestfontein	329,44	16,42	2	309,74	15,96	2	-19,70	-5,98
Vaal Reefs	1 313,40	65,47	1	1 222,30	62,98	1	-91,10	-6,94
Western Areas	270,09	13,46	3	286,68	14,77	3	16,60	6,14
Palabora	93,04	4,64	4	121,95	6,28	4	28,91	31,07
Total U_3O_8 (t)	2 005,96	100,00		1 940,67	100,00		-65,29	-3,26
Total U (t)	1 699,97			1 644,63			-53,32	

Table 3: South African uranium production 1993 and 1994

Uranium production

South Africa has been a steady and reliable uranium producer since the inception of the industry in 1952, with production levels fluctuating according to the state of the international market and political considerations. The rapid rise in production from the mid-1970s resulted from the world oil crisis, and peaked in 1980. The crash in the uranium price thereafter is reflected by a steady decline in production to current levels of about 1 650 tonnes U. By far the majority is derived as a by-product of gold mining in the Witwatersrand Basin, with only about 120 tonnes coming from Palabora. Table 3 compares South Africa's uranium production for 1993 and 1994 on a mine-by-mine basis.

At the end of 1994 only four mines were producing uranium, namely Hartebeestfontein and Vaal Reefs at Klerksdorp, Western Areas on the West Rand, and Palabora in the Northern Province. All these produce uranium as a by-product, gold being the primary product in the first three, and copper in the last.

Hartebeestfontein has one uranium plant which has the capacity to treat 3 200 000 tonnes of ore per annum. The plant operates on a reverse leach cycle where the uranium is recovered prior to the gold. This improves the liberation of gold and enhances the gold recovery. Since 1991 this plant has operated at a recovery factor of 65% which optimises the recovery costs of the uranium. Losses are made on the production of uranium, but the significant increase in gold recovery as a result of the reverse leach process enhances the overall profitability of the operation.

Vaal Reefs has three uranium plants, one of which is on a care-and-maintenance basis, while a second is operating at 50% capacity. The three plants between them have the capacity to treat 9 000 000 tonnes of ore per annum, but during 1992 only 6 000 000 tonnes of ore were treated. The mine is fortunate in being large enough to have sufficient flexibility to tailor its output to suit the market needs, and it is likely to continue as a major producer in the foreseeable future.

> “The gold and uranium markets have detrimentally influenced South Africa's uranium resources, which have declined steadily over the last six years, resulting in these resources dropping from over 14% to less than 10% of the Western world's uranium resources.”

Western Areas is the richest uranium producer of the Witwatersrand and has one plant which has the capacity to treat 650 000 tonnes of ore per annum. In 1991/92 the mine made a loss on its gold production, but the profits generated by its uranium production have comfortably exceeded those losses and rendered the operation profitable as a whole. In 1993 and 1994 the mine's gold production returned to profitability but uranium production still contributes significantly to the profitability of the mine.

Palabora is a major open pit copper producer which produces uranium as a by-product. The radioactive mineral uranothorianite is first concentrated in a gravity separation plant, along with other heavy minerals, then the uranium is recovered by an acid leach and solvent extraction process. The uranium plant has an annual capacity of 2 000 000 tonnes of gravity concentrate.

Major reductions in production capacity in the Witwatersrand took place prior to 1991/1992, but during this period only one plant closed down, that of Buffelsfontein, resulting in a reduction in production capacity of about 250 tonnes U per annum. It is expected that further reductions in production capability will take place if the gold and uranium markets do not improve, and it is likely that production will decline to about 1 000 tonnes U within the next five years.

Re-examination of alternative uranium resources

In the light of the uranium industry's reliance on the state of the gold market, it may be prudent to re-examine the lower-cost category Karoo uranium deposits which are the only known significant alternative uranium resources outside the Witwatersrand Basin. Evidence of uranium mineralisation in the granitic rocks of the Namaqualand Metamorphic Complex is coming to light, but is of lesser significance. However, it is of interest, particularly where it is associated with rare earth element-bearing monazite ores. Uranium mineralisation is also found in surficial deposits in the north-western Cape, in heavy mineral sands along the Kwazulu/Natal coast and in submarine manganese nodule deposits off the southwestern coastline, but these are too low-grade to warrant any attention in the light of the current uranium market.

Uranium in the Karoo

During the 1970s considerable effort was put into uranium exploration in the main Karoo Basin resulting in the discovery of a total resource of about 100 000 tonnes U, including the high-cost categories. Most of the deposits are small, having a median of 180 tonnes U and an average of 628 tonnes U. There are only two, Kareepoort and Rystkuil, that are in excess of 3 000 tonnes U. Therefore the strategy would be to locate uranium deposits that have tonnages greater than 3 000 tonnes U. Most of the deposits discovered to date are scattered and should they ever be exploited, transport costs will form a major component of the working costs of the mines. In addition, a cursory financial analysis of the smaller deposits shows that the rate of return is quite sensitive to exploration costs, but more sensitive to milling costs(10). The sensitivity analysis also shows that the economic exploitation of the deposits is most sensitive to changes in the uranium price(10). Recent work commissioned by the authors shows that with heap leaching and a small mining scenario, the Karoo deposits could be brought into production within the range of the current long-term contract prices for uranium. More recent sensitivity analyses show that the price of uranium is the most critical variable and that should the price rise above US$50/kg U_3O_8 (US$23/lb.) mining could be marginally positive.

Exploration for Karoo Uranium

The most successful tools applied in the search for uranium in the Karoo Basin have been airborne radiometric surveys and drilling. A major airborne radiometric survey conducted in 1976 by the Geological Survey of South Africa identified hundreds of anomalies. These were classified into high-, medium-, low- and slight-intensity anomalies on the basis of the spectrometer data. The ground follow-up work carried out on the high- and medium-intensity anomalies by the Geological Survey was comprehensively documented by Cole *et al.*(3). It is felt that the majority of deposits which could have been found employing these techniques, have been found and that new deposits will only be found through the application of multidisciplinary geological, geophysical and geohydrological techniques. Wadley and Hoffmann(16) in fact recommend in their paper that future exploration should be directed towards the identification of the depositional conditions most conducive to uranium precipitation, to the identification of those facies associations in which such conditions are best developed and to the location of those facies within the basin. Brynard *et al.*(1) propose an exploration model which they feel will lead to the discovery of additional uranium in the Karoo basin.

GROUP	SUB-GROUP	FORMATION	MEMBER	DOMINANT LITHOLOGY
Beaufort	Adelaide	Teekloof	Steenkampsberg	Red Mudstone
			Oukloof	Sandstone
			Hoedemaker	Mudstone (often red)
			Poortjie	Sandstone
		Abrahamskraal	Moordenaars	Mudstone with stacked sheet sandstones
			Wilgebos	Mudstone
			Koornplaats	Mudstone and yellow weathering sandstones
			Leeuvlei	Mudstones and sheet sandstones
			Combrinkskraal	Sandstone
Waterford Formation (Ecca Group)				

Table 4: Stratigraphic subdivision of the Lower Beaufort in the SW Karoo(5,7)

Stratigraphy

Originally the largest Karoo uranium deposits were considered to be located only in the Poortjie sandstone unit of the Beaufort Group (Adelaide sub-group). Subsequently, it was found that uranium deposits occur throughout the Karoo stratigraphy with the exception of the Dwyka tillite and the Drakensberg lava formations. Recent work in the south-western part of the Karoo basin has placed the Karoo uranium anomalies in their correct stratigraphic position and this will assist in any future uranium exploration. As the selection of target areas and target beds depends on a detailed knowledge of the stratigraphy, a prerequisite for any exploration programme for uranium in the Southern Karoo would be that the units described by Loock *et al.*(9) in the Moordenaarskaroo be traced north-eastwards and eastwards.

The stratigraphic subdivision of the Lower Beaufort is given in Table 4.

Traps

Organic carbon is probably the most important reducing and precipitating agent of uranium in the Karoo Basin(7). It would thus be useful to be able to pin-point where plant material would concentrate in a fluvial system, where it came from and how it entered the river system. This was looked at by Smith(15) who found that lacustrine transgression resulted in plant-rich silt which provided the permeability interface and the local reducing conditions necessary for uranium precipitation. He felt that this would explain why the bulk of the uranium prospects in the southwestern Karoo Basin are confined to relatively narrow stratigraphic intervals of regional extent(15).

Conclusions

The majority of South Africa's resources are found in the quartz-pebble conglomerates of the Witwatersrand Basin, with a significant amount being present in sandstone and coal deposits of the Karoo Supergroup. Other high cost resources are found in other geological environments, but are of little significance because of the poor state of the uranium market. The gold and uranium markets have detrimentally influenced South Africa's uranium resources, which have declined steadily over the last six years, resulting in these resources dropping from over 14% to less than 10% of the Western world's uranium resources.

The Witwatersrand gold deposits are still important uranium producers but spiralling working costs in the gold industry have hampered South Africa's ability to produce uranium economically. Uranium is produced as a by-product to the gold, which allows the mines to tailor their production to suit the market requirements. The converse is that the viability of the uranium resources is closely tied to the state of the gold market, which is not ideal. Potential primary uranium deposits appear to be restricted to the Karoo Basin at present, and these have been investigated to assess their economic viability. The poor uranium market prevents their exploitation, but improved market conditions will change this picture. A recent investigation of the sandstone deposits of the Karoo was aimed at clarifying the mineralisation controls to aid the identification of further deposits in this environment.

South Africa has been an important participant in the international uranium market since its inception, but politics, economics and the poor state of the uranium and gold markets have resulted in this importance waning in recent years. The political isolation of South Africa ceased at the last elections (1994), but the economic and market factors need to improve to allow South Africa to increase its stature in the world uranium market.

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Modelling the air pollution impact from the energy usage in the Greater Cape Town region

*D A DRACOULIDES

The energy usage in the Greater Cape Town (GCT) region was estimated from the fuel consumption in each magisterial district. The sulphur dioxide (SO_2), nitrogen oxides (NO_x) and particulate matter emitted from this consumption was calculated for each of the industrial, domestic, vehicular, township and aviation sectors. Although the industrial sector consumes 37% of the energy of the fuel consumption, it accounts for 90% and 79% respectively of the total SO_2 and particulate matter emitted in the GCT area. Vehicles account for 64% of the total NO_x emitted. The EPA-approved ISC2 multiple source Gaussian model was applied to SO_2 emission data, in order to estimate the impact on the ground-level concentrations. Its performance was evaluated at three monitoring sites in the area and under different meteorological conditions, over a selected period of days, for the years 1991 and 1992. It was found that, for the selected periods, the 01:00 and 24:00 predicted concentrations were in good agreement with the observations at the Bellville monitoring station. At Goodwood and Cape Town's central business district (CBD) the model under-estimated by a factor of two and four respectively. However, when the maximum predicted and observed concentrations, irrespective of the time of occurrence during the day, were examined, the model performance was within the acceptable accuracy limits at both the Bellville and Goodwood sites. Segregation of the data according to atmospheric conditions revealed poor model performance under very stable conditions (classes: E and F) and low wind speeds (less than 3 m s^{-1}). Further, the analyses suggested that improvement in the ISC2's performance may be obtained through a better characterisation of the area source emissions within the region.

Keywords: Cape Town; emissions; energy consumption; dispersion modelling; ISC

Introduction

Energy conversion and, in particular, fuel combustion is the major contributor to air pollution. The degradation of air quality in the modern metropolitan areas has dictated the need to regulate the environmental effects of energy usage. The Atmospheric Pollution Prevention Act No.45 of 1965 assisted in setting the basis for air pollution control policies in South Africa. In Cape Town, the initiation of an air pollution control programme in 1968 resulted in great improvement in the measured concentrations(1). Some of the main and least expensive tools for the development of air pollution control policies are computer simulation dispersion models. They provide the capability of assessing the pollution impact from possible additional sources or worst scenario situations. In this way, several air pollution control strategies can be tested. Thus the strategy which best improves air quality and is most cost-effective can be chosen.

Unfortunately, air pollution has many sources, such as tyre burning, grass fires, backgarden fires, spray painting, etc. which are difficult to quantify. There is a vast variety of primary and secondary air pollutants, such as carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), hydrocarbons, particulate matter, wind-blown dust, resuspended road dust, ozone, peroxyacetyl nitrate (PAN), and many others. Therefore, the approach towards the improvement of air quality is a rather complex process. To date, there are no available emission records for the Western Cape or the Greater Cape Town region detailed enough to be used for dispersion modelling. The Brown Haze pilot study carried out by the Energy Research Institute in 1992 could not provide the appropriate information for a dispersion study, since it was based on source apportionment and receptor modelling.

For the Cape Town air pollution modelling study it was decided, firstly, to compile an emissions inventory database, which could provide the emission input to a dispersion model, and secondly, to utilise sulphur dioxide (SO_2) measurements readily available from the Cape Town City Council's Scientific Services Branch, in order to evaluate the model's predictions.

This paper describes the required stages for the application of a dispersion model, in order to determine the air pollution impact from the energy usage in the Greater Cape Town (GCT) area. The chosen model for this study is the EPA-approved Industrial Source Complex 2 (ISC2). Due allowance has to be made for the topographical complexity of the region and the model is accepted as being applicable to certain areas under given meteorological conditions. The model's accuracy was assessed with the use of available hourly SO_2 concentrations, at three monitoring stations in the area and under different meteorological conditions. Figure 1 illustrates the urban and main industrial areas of the Greater Cape Town region, as well as the locations of the three monitoring stations at Bellville (S1), Cape Town's CBD (S2) and Goodwood (S3).

Energy consumption in the Greater Cape Town region

The energy usage, as well as the emissions from pollutants in the GCT region, were based on the fuel consumption in each magisterial district. Accurate allocation of the fuel usage is essential to dispersion modelling. Therefore, the collection and compilation of a comprehensive emission inventory formed a considerable part of this study. Available figures of fuel consumed by the residential sector of the GCT region included the fuel consumption of the townships. The contribution of different types of fuel to the domestic energy demand is very different in the townships, as opposed to the fully electrified urban areas(2). Therefore, in order to allocate the urban domestic fuel according to urban population densities, the township consumption was first subtracted from total residential consumption. The fuel usage of all the large industries in the area was calculated with

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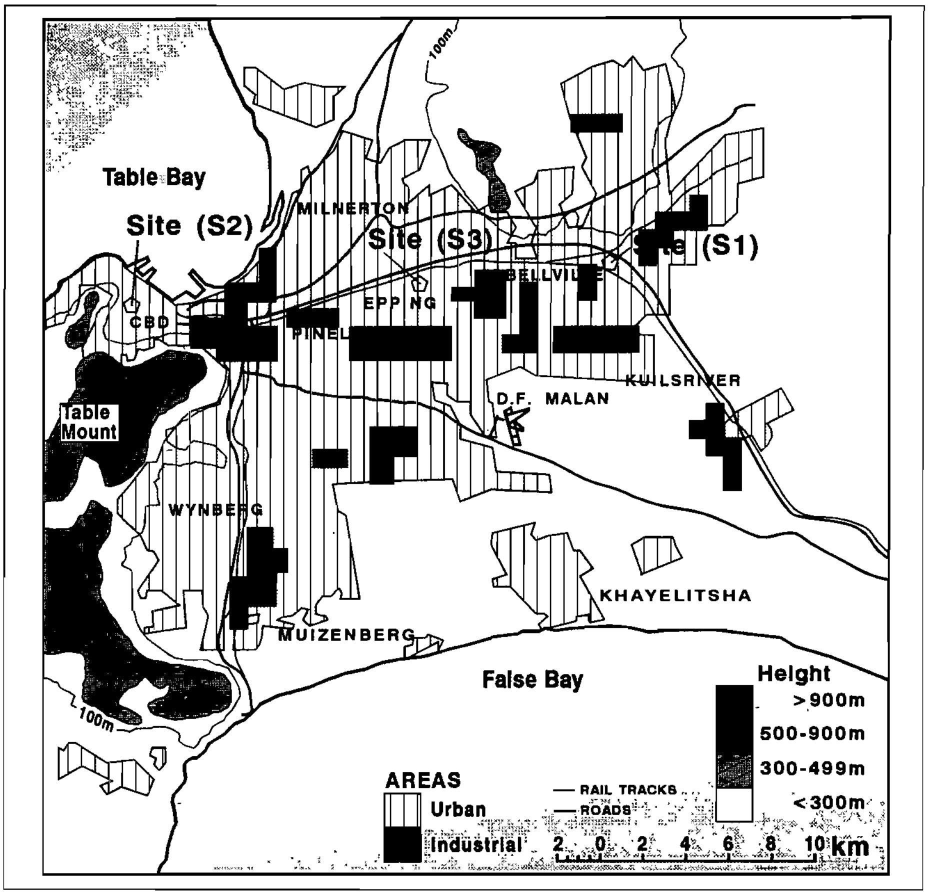

Figure 1: *The Greater Cape Town (GCT) region with the main urban and industrial areas. The three monitoring stations are situated at Bellville (S1), Cape Town's CBD (S2) and Goodwood (S3)*

the assistance of the Cape Town City Council's Air Pollution Control Division and the Air Pollution Group of the Western Cape Regional Services. A database code was developed for the information storage and the emission calculations from each industry. This database is currently being used by the Cape Town City Council's Air Pollution Control Division and can provide up-to-date information on the SO_2, NO_x and particulate matter emissions of the industrial and commercial sectors in the Cape Town area.

Table 1 shows the percentage of energy consumed by the four sectors: industrial, domestic, vehicular and that of the townships. The energy usage in the Greater Cape Town region was based on the monthly fuel consumption averages utilising the calorific values shown in Appendix A.

	SECTOR				
	INDUSTRIAL	DOMESTIC	VEHICULAR	TOWNSHIPS	TOTAL
Coal	–	–	–	–	–
Diesel	13,7	–	6,6	–	20,3
HFO	14,5	–	–	–	14,5
Petrol	–	–	51,7	–	51,7
Gas	8,5	2,3	–	0,3	11,1
Paraffin	–	0,4	–	1,9	2,3
Wood	–	–	–	–	–
TOTAL	36,7	2,8	58,3	2,2	100

* Energy usage is based on the 1991 fuel consumption.
The dash denotes a value lower than 0,1%

Table 1: *Energy usage in the Greater Cape Town region as a percentage of the total consumption*

The industrial sector consumes only 37% of the total energy of the region, whilst its contribution to the actual pollutant emissions is much greater, as will be discussed in the following section. Vehicles consume 58% of the total energy, of which 89% is derived from petrol consumption. Most of the diesel is attributed to industrial usage. Examination of the diesel consumption in the emissions inventory database revealed that approximately 3% is consumed by large industry. Most of the industrial diesel energy is used by small industries and commerce. A detailed allocation of the fuel consumption according to sector, magisterial district and type of fuel, was undertaken(3).

Emissions according to sectors

The air pollution load in the Greater Cape Town region was calculated according to fuel consumption, by applying the appropriate emission factors (see Appendix B). Emissions from the large industrial complexes were obtained from the inventory database described earlier. The remainder of the industrial, residential and vehicular sources were allocated according to industrial activity and population density respectively. Pollutant emissions from Cape Town International Airport were based on the monthly average number of landings and take-offs. Figures 2 and 3 illustrate the spatial distribution of the point and area SO_2 emissions respectively in the GCT region. Similar emission spatial patterns are evident for NO_x and particulate matter in the GCT region(3). A significant factor is the accumulation of strong emitting sources along the east-west axis, following the railway tracks through Maitland, N'Dabeni, Epping and Bellville, and along the north-south tracks through Wynberg, Plumstead and Dieprivier.

The contribution percentages of SO_2, NO_x and particulate matter emitted from the industrial, residential, vehicular and aviation sectors are illustrated in Figure 4. It is evident that the industrial sector accounts for most of the SO_2 and particulate matter emitted in the GCT region. The vehicular and aviation sectors account for 66% of the nitrogen oxides emitted. Even though the energy consumption of the industrial sector is lower than the total energy used by vehicles (see Table 1), industrial SO_2 and particulate matter emissions are higher by a factor of 11 and 4 respectively.

Dispersion modelling

An emissions inventory, irrespective of its accuracy, cannot, on its own, provide a correct representation of the main contributors to the ground-level concentrations. This is due to the fact that the condition of the ambient atmosphere has a strong effect on the transport and diffusion of the pollutants. The Greater Cape Town region is situated in a coastal environment with complicated meteorology as a result of the two opposing sea-land interfaces. In addition to the sea-breeze situation, there is also the effect of Table Mountain which, with a height of 1 000 metres and a sheer face, has a significant effect on the air circulation in its vicinity. In spite of these topographical effects, it is possible to subdivide the area into a number of zones where the classical diffusion equations may be expected to apply. These zones will be effected by the wind direction. Dispersion models combine the emissions with the physical processes of atmospheric diffusion and transport, in order to provide a deterministic source-receptor relationship. In this section an EPA-approved model, the Industrial Source Complex 2 (ISC2) model, is assessed for its accuracy to predict the SO_2 concentrations which result from the energy consumption in the Greater Cape Town region.

The SO_2 point and area emissions, as described in the previous section, were coded and gridded to form the emissions input for the ISC2 model. A total of 187 point and 263 area sources were allocated to the GCT region(3). Meteorological parameters needed for the model runs were collected from Cape Town International Airport. These data included wind direction and velocity, cloud cover, standard level sounding and significant level sounding. However, required parameters, such as the mixing height and the atmospheric stability class, were not readily available and thus needed to be calculated.

Three methods for determining the mixing height and three methods for determining the stability class were used in the model, and the accuracy of each combination was assessed. The methods for the atmospheric stability computation were the Pasquill scheme, the inverse Monin-Obukhov length (1/L) and the Kazanski-Monin parameter ($\mu\sin\phi$). Estimations of the mixing height were made utilising the significant pressure levels obtained twice a day from Cape Town

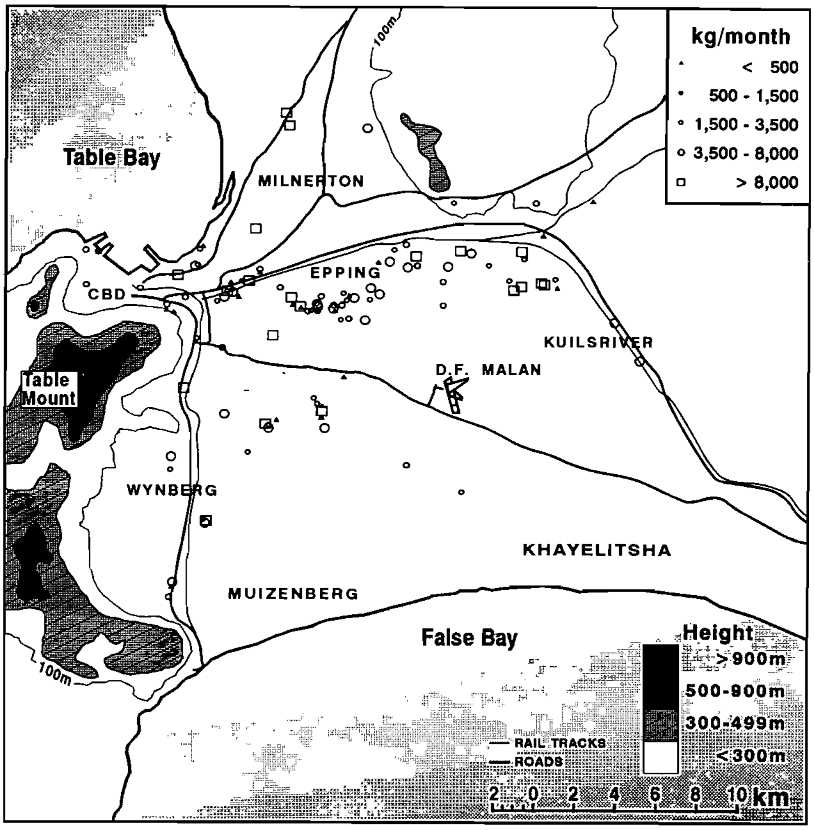

Figure 2: Sulphur dioxide point sources for the Greater Cape Town region

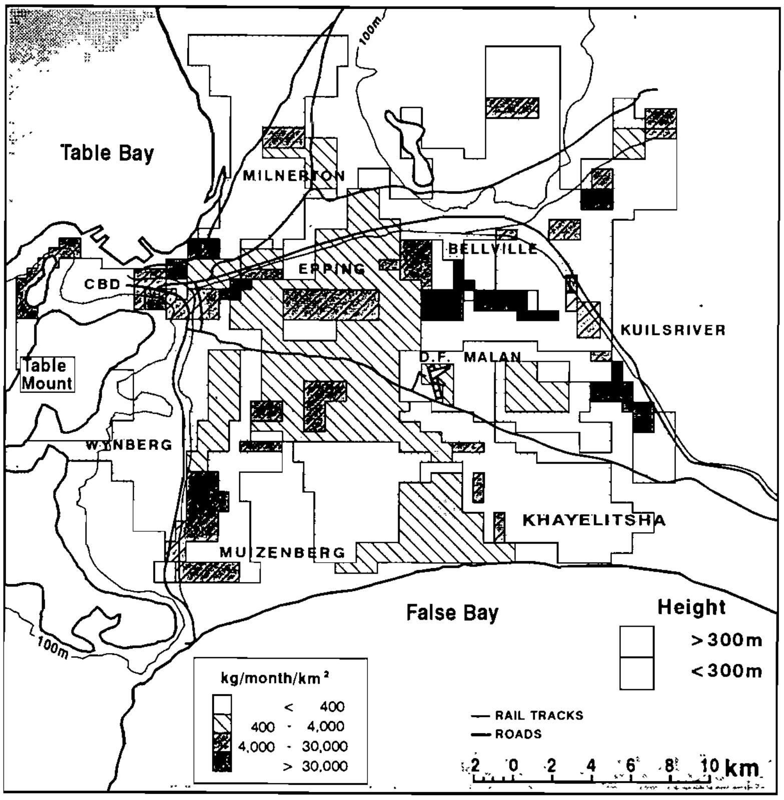

Figure 3: Sulphur dioxide area sources for the Greater Cape Town region

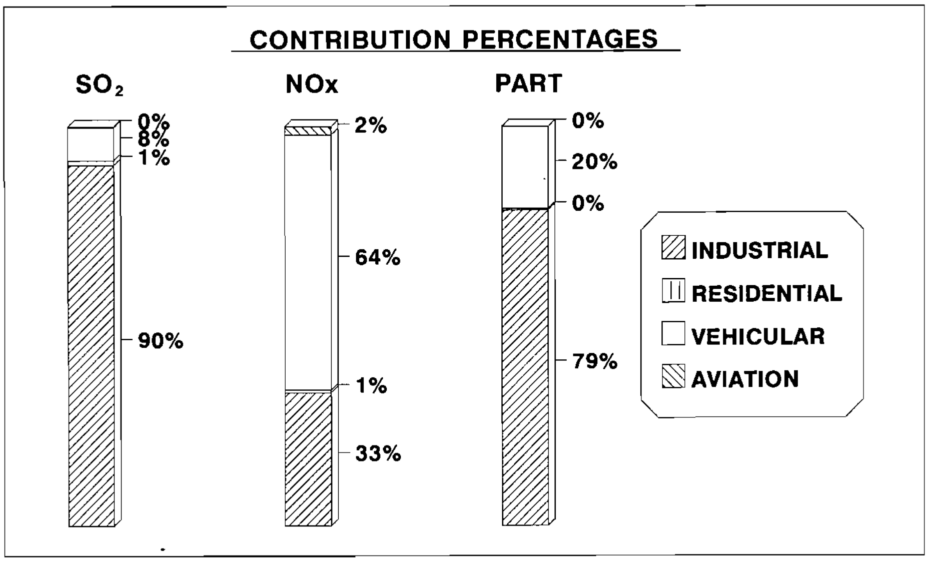

Figure 4: *Emission contribution percentages of SO_2, NO_x and particulate matter, according to emitting factors: industrial, residential, vehicular and aviation*

International Airport soundings. A sine function interpolation scheme was employed for the hourly mixing heights on the basis of the early morning and afternoon mixing heights. The first method to calculate the morning and afternoon heights was based on the pressure equation. The second utilised the Holzworth procedure. The latter method is also used by the EPA's meteorological pre-processor RAMMET. The third procedure utilises different empirical equations corresponding to atmospheric conditions, and is based on the heat exchange between the earth's surface and the atmosphere. Details of the above-mentioned methods and empirical procedures can be found in Dracoulides(3).

Several statistical measures utilising the model's predictions and the measured concentrations at three monitoring sites were used in order to quantify the model's performance. The first monitoring station was at Labiance, Bellville; the second at Cape Town's CBD and the third at the Goodwood Showgrounds. The areas in which the first and third sites were situated can be described as urban areas, with rolling terrains. The second monitoring station in Cape Town was situated in a location surrounded by Table Mountain and Table Bay respectively. This region can be described as one with a complex terrain. The area's meteorology is strongly effected by Table Mountain's sheltering effects and by the land- and sea-breeze systems. The ISC2 model is not a complex terrain model, nor does it provide for plume fumigation along the coastlines(4). Its application is thus recommended for fairly flat terrains and uncomplicated meteorological conditions. Employing this model to predict concentrations at the above-mentioned stations served the purpose of comparing the model's performance at three locations, all with different characteristics.

Model evaluation

The evaluation of the ISC2 model included paired and unpaired analyses. The measures employed were: the mean predicted ($\bar{P}$) and observed ($\bar{O}$) values, the slope and intercept of a linear regression, the root mean square error (RMSE), the systematic and unsystematic mean square errors (MSE_s, MSE_u), the normalised mean square error (NMSE), the index of agreement (D) and the fractional bias (FB). More details about the measures, as well as their analytical formulas, can be found in Fox(5), Hanna(6) and Rao *et al.*(7). In order to estimate the uncertainty or reliability of the calculated parameters, such as the fractional bias, index of agreement and mean difference ($\bar{d}$), the basic assumption required is that the frequency distribution of the data follows the normal distribution. Air quality data do not generally follow the normal distribution, nor can they be easily transformed to follow the normal distribution. This problem can be resolved by employing the blocked bootstrap resampling procedure, since it does not depend on the underlying distribution function(8).

A typical illustration of the comparison of the 01:00 predicted (PR) and observed (OBS) concentrations for the three monitoring stations is shown in Figure 5 (a)-(c). At Cape Town's CBD (S2) and Goodwood (S3) a bias towards under-prediction is evident. The fact that predictions at certain hours are close to zero whilst observed concentrations are high, indicates that the error might be a result of inaccurate hourly emission data. Air recirculation regimes or pollution oscillation carried by the land- and sea-breezes, particularly at site S2, can also be a possible explanation. At the Bellville location the hourly observed and predicted concentrations revealed a better model performance than at the other two sites.

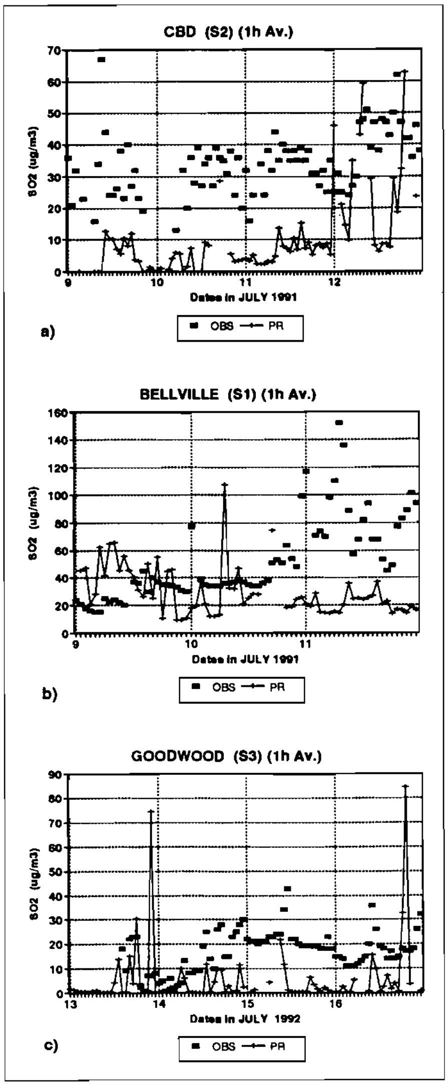

Figure 5(a)-(c):

Typical hourly observed and predicted concentrations at the monitoring stations: (a) Cape Town's CBD (S2), (b) Bellville (S1), and (c) Goodwood (S3)

The maximum hourly concentrations, irrespective of the time of occurrence during the day, are depicted in Figure 6(a)-(c). These concentrations are of great importance to air pollution control, since they would represent a possible violation of the maximum permissible pollutant concentrations. At Bellville (S1) and Goodwood (S3) sites, the model predictions were generally within a factor of two from the observations, with a tendency towards over-prediction (Figure 6(b),(c)). The maximum concentrations at the CBD (S2) station revealed a bias towards under-prediction, although, according to the statistical measures, on average, the performance was also within a factor of two (Figure 6(a)).

The 24:00 averaged concentrations for the three monitoring stations are shown in Figure 7(a)-(c). It is clear that the general trends in the observed concentrations are followed by the model's predictions. The best performance was evident at Bellville (S1) station. At the CBD (S2) and Goodwood (S3) the model generally under-predicted the concentrations by a factor of four and two respectively. The under-prediction at site (S3) could be partially explained by the fact that the calculated concentrations were based on 1991 emission information, whereas the fuel consumption of the year 1992 was 15% higher.

The time-averaged concentrations were calculated so as to evaluate how the predictions compare with the observations at each hour of the day. Figure 8(a)-(c) shows the mean predicted and observed concentrations for the three monitoring stations as a function of the local time. At the CBD (S2) site, the model consistently under-predicts at all hours of the day. However, it follows the general trend of the observed concentrations (Figure 8(a)). The temporal variation at Goodwood (S3) monitoring station also reveals a bias towards under-prediction (Figure 8(c)). At this site the model predictions seem to be higher during night-time. This is a possible result of area sources which should have been characterised in greater detail as several point sources.

The best results were produced at the Bellville site (Figure 8(b)). This performance was expected firstly, because of the topographical features of the area. Bellville is situated on a plain terrain with a small rolling hill north-west. Secondly, the land- and sea-breezes have little effect on the meteorology of the area due to the long distance from the coastlines. Thirdly, Cape Town International Airport meteorological measurements are more representative of the Bellville area than the other two locations. At this site the model also seems to over-predict during the hours before sunrise and after sunset. Similar to the Goodwood monitoring station, a more detailed characterisation of some of Bellville's area sources could improve the predictions during these hours.

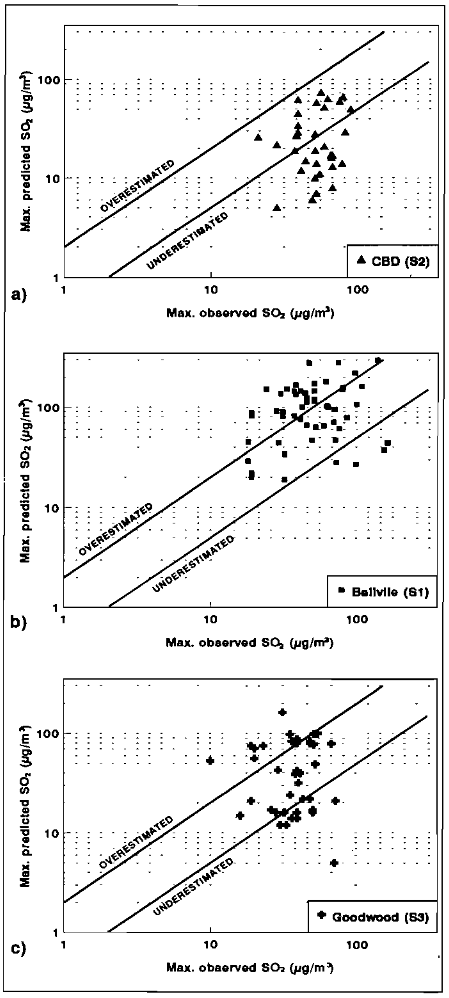

Figure 6(a)-(c):
The daily maximum predicted and observed concentrations independent of time of occurence during the day for the monitoring stations of: (a) the CBD (S2), (b) Bellville (S1) and (c) Goodwood (S3). The solid lines represent the over- and under-estimation by a factor of two.

In order to estimate the uncertainty of the model predictions, the bootstrap procedure was applied on several of the statistical measures which were used for the model evaluation. Figure 9(a) and (b) illustrates the 95% confidence intervals of this analysis for the mean difference of the maximum observed and predicted concentrations, independent of time of occurrence, as well as of the 24:00 averaged concentrations. Examination of the 24:00 averages reveals that the model predictions will have a difference close to zero from the observations 95% of the time only at the Bellville site (S1), since the confidence interval of the mean difference includes the zero value (Figure 9(a)). At Goodwood (S3) and Cape Town's CBD (S2) sites the intervals do not overlap zero, thus revealing a consistent bias towards under-prediction. However, the degree of the under-estimation at Goodwood is not as high as at the CBD site.

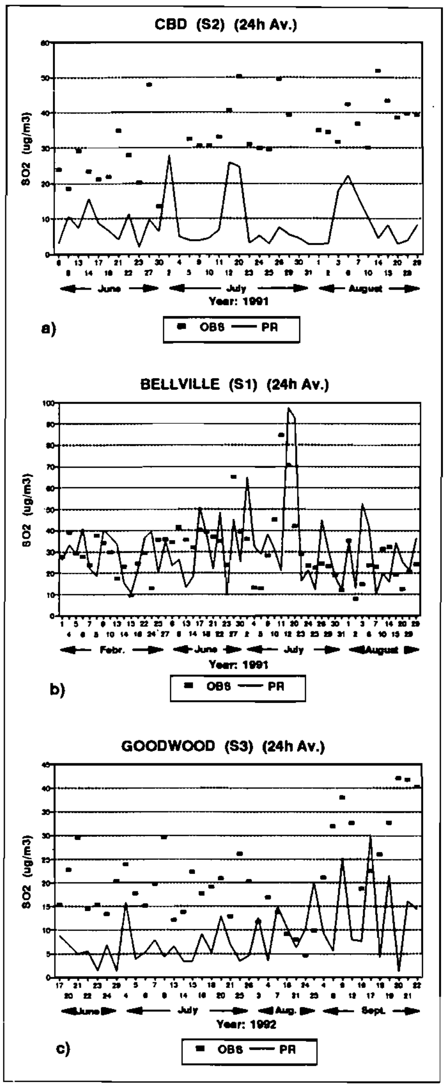

Figure 7(a)-(c):
Typical 24:00 averaged observed and predicted concentrations at the monitoring stations: (a) Cape Town's CBD (S2), (b) Bellville (S1), and (c) Goodwood (S3)

When the 95% bootstrap confidence intervals are based on the maximum concentrations, irrespective of time of occurrence during the day, it is evident that the model over-estimates the observed concentrations at Bellville (S1) and Goodwood (S3) sites (Figure 9(b)). Consistent with the previous analyses for Cape Town's CBD (S2), the predictions are biased towards under-estimation at the 95% confidence level.

The model's performance was also examined according to different meteorological conditions. The data were segregated according to three stability categories (i.e. stable, neutral and unstable). The statistical measures applied to this data indicated that the model predicts approximately 12% more

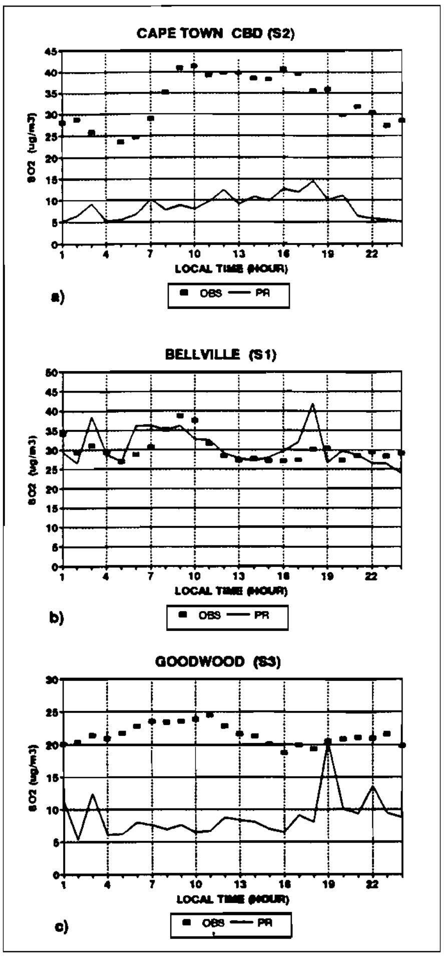

Figure 8(a)-(c):
Temporal variations of the observed and predicted concentrations at the monitoring stations: (a) Cape Town's CBD (S2), (b) Bellville (S1), and (c) Goodwood (S3)

accurately under unstable rather than stable conditions, at all three sites. When the data were grouped according to wind velocity (≤3 m s^{-1}, 3-6 m s^{-1}, ≥6 m s^{-1}), the poorest performance was evident under low wind speeds (i.e. ≤3 m s^{-1}). Under these conditions the model either overestimated the observed concentrations, or revealed poor performance, as indicated by the statistical measures, such as the index of agreement and the root mean square errors.

Conclusions

The air pollution emissions from the industrial and vehicular sectors were found to constitute more than 95% of the total emissions in the Greater Cape Town region. The impact of these SO_2 emissions on the ground-level concentrations was simulated with the application of the ISC2 model. Analysis of the model's performance revealed that this model is appropriate for maximum concentration predictions at locations with uncomplicated terrain and away from Table Mountain, such as the Bellville and Goodwood areas. However, a further examination of the model's accuracy utilising more monitoring sites, as well as different locations for the derivation of the meteorological observations, is recommended. For the CBD, due to the local effects of Table Mountain on the meteorology of the area, the implementation of a complex terrain model and the use of local meteorological data would be more appropriate.

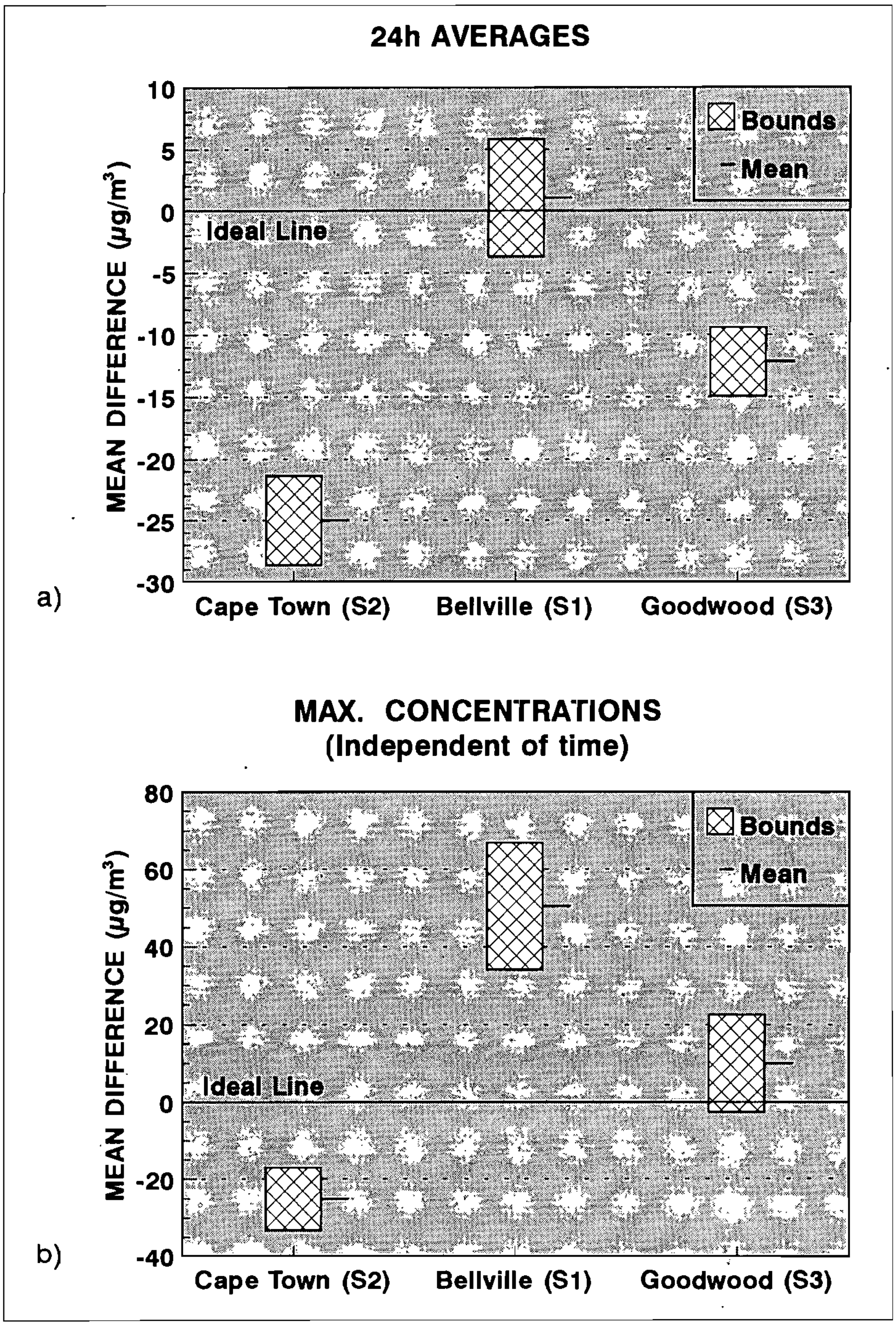

Figure 9(a)-(b): The 95% confidence intervals for the mean difference calculated from: (a) the 24:00 averaged predicted and observed concentrations and (b) from the 01:00 maximum concentrations independent of time of occurence

In order to be able to implement dispersion modelling in air pollution control strategies, the necessity for a more accurate emissions inventory is stressed. A few necessary steps should be taken for the improvement of the existing emissions inventory:

(a) include the characteristics of the building near the emitting stack, in order to account for building-downwash effects;

(b) collect accurate information of the operating hours of the fuel-burning industrial appliances. The present inventory was based on factory operating hours;

(c) allocate the residential area sources according to population densities by also taking into consideration specific areas and average annual income;

(d) generate a gridding system for vehicular sources based on the available traffic volumes.

Since modelling is the most inexpensive way to investigate different pollution scenarios, the formulation of a uniform state inventory policy is strongly recommended. The initial information and the manpower needed for the compilation and data collection of such comprehensive inventories is already available at state departments, such as the Department of Health and the Department of Manpower. Organising steps should be taken towards the direction of registering information with a focus on air pollution studies.

Emission factors

The emission factors used in the present study to calculate emissions from different types of fuels, are shown in Appendix B table. The sulphur (S) and ash (A) content of each fuel are also included in this table.

Since most of the aviation fuel is consumed during the flight, the pollutant emissions of the aviation sector were calculated in terms of take-offs and landings (t-l). These emission factors are also shown in the table according to two aircraft categories: the first consists of aircraft smaller than or equal to a Boeing 707 and the second from a Boeing 707 up to a Boeing 747.

Appendix A: Calorific values (CV) for different types of fuel

All values are shown in MJ/litre except coal and wood, which are shown in MJ/ton.

	COAL (MJ/t)	DIESEL (MJ/l)	HFO (MJ/l)	PETROL (MJ/l)	LPG (MJ/l)	PARAFFIN (MJ/l)	WOOD (MJ/t)
C.V.	0,0243	38,3	41	34,7	27,4	38	0,017

Values have been taken from *Selected Energy Statistics: South Africa*(9), and Borchers and Eberhard(10).

Appendix B: Emission factors for SO_2, NO_x and particulate matter according to emitting sectors: industrial, domestic, vehicular and aviation

FUEL	EMIS. UNITS	SO_2 EMISSION FACTOR	NO_x EMISSION FACTOR	PART. MATTER EMISSION FACTOR
Coal (ind.)	kg/t	$\left.\begin{matrix}19\ S^{a}\\ S+1\%^{c}\end{matrix}\right\}\Rightarrow 19$	$7{,}5^{b}$	$\left.\begin{matrix}6{,}5\ A^{b}\\ A=20\%^{c}\end{matrix}\right\}\Rightarrow 130$
Coal (dom.)	kg/t	$\left.\begin{matrix}19\ S^{b}\\ S=1\%^{c}\end{matrix}\right\}\Rightarrow 19$	$1{,}5^{a}$	10^{b}
HFO (ind.)	kg/kl	$\left.\begin{matrix}19{,}6\ S^{d}\\ S=3{,}2\%^{c}\end{matrix}\right\}\Rightarrow 62{,}72$	$5{,}72^{d}$	$2{,}75^{e}$
Diesel (ind.)	kg/kl	$\left.\begin{matrix}17{,}6\ S^{d}\\ S=0.53\%^{c}\end{matrix}\right\}\Rightarrow 9{,}33$	$8{,}47^{d}$	$13{,}2^{d}$
Diesel (veh.)	kg/kl	$\left.\begin{matrix}17{,}6\ S^{d}\\ S=0.53\%^{c}\end{matrix}\right\}\Rightarrow 9{,}33$	37^{f}	33^{f}
Petrol (veh.)	kg/kl	$1{,}7^{g}$	19^{f}	14^{f}
Gas (dom.)	kg/kl	$0{,}0059^{d}$	$1{,}446^{d}$	$0{,}22^{d}$
Paraffin (dom.)	kg/kl	$\left.\begin{matrix}17{,}6\ S^{e}\\ S=0{,}5\%^{b}\end{matrix}\right\}\Rightarrow 8{,}5$	$1{,}5^{e}$	$1{,}2^{e}$
Wood (dom.)	kg/t	$0{,}75^{e}$	5^{e}	15^{e}
Coke (dom.)	kg/t	$\left.\begin{matrix}17\ S^{d}\\ S=1{,}5\%^{k}\end{matrix}\right\}\Rightarrow 25{,}5$	9^{d}	$\left.\begin{matrix}6{,}5\ A^{b}\\ A=8{,}5\%^{k}\end{matrix}\right\}\Rightarrow 55{,}25$
Anthracite (dom.)	kg/t	$\left.\begin{matrix}19\ S^{b}\\ S=0{,}9\%^{c}\end{matrix}\right\}\Rightarrow 17{,}1$	9^{b}	$\left.\begin{matrix}8{,}5\ A^{b}\\ A=20\%^{c}\end{matrix}\right\}\Rightarrow 170$
Waste (ind.)	kg/t	$1{,}25^{e}$	$1{,}5^{e}$	15^{e}
Aricraft (small)[m]	kg/t-l	1,94	11,64	2,05
Aircraft (large)	kg/t-l	3,61	48,76	2,36

[a] Emission factor for industrial coal combustion(11).
[b] Adapted from Gerson(12).
[c] South Africa's sulphur content per weight for different fuels(13).
[d] After Kato and Akimoto(14).
[e] Factors taken from Sitting(15).
[f] Emissions for South African vehicles after Dutkiewicz(16).
[g] From de Villiers(17).
[k] After Williams(18).
[m] Emissions for every take-off and landing (t-l)(11).

Acknowledgments

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*Comparative evaluation of human exposures to air pollution from low-smoke and conventional household coal usage

**A P S TERBLANCHE, ***I R DANFORD AND ****A S POLS

Levels of gaseous and total suspended particulates (TSP) emissions from three low-smoke coal types under conditions where as many variables as possible were controlled, were monitored in July 1993 in Sebokeng, Vaal Triangle, South Africa. The primary aim of the project was to provide decision support on the acceptability, in terms of health risks, of various types of low-smoke coal being used in real-life conditions in a township. The field testing was conducted during winter (July). The following coal types were included in the study: Wundafuel, manufactured from waste material, CSIR low-smoke briquettes and low-smoke coal produced by United Coal Producers (UCP).

Ninety homes (30 per coal type) were included in the sample. These homes were selected on the basis that a coal stove was used and that the home owner was willing to undergo training and to standardise coal usage procedures.

Monitoring of gases (sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and carbon monoxide (CO)) and TSP, was conducted simultaneously inside each designated home over a period of 8-12 hours to include peak cooking and heating periods. TSP sampling was done actively at 2 litres/min., and both gravimetric and atomic absorption analyses were performed on the filters. The key results indicated that Wundafuel generated significantly lower levels of gaseous and particulate pollutants when compared with the CSIR and UCP coal types. However, even in the case of Wundafuel, the levels of SO_2 exceeded the hourly health standards in 17% of the measurements. This could cause respiratory tract irritation. The relatively high TSP levels monitored for all the low-smoke fuels could be influenced by high background levels in the township. This study emphasised that partial replacement of "dirty" coal is not the optimal solution. The real health benefits derived from the use of low-smoke fuels are only likely to be realised once complete transition in a given area has been achieved. It is also vitally important that in evaluating low-smoke coals, not only visible pollution but also gaseous pollutants, such as SO_2 be considered.

Keywords: coal; low-smoke coal; air pollution; health

Introduction

Human exposure to TSP and gaseous pollutants associated with household fuel combustion has been shown to be detrimental to health[1-4]. The gaseous pollutants emitted by household fuels and coal in particular, which can adversely affect human health, include CO, SO_2, NO_2 and particulates. Research conducted in South Africa has indicated an urgent need for cleaner household fuels since the use of conventional coal and wood has an adverse impact on health[1,2]. Low-smoke coal is one alternative which could decrease human exposure to TSP and related health risks. This project, which was part of a multi- disciplinary study on various aspects of the use of low-smoke coal, focused on the indoor air pollution aspects of three different low-smoke coals.

Methodology

The project consisted of three parts: (i) monitoring of gaseous pollutants and TSPs emitted by three different low-smoke coals; (ii) comparisons with data collected in 1992 on conventional household coal usage, using the same methodology, and (iii) evaluation of the above-mentioned coal types in terms of human exposures and potential health risks. The study formed part of a multidisciplinary investigation into the social acceptability of low-smoke coal as well as the practical aspects of introducing it into townships[7].

Household selection

Initially 90 homes in Evaton were identified by the Chief Directorate: Energy of the Department of Mineral and Energy Affairs for participation in the project. The criteria on which the recruitment of participants were based were that a coal stove was used in the home, and that the member of the household responsible for cooking was prepared to undergo training.

Three training sessions were held, one for each group using one of the three types of low-smoke coal. The aim of the training sessions was to familiarise participants with the appearance of the coal as well as the lighting procedures. The operation of the gas and TSP monitors were also demonstrated to participants during training.

The homes were divided into three groups of 30 participants each for testing each of the three types of coal. As far as was possible, the homes in each group were clustered homogeneously so as to facilitate delivery of the coal, as well as the positioning of the monitoring equipment.

Coal types

The following coals were used in this project:

(a) Wundafuel, a product manufactured by the company Wundafuel, from waste material.

(b) A low-smoke briquette type fuel produced by the Division for Energy Technology at the CSIR and referred to as CSIR coal.

(c) A low-smoke coal obtained by means of a process whereby duff

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discard coal is passed through a furnace and some of the volatiles burnt off. This fuel was provided by United Coal Producers (UCP).

Monitoring procedures

(a) *Gaseous pollutants*
Gaseous pollutants, comprising CO, NO_2 and SO_2, were measured inside each of the participating homes by means of four EXOTOX 75 gas monitors. These monitors ran for an average monitoring session of 8 hours, which included the peak cooking and heating periods. The data were stored in the memories of the monitors and downloaded onto a personal or mainframe computer after completion of the monitoring session. The lowest detection limit of the monitors is 0,1 parts per million (ppm).

(b) *Total suspended particulates (TSP)*
Monitoring of TSPs was conducted inside homes in each coal group over a 12-hour monitoring session to include the peak cooking and heating periods. Sampling was done actively at 2 litres/min. Gravimetric analysis was performed on the particulate matter filters using standard procedures. These filters were also sent for X-ray fluorescence (XRF) elemental analysis.

(c) *Temperature*
The temperature was monitored continuously at 30-second intervals, using the EXOTOX 75 gas monitors. Temperature was included in the statistical analysis as a confounding variable (co-variable) to compensate for differences which may have occurred between 1992 and 1993. All analyses which included the 1992 conventional coal data were done using temperature as a covariant.

X-ray fluorescent analysis (XRF)

XRF analyses were performed to provide a full profile of the elements on the TSP filters collected in the project. XRF is a powerful tool for determining the composition of TSPs and the presence of air toxics, such as lead and cadmium, in a given environment. Similar analyses were performed on 30 TSP filters from this project. Ten filters were selected randomly (5 for daytime and 5 for night-time) for each of the three low-smoke coal types. Available historical data on conventional coal were used for comparison purposes. XRF elemental screening was done for the following elements: Na, Mg, Al, Si, P, S, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, Se, Br, Cs, Au and Pb. Quantitative data were obtained for each element.

Data processing

All data analyses were done using the Statistical Analysis System (SAS) system. It was observed that some of the data were skewly distributed, and the appropriateness of using a log transformation of each of the dependent variables was considered. However, it was found that this transformation did not change any of the statistical results and it was therefore omitted.

> “The levels of CO and SO_2 measured indoors in the case of all three low-smoke coals indicated that these coals are in fact capable of emitting unhealthy levels of gaseous pollutants. The relatively high levels of particulates associated with the low-smoke coals could have been as a result of high background levels as particles are the dominant pollutants in coal-burning townships.”

The available data were obtained by monitors placed inside the selected houses. The monitors were switched on and observations of pollution levels (SO_2, NO_2 and CO) were recorded at 30-second intervals until their batteries were discharged (8-10 hours). In this way a sequence of observations was obtained for each house. In order to obtain a data set of manageable size, the hourly averages and maxima were computed for each house, and these were used in the further analyses. For a particular monitor, the successive hours are important and this was borne in mind during the statistical analysis.

The stove type proved to be a complicating factor in previous studies and was standardised for the home selection criteria in this investigation. Only formal housing structures were included in the project.

Quality assurance

Quality control procedures were followed in order to ensure that the data obtained were accurate. The suppliers of the gas monitors performed gas calibrations on each monitor before the start of the project and zero calibrations were carried out at regular intervals during the course of monitoring. The pumps used to measure the TSP levels were calibrated to sample at a rate of 2 litres/min. before each monitoring session. A random number of samples were reweighed to improve data quality. Gaseous pollutants and TSP levels were measured during several monitoring periods over the duration of the project, in order to test the reproducibility of the data. Careful control by field-workers ensured that the coal being tested was in fact used at the time of the air pollution monitoring.

Statistical analysis

In view of the representative data available, the aim of statistical testing is to establish any differences which may occur. Failure to establish *significant* differences does not prove that they do not exist but may reflect on confounding variables not included in the data set. A number of statistical analyses were carried out which included graphical methods, generalised linear models (GLM), multivariate analysis of variance (MANOVA) and discriminant analysis. The methods used are described briefly below:

(a) *Graphical methods*

As a means of obtaining overall indications, the hourly averages were computed for various groupings (e.g. coal types) of the data set and plotted on the time axis. These plots indicate overall visual trends but do not indicate significance or lack of significance as variance of observations is not accounted for.

(b) *Generalised linear models (GLM)*
This method fits linear models to experimental data for various dependant variables (CO, NO_2 or SO_2) to be tested simultaneously. If overall significance is obtained for an effect with more than two levels, multiple comparisons can be carried out to identify individual differences. When working with one factor at two levels, GLM is equivalent to performing the well-known t-test which is applicable to the data set evaluated in this paper.

Correct application of the GLM enabled testing for individual hours in this data set. If all hours are combined (all hours must be measured at each monitor), the resulting test is indicative only, and the values are probably not accurate. In general, using GLM in this way resulted in a liberal test. GLM was used to compare dependant variables in the analysis of this data set.

(c) *Multivariate analysis of variance (MANOVA)*
This is a multivariate analogue of the GLM procedure. The advantage of this approach was that the different hours could be tested simultaneously for different factors (e.g. coal types).

(d) *Discriminant analysis*
This is a procedure closely allied to discriminant analysis in which the data are used to establish the profile data groups (coal types), and then to reclassify data into one of the groups. The procedure is evaluated by the number of correct reclassifications. A high success rate implies that the groups are well defined (different).

Results

The total number of observations obtained for each pollutant in the three different low-smoke and conventional coal groups for day and night monitoring sessions varied from 26-30 for TSPs, 47-114 for SO_2, 53- 115 for both NO_2 and CO. These measurements were taken over a period of 22 days. A total of 39 651 single gaseous measurements (30-second intervals) and 116 TSP measurements was obtained.

The hourly average concentrations for the different pollutants are given in Table 1. They are given for the data set as a whole, and separately for the different coal types. The hourly U.S.A. health standards for SO_2, NO_2 and CO are also shown, and the average exposures documented per hour

COAL TYPE		POLLUTANT:		
		SO_2 ppm	NO_2 ppm	CO ppm
Hourly health standard		**0,40**	**0,60**	**35**
Average exposure^{+}		**0,31296**	**0,01655**	**6,63906**
ALL coals	Max hourly average^{++}	3,90917	0,44615	145,217
	Corresp. hour	18	22	20
	Coal Type	UCP	Normal	Normal
	Day / Night time	Day	Night	Night
Normal coal	Max hourly average^{+++}	1,8325	0,44615	145,217
	Corresp. hour	18	22	20
	Day / Night time	Day	Night	Night
CSIR coal	Max hourly average^{+++}	3,36417	0,005	55,292
	Corresp. hour	18	16	16
	Day / Night time	Day	Night	Day
UCP coal	Max hourly average^{+++}	3,90917	0,18	83,15
	Corresp., hour	18	22	18
	Day / Night time	Day	Night	Day
Wundafuel	Max hourly average^{+++}	3,28583	0,19701	15,858
	Corresp. hour	16	0	17
	Day / Night time	Day	Night	Day

\+ One overall average for the 365 hourly averages in the data set was computed for each of the three pollutants.

++ The maximum of the 365 hourly averages, as well as its corresponding information, was selected for each of the three pollutants.

+++ The 365 hourly averages were divided into the different coal types. From each subset (coal type), the maximum average, as well as its corresponding information, was selected. This was done for each pollutant.

Table 1: Hourly average exposures for gaseous pollutants per coal type

TSPs (REGARDLESS OF DAY OR NIGHT TIMES)				
COAL TYPE	**% READINGS ABOVE HEALTH STANDARDS**			
	Expressed as a % of the number of observations per coal type		**Expressed as a % of the number of observations for total data set^{+++}**	
	180 µg/m^3	**260 µg/m^3**	**180 µg/m^3**	**260 µg/m^3**
CSIR	100	100	26,09	26,09
Wundafuel	100	100	26,09	26,09
UCP	100^{+}	100^{+}	25,22	25,22
Normal	96,15^{++}	84,62^{++}	21,74	19,13

\+ UCP coal had 1 missing value. Of the 96,67% data that are present for UCP coal, 100 exceeded 180 and 260 µg/m^3.

++ Normal coal - all the daytime TSP values exceeded the health standards. Some of the night-time TSP values did not exceed the health standards.

+++ One of the 116 observations in the whole data set is missing (UCP coal). Thus, 99,14% of the data is present. The number of observations per coal type that exceeded the health standards, is presented as a % of the 99,14% present data.

Table 2: Percentages of TSP 12-hour averages exceeding the U.S.A. 24-hour health standard (260 µg/m^3) as well as the WHO Standard (180 µg/m^3) for the various coal types

% READINGS ABOVE HEALTH STANDARDS						
COAL TYPE	**Expressed as a % of the number of observations per coal type**			**Expressed as a % of the number of observations for total data set**		
	SO_2	**NO_2**	**CO**	**SO_2^+**	**NO_2**	**CO**
CSIR	13,16	0	3,51	4,18	0	1,10
Wundafuel	17,58	0	0	4,46	0	0
UCP	28,97	0	6,54	8,64	0	1,92
Normal	$29,79^{++}$	0	5,66	3,90	0	0,82

\+ SO_2 had 6 missing values. The number of observations per coal type that exceeded the health standard, is presented as a % of the 98,36% data that is present for the whole SO_2 data set.

\++ SO_2 had 6 missing values. The number of observations for normal coal that exceeded the health standard, is presented as a % of the 88,68% data that is present for that coal type.

Table 3: Percentages of SO_2, NO_2 and CO hourly averages exceeding the U.S.A. health standard for the various coal types

ELEMENT	**AVERAGE CONCENTRATIONS, $\mu g/m^{3+}$**			
	Conventional Coal	**UCP Coal**	**CSIR Coal**	**Wundafuel**
Silica	75,7	66,69	91,11	51,23
Iron	60,2	48,07	77,40	34,54
Aluminium	43,7	38,76	49,97	29,57
Sulphur	15,8	13,74	7,68	2,64
Calcium	22,7	16,10	35,90	12,07
Potassium	7,8	7,52	9,51	7,55
Titanium	6,4	5,02	7,94	3,62
Phosphorous	1,2	1,77	1,54	0,98
Lead	1,4	0,37	0,49	0,26
Magnesium	1,6	0,49	0,68	0,54
Sodium	1,7	1,89	0,85	1,44
Chromium	0,4	0,35	0,40	0,04
Manganese	1,8	1,35	2,72	1,15
Arsenic	0,4	0,0	0,0	0,0

\+ Day and night averages combined

Table 4: Summary of results of 30 TSP filters as well as historic data on 10 filters from conventional coal

for each pollutant, regardless of coal type. For each coal type the maximum hourly average for SO_2, NO_2 and CO, the hour of the day at which that maximum was recorded and the period of the day are summarised in this table. The maximum hourly average for each pollutant and the associated time of day and coal type are also given.

The percentage excesses of the relevant health standards are given in Table 2 for TSPs and in Table 3 for the gaseous pollutants. The U.S.A. 24-hour health standard, as well as the World Health Organisation's no-effect-exposure-limit, were used as bench-marks for TSP. The U.S.A. hourly average health standards were used for SO_2, NO_2 and CO evaluations. The reason for using the short-term and not the 24-hour average for the gaseous pollutants in contrast with TSP is mainly that short-term health standards exist for the gaseous pollutants and monitoring was conducted over a maximum period of 8 hours continuous monitoring. For TSP, the sampling is integrated over a 12-hour period and gives a sensible projection of the levels which can be expected.

The findings of the XRF analysis of 30 TSP filters taken during combustion of low-smoke coals and 10 filters from converted coal are summarised in Table 4. The average elemental concentrations for the different coal types are given for elements which are considered important from a health point of view and which were prominent in all coal types.

The relatively high silicia, calcium, iron and manganese content of the CSIR coal compared with the others needs further evaluation. The higher content of hazardous substances, such as arsenic and lead, on the conventional coal filters also warrants closer investigation as this constitutes an additional risk not covered in the analysis of TSPs.

Multivariate comparative analyses were performed on the pollution monitoring database. A one-way variance analysis to compare the four different coal types was done at each hour the monitoring took place. The SAS procedure "GLM - General Linear Models" was used for the tests. Temperature was included as a co-variate in the model to act as a correction factor for the changes in temperature between the 1992 (conventional coal) and 1993 monitoring.

The different coal types were compared for each hour monitored during the day and night sessions. For the hours 01:00, 02:00, 03:00, 04:00, 05:00, 06:00, 07:00, 08:00, 13:00, pollution levels were below detection limits most of the time for all coal types due to the absence of the source.

For the hour 14:00, data were available only for normal coal (3 observations) and UCP coal (6 observations). No differences between these coals were found for any of the three gases. Temperature did not play a role.

For the hour 15:00, no differences were found between the four coal types for SO_2 and CO. For NO_2, the CSIR coal and Wundafuel were below the detection limit of 0,1 ppm. There was no significant difference between UCP and normal coal for NO_2 levels. Temperature did not play a role. Neither was statistically different from the detection limit of 0,1 ppm.

For the hours 16:00 and 17:00, no differences were found between the four coal types for any of the pollutants. For CO and NO_2 temperature did not play a role. However, temperature is a significant covariate for SO_2.

No differences were detected in gaseous pollutant levels for the four coal types at the hours 18:00-23:00. Temperature was found to be a significant covariate and corrected for in all cases for all hours. The average hourly indoor temperatures varied between 15,6 degrees C and 26,7 degrees C.

Comparisons of gaseous pollutants were done using a two-way analysis of variance to compare firstly, day *vs* night, and secondly, the four coal types over the whole monitoring time. It is also possible to detect interaction between coal type and time of day (Interaction: Is there one particular coal type where the effect of the time of day differs from the other coal types?)

The findings with temperature included as a covariate were:

- There is no difference between the coal types when controlling for temperature.
- Day and night values differ significantly (P<0,0004) with day values higher than night values.
- No interaction was detected between coal type and time of day.
- Temperature is therefore a significant covariate (P<0,0001) when comparing coal types.
- Coal type is significant (P<0,0038) with normal coal having the highest NO_2 concentrations.
- Day and night times differ significantly (P<0,0009) with daytime having the highest levels.
- Coal type remains significant even after controlling for temperature. (P<0,0074). (The test of Scheffe indicated that on average of all hours, normal coal is different from the other three coal types.)
- Day and night times differ significantly (P<0,0131) with daytime having the highest exposures.
- Temperature is a significant covariate on the 10% level (P<0,0638) for the different coal types.

COAL TYPE	POLLUTANTS AVERAGE CONCENTRATIONS (ppm)		
	SO_2	NO_2	CO
CSIR	0,205	0,0005	5,9
UCP	0,469	0,010	8,7
Wundafuel	0,212	0,011	2,5
p-value 95% confidence level	<0,006	<0,004	<0,003

Table 5: Differences between coal types for gaseous pollutants

COAL	TSP		
	N	MEAN	STD
CSIR	30	1064,6667	497,8349
UCP	29	722,7586	286,3801
Wundafuel	30	654,0000	377,6570
Normal	26	732,2308	448,7607
TIME:	N	MEAN	STD
DAY	78	923,5513	448,2208
NIGHT	37	527,5946	251,7816

Table 6: TSP concentrations for the different coal types

The reason for the significant main effects in coal type and time of day lies in the change in the normal coal mean from day to night. Time of day has an effect on normal coal which is not the case with the other coal types. For normal coal the NO_2 gas level drops from day to night time, whereas for UCP, Wundafuel and the CSIR coal the NO_2 levels remain constant. Because the day mean for normal coal is high, the average over time is significantly higher than for the other coals. Similarly the large normal coal mean for day contributes to a significantly higher day than night mean over all coal types. Clearly the large mean for normal coal from the day measurements is responsible for the significant main effects.

Low-smoke coal types only

Comparisons of the three low-smoke coal types were done to exclude the possible confounding influence of the different years of monitoring expressed in the analysis as temperature differences. The differences between the coal types are given in Table 5 for the various pollutants.

When looking at day *vs.* night separately for the three coal types, differences are:

- For SO_2, the CSIR coal and Wundafuel performed similarly, while UCP fuel showed higher levels during the day (P<0,009).
- For NO_2, the Wundafuel and UCP coal were similar with CSIR coal having lower levels during the day periods (P<0,01).
- For CO, the CSIR and UCP coals did not differ during the day monitoring period and had significantly higher CO levels compared with Wundafuel (P<0,0001).

The analyses that were done for SO_2, NO_2 and CO at the different monitoring times did not indicate any difference between the four coal types. In all cases the standard deviations were greater than the means and the sample sizes relatively small. This is an indication that the underlying variability is too large and the sample size too small to pick up any statistically significant differences.

In the overall analyses for the gases (all hours taken together), the standard deviations were also greater than the means. However, the numbers of observations were sufficiently large for significant differences to be found. In all the analyses (gases hourly and overall), when looking at the temperature adjusted means, Wundafuel was almost always lower than the other coal types. This was also observed for the TSP means.

Comparisons of TSP - Two-way Analyses of Variance

A two-way analysis of variance was done to firstly, compare day *vs.* night-time, and secondly, the four different coal types over all the monitoring hours. It was also possible to see if there is interaction between coal type and time of day. No temperature data were available for the TSP data and they were thus excluded from the analyses. This is summarised in Table 6.

- Coal type is significant ($P<0,0004$). (The test of Scheffe indicated that on average for all hours, CSIR coal has higher TSP levels than the other three types.) Wundafuel has a tendency towards lower levels.
- Day and night times differ significantly ($P<0,0001$) with the day time being associated with the highest levels.

The contribution of background levels of TSPs generated by either coal-burning or geological dust (unpaved roads) to indoor concentrations is difficult to calculate. The assumption is made that as the different clusters of homes using the same coal type in this study are close to each other and located in a coal-burning area, the contribution of background levels is comparable. If this assumption holds, then the CSIR coal yields significantly higher TSP emissions. For all coal types TSP concentrations exceed those specified in the the health standard, probably as a result of background contributions. This illustrates that the partial introduction of low pollution potential energy sources will not have a measurable health benefit. The approach should be a holistic one.

When looking only at the main effect coal type, it can be seen that the CSIR coal differs from UCP, Wundafuel and normal coal. When the interaction between coal type and time of day is taken into account, it was found that time of day has a different effect on some of the coal types. Although the CSIR coal has the highest TSP level, normal coal shows a similar behaviour pattern from day to night as the CSIR coal. The TSP level of UCP coal remains constant. For Wundafuel there is a drop from day to night-time monitoring - but not as large as in the case of the CSIR and normal coal.

Discussion

There is a direct relationship between the health of a community and the energy sources used. Ample evidence exists that household energy sources which have high air pollution-generating potential have serious adverse effects on health(1-5). It is therefore important to look for cleaner alternatives, such as low-smoke coal. It is also important to evaluate "new" energy sources to ensure that the risk to human health is in fact reduced and has not only been shifted from the visible pollutants (particles) to invisible pollution (gases). The three low-smoke coals tested here in a field situation were evaluated in a laboratory measuring emissions of gaseous and particulate pollutants under controlled conditions(6). This study confirmed that the three low-smoke coals produce significantly less smoke than conventional coal. However, the NO_2 and CO emissions were no different. In the case of Wundafuel and the CSIR fuel, the SO_2 emissions were on average lower than those of conventional coal(6).

These trends in the laboratory findings were also present in the field study with respect to gaseous pollutants. The levels of CO and SO_2 measured indoors in the case of all three low-smoke coals indicated that these coals are in fact capable of emitting unhealthy levels of gaseous pollutants. The relatively high levels of particulates associated with the low-smoke coals could have been as a result of high background levels as particles are the dominant pollutants in coal-burning townships.

The findings of this project emphasise the point that careful evaluation of alternative energy sources is of critical importance before the large-scale introduction of these energy sources is implemented.

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[*]A framework for energy strategy formulation in the South African context

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The pervasive nature of energy makes it central to the reconstruction and development prospects of South Africa. As the South African economy is confronted with many competing claims on its resources it is essential to allocate and utilise these scarce resources optimally so as to meet the basic energy needs of poorer communities in an equitable, efficient and sustainable manner. To achieve this a proper energy planning framework is required.

This paper therefore proposes a planning framework to provide direction for an ongoing process of strategy formulation which is designed to maximise the contribution of adequate, secure and affordable energy to the socio-economic upliftment and empowerment of individuals, the community and industry, and which is applicable to the specific energy-related needs of the people of the nine provinces of South Africa.

This framework has been designed against the background of South Africa's changing social and economic environment, to reflect the dynamic nature of energy and to stress an integrated approach to the formulation of the energy strategy. The approach is end-use focused (i.e. focused on the consumer) and reveals that *ad hoc* planning for separate energy subsectors in isolation is not appropriate. The framework moreover provides a consistent approach to energy strategy formulation.

Keywords: energy planning; energy strategies; integrated approach; South Africa; development

Introduction

The aim of this paper is to provide a framework within which an energy strategy can be formulated, to maximise the contribution of energy to the social and economic upliftment of all the people of South Africa. The main focus is on the poor communities which comprise roughly 60% of the total South African population, who have no access[***] to electricity for domestic purposes and are dependent on a wide range of energy sources to meet basic needs.

Given the pervasive and dynamic nature of energy and the current state of flux in the political and institutional environment, the proposed framework has the flexibility to adjust to change. The framework is therefore not a static blueprint; rather, it provides direction for an ongoing process within which energy for development can evolve to its full potential. This framework also provides a consistent approach to energy strategy formulation.

For the purposes of this paper it is postulated that energy is an essential input for social and economic development and is not needed for its own sake. Energy is a necessary but not sufficient precondition for development.

The strategic significance of energy

Development challenges facing South Africa

Development is a multidimensional process through which the ability and aspirations of people to serve their own needs and legitimate desires,[****] as well as those of others, are increased. Development consists of progress in fulfilling five interrelated and mutually supportive dimensions, *viz.:*

- the economic dimension
- the scientific and knowledge dimensions
- the governance dimension
- the ethical dimension
- the cultural dimension.

The South African economy is confronted with many competing claims on its resources to meet the aspirations of the populace to serve their own needs. However, many of these claims and aspirations have to be balanced against available resources and economic realities, as is apparent from, amongst others, the following:

- poor overall economic performance
- high and growing levels of unemployment
- abject poverty and malnutrition
- the high degree of disparity in income between rich and poor
- escalating urbanisation of poorer communities
- vast backlogs in housing and education, health and other services, such as water provision, sanitation and electrification
- regional and local disparities in development
- growing expectations of income and wealth redistribution, as well as compensation for past inequities.

Development impact of energy

Because energy affects all aspects of production and all facets of resource use, energy for development is central to the overall development prospects of South Africa. Economic growth is dependent upon the adequate and cost-effective availability and utilisation of energy. There is a strong correlation between the standard of living as measured by per capita gross national product and per capita energy consumption. However, the importance of energy for development is much more than its direct contribution to the gross national product, as it serves not only as a basic input to all production sectors but also as a catalyst to development and growth. It is also an integral component of final consumption of goods and services.

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[***] Ability to receive an electrical connection if desired.

[****] These are desires which, if fulfilled, will not subtract from the rights of other people.

The provision of cost-effective and adequate energy could encourage increased economic activity and enhance the quality of life of all the people in South Africa. Some of the benefits of an adequate and cost-effective energy supply are direct and evident. However, many other benefits, such as improved health, greater social cohesion, improved literacy and general education, time savings, and reduced rural-urban migration, are diffuse, indirect, and difficult to quantify. While these benefits may not always be quantifiable using conventional cost-benefit analyses, they are immense.

Strategy formulation

Definition

Before outlining the proposed framework for developing an energy strategy it is important to highlight briefly the broad characteristics of an integrated approach to energy strategy formulation. Integrated energy strategy formulation in general means a detailed and disaggregated analysis of the energy sector; the linkage of the entire energy system with economic development and environmental issues relating to all institutional, financial and technical aspects; and interaction between the various energy subsectors. It is becoming increasingly accepted that energy-related problems can only be effectively tackled through a comprehensive integrated approach. Separate *ad hoc* planning for energy subsectors in isolation is therefore not appropriate.

Traditionally energy strategy formulation throughout the world has taken the supply-side approach, that is, if energy resources are available demand will follow. Moreover, subsectors have mainly been defined by the various sources of energy. Subsequent analysis followed the path from the energy source through exploration, extraction, concentration, transportation, refining, storage conversion and distribution, to consumption by the end-user.

An integrated approach to energy strategy formulation, in contrast, is end-use focused, that is, focused on the consumer. It stresses the fulfillment of energy services working through the energy system towards supply. The end-use focus also offers better possibilities for including the environmental impacts related to the specific energy sources and technologies under consideration(1).

Rationale

The broad rationale underlying the concept of strategy formulation is founded on four elements. These basic elements are(2):

- making choices between alternative courses of action
- making decisions on how to make the best use of available resources (in their broadest sense)
- making decisions about alternative ways of achieving particular goals
- as the goals of strategy formulation lie in the future, strategy formulation is concerned with scheduling future activities to achieve these goals.

Principles

Energy strategy should be formulated according to a number of guiding principles, some of which are outlined below.

(1) An integrated approach to strategy formulation

An integrated approach to strategy formulation should be adopted with the principal emphasis on three levels of analysis, namely:

- the energy sector and its interactions with the macro-economy. This includes assessing the economic, social, technological, environmental, institutional and resource linkages to energy. The analysis of the first level ensures that, whatever the energy strategy may be, it will be consistent with other priorities, and will support the many interrelated and often conflicting national and provincial objectives as effectively as possible;
- the linkages between the different energy subsectors. This second level deals with issues such as the optimal mix of the different energy subsectors, diversification of supply, energy demand analysis, substitution and energy consumption by energy type and by sector;
- the management of each energy subsector, dealing with issues such as pricing, end-use analysis and supply options.

(2) Development orientated

An energy strategy should not be considered as an end in itself but as a means of reaching broader development objectives and priorities. It should also support and augment national and provincial development policies, and recognise co-operation across borders in a regional context and linkages to national development planning.

(3) Community involvement

All relevant stakeholders must be afforded an opportunity to participate in the strategy formulation process on an ongoing basis. Planning should never be done for, only with and by, an organisation, community or nation. According to Ackoff(3): "No-one can plan effectively for someone else, it is therefore better to plan for yourself, no matter how badly, than for others, no matter how well".

(4) Market equity

All energy carriers should be allowed to compete on an equal basis in the energy market (equal access to financing facilities) with due consideration to strategic, fiscal, environmental and socio-economic needs.

(5) Role of government

The role of government in energy provision should focus on:

- providing an enabling environment for private sector participation in the energy market
- intervention in the energy market where it is justified on economic and social considerations.

(6) Economic and financial sustainability

There are limited financial resources within the South African financial system. Thus energy options should be considered in the context of sectoral balance, development impact and fiscal impact at local, provincial and national levels. Energy prices should, as far as possible, reflect the opportunity costs (all social costs) and the value of energy commodities. Where subsidisation is considered this should be based on considerations of national socio-economic needs (welfare issues), sustainable development (economic viability in the longer term coupled with short-term afford-ability problems), clearly identified targets (consumer- not process-orientated and clearly transparent) and specific time-frames.

(7) Institutional considerations

Provision should be made for the training and utilisation of local labour during electrification or in the installation, operation and maintenance of solar systems. Other local resources (financial, natural, physical and technological) should also be utilised to their fullest extent. Special emphasis should be placed on appropriate structures and systems or models for implementing this strategy.

(8) Environmental sustainability

All energy sources have some form of environmental impact. This should be recognised in order to minimise their impact in the most cost-effective way.

(9) Youth and gender issues

Cognisance should be taken of the central role played by women and youth in the provision of energy.

Process

Energy strategy formulation should be undertaken as a continuous and iterative process with specific generic components, such as:

- establishing a planning body
- conducting a situation analysis, through the
  - * collection and collation of energy information
  - * disaggregated analysis of energy demand and supply
  - * assessing the development context
- establishing development objectives
- formulating development and energy scenarios
- establishing an energy strategy
- implementing the strategy through
  - * physical controls
  - * technical means
  - * investment instruments
  - * education and promotion
  - * pricing, taxation and subsidies
  - * institutional, regulatory and market reforms
- designing a mechanism for the evaluation of the strategy which was implemented
- continuously evaluating the strategy implemented.

In view of the iterative nature of strategy formulation, a strict sequential adherence to these components is not necessary as conclusions reached during the later components often influence decisions taken in earlier components. It then becomes necessary to review the earlier decisions to achieve the requirements of an integrated approach to energy strategy formulation.

Establishment of a planning body

A representative planning body, forum or steering committee, comprising all the key interest groups, should be established. The formation of such a representative planning body is influenced by:

- the origin of the planning initiative: the credibility and legitimacy of the body which initiated the planning initiative will determine how readily other groups will be prepared to participate;
- the characteristics of the population or communities in the planning area: the constituencies, power bases, alliances and viewpoints of existing interest groups should be established. Communities vary greatly with regard to cohesion, conflict with and level of co-operation in development activities;
- the length of time allowed for the negotiation process to obtain representative participation and agreement on the form of such participation;
- the composition and functioning of the planning body which needs to be monitored throughout the process to ensure balanced participation by all participants.

The credibility and legitimacy of the planning body are essential as the emphasis is on acceptable political applications, representation and the capacity to carry out a particular function in the current socio-political climate. Credibility refers to the planning body's trustworthiness in the eyes of the population at large, while legitimacy refers to acceptability in terms of principles and standards set by the broader community.

The purpose of the planning body is to structure participation in the process of formulating an energy strategy and to open up this process to participants representing different communities or organisational interests.

The planning body should also be used as a co-ordinating mechanism for formulating an energy strategy. It allows the opportunity for:

- orientating participants to the process of team learning
- gaining the understanding, commitment and consensus of the participants at an early stage on the purpose, principles, objectives and procedures of the energy strategy formulation process.

The role of the steering committee, functioning under the auspices of the planning body, is to ensure:

- the proper management of the process of formulating an energy strategy
- the continuous involvement of those institutions ultimately responsible for the implementation of the energy strategy.

Notwithstanding the need for a representative steering committee, care should be taken that it does not become unmanageably large.

The function and involvement of professional planners in the planning body should be to encourage and facilitate the process of strategy formulation by providing motivation, information, knowledge, insight, understanding, imagination and wisdom to participants.

Situation analysis

The situation analysis (description of the energy system within a development context) component comprises two distinct elements, namely a broad systems analysis element and an obstruction analysis element.

(i) Broad systems analysis

Broad systems analysis requires a multiple perspective approach (economic, financial, social, institutional, environmental, technological and resource approach) to investigating the current energy and development system. This approach entails the following:

- identifying and confirming the scope and planning horizon of the energy strategy, whether short- or long-term, or within a national, provincial or local context;
- developing an information base through the identification of specific information needs, information collection and collation;
- collecting and collating information on energy, involving the identification of:

(a) *energy consumption sectors* disaggregated by end-use, consumer category and fuel type. The following consumer categories are identified according to their energy needs:

- * *domestic consumers:* their principal needs are for cooking, heating (of space, water, etc.), communication and lighting.
- * *institutional consumers:* their needs range from street light-

ing, operation of public community centres, schools, clinics, hospitals and water provision.

* *transportation consumers:* their main demands for transport are for commuting to work, hauling crops to and from fields, moving materials to their place of use. These needs are met by carts pulled by oxen or donkeys, tractors, buses, bakkies, cars and trains.
* *agricultural consumers:* their principal needs are for soil preparation, planting, irrigation, harvesting, threshing, grinding, preserving and fertilising.
* *commercial consumers:* their principal needs are for refrigeration, storage cooling, the processing of food, etc.
* *industrial consumers:* these include large consumers in the metallurgy, mining and quarrying, manufacturing and chemicals industries; medium-sized industrial consumers; and small industrial consumers, such as a person in the handicrafts business, welders and spray shops.

(b) *the energy supply sector,* for example, electricity, petroleum

(c) *development variables* relevant to the energy situation, such as population dynamics, socio-political stability, provision of social infrastructures and services (health, education and security), economic activities, employment, income generation, natural resources, demand for local goods and services, investment climate, development priorities, objectives, policies, institutional arrangements and capacities.

(d) *disaggregated analysis of current and historic*

* *energy demand,* with due cognisance of affordability, consumer and cultural preferences, existence of economic bases, level of economic activity, prices or energy commodities, possible supply constraints and linkages to other services
* *energy supply,* with regard to indigenous energy resources, resource alternatives, imports, conversion technologies and supply technology alternatives.

(ii) Obstruction analysis

Obstruction analysis involves the identification of obstructions to development in general, and the energy systems in particular. General obstructions to development might include the following: a limited economic base; structural imbalances; a lack in the legitimacy of or competence in institutional structures; lack of access to development resources in general and energy (electricity) resources in particular; high political and social tensions; personal and cultural insecurity; insufficient medical care, shelter, sanitation, nutrition or skills. An obstruction analysis may be done before the establishment of the development objectives or may follow these objectives.

Establishment of development objectives

Specific development objectives and priorities need to be established. Some specific objectives (development- and energy-orientated) listed in the energy literature include the following:

- reducing poverty
- maximising employment
- diversifying energy supply
- promoting equity of access to affordable, adequate and secure energy supplies
- supporting sustainable and economically rational settlement patterns, and taking cognisance of trends in migration and concentration
- maximising indigenous energy supply (including renewable energy resources) and reducing dependence on foreign sources of supply (saving scarce foreign exchange)
- preserving the environment through minimising the environmental impact of energy in the most cost-effective way
- developing decentralised energy supply systems in off-grid areas
- widening the scope for the training and utilisation of local labour in the provision of energy
- developing appropriate technical norms and standards for energy provision
- satisfying the needs and legitimate desires of the developing energy sector within a sustainable development framework
- developing a sustainable energy economy in support of sustainable economic development through maintaining a balance between people, capital, materials and the environment
- choosing the mix of energy sources and technologies to meet future energy requirements at lowest cost
- maximising economic growth and development through economic efficiency by ensuring the least-cost energy supply mix, optimal energy use and energy resource allocation
- supporting provincial development or possible priority development of special sectors of the economy, such as export-oriented industries
- stabilising prices
- rationalising energy supply systems in the national/provincial and rural/urban/metropolitan contexts
- conserving energy resources through wise and efficient exploitation and use
- promoting applied energy research and its results into workable production systems (commercialisation)
- raising sufficient revenues from energy sales in certain energy sectors to self-finance energy sector development.

Formulation of scenarios

Scenario development is eminently suitable for explaining the present *energy* and *development* situation by analysing the past and by identifying problems, constraints, trends and opportunities which will assist in achieving the objectives in the future. A scenario is not a prediction of the future but rather an indication of a possible future.

Another important contribution of scenario development is that it provides a potentially powerful communication link between decision-makers and planners. An important first step for planners is to reach an agreement, or develop a common mind-set, on an appropriate context within which energy strategy formulation should be carried out. Such a context should take into account, *inter alia:*

- costing the various energy options (capital and recurrent);
- existing and projected energy demand;

- development resource constraints in general, and energy sources in particular;
- institutional and skills constraints;
- energy supply plans involving indigenous resources, conversion technologies, etc.;
- energy technology developments;
- projected development variables and dominant socio-economic forces that could influence future events;
- desired development objectives and priorities.

It may be useful first to develop a business-as-usual scenario (encompassing both developmental and energy aspects), assuming that whatever the current changes are, they will persist in the future. Thereafter alternative scenarios could be developed to capture what the future situation could, or should, be by changing certain rules of the game.

Specific development scenarios against which an energy strategy must be tested should be selected.

An energy strategy

The strategy formulation process described above should culminate in an energy strategy which encapsulates the programmes of action to achieve a set of goals within a specific time-frame, by means of instruments of modification (policy measures).

Implementation of the strategy

An energy strategy may be implemented through a set of supply and demand management policies and programmes. To achieve the desired objectives, policy instruments in support of optimal energy management could encompass, amongst others, the following(4):

- physical controls, such as electrical load shedding, which are most useful in the short term;
- the technical means to manage the supply of energy, including the research and development of alternative supply technologies, and to influence energy demand, such as the promotion of solar water-heating devices;
- investment instruments which have a major effect on both energy supply and consumption patterns over the longer term;
- education and promotion which may have a major impact on the energy supply situation through efforts to create awareness amongst the populace of cost-effective ways to reduce energy consumption;
- pricing, taxation, subsidies and other financial incentives which can have a marked effect on energy consumption patterns in the long term.

Failure to implement the policies and programmes contained in a strategy is widely recognised as one, if not *the* major, weakness of planning in general in developing countries.

A properly functional institutional framework is therefore a vital precondition for the success of the energy strategy formulation process. The greatest challenge to implementing an integrated energy strategy focuses on the institutional, rather than on the methodological, side.

It is thus imperative that the functional responsibilities of energy support institutions should be delineated in terms of the energy policies and programmes adopted. Special attention should be given to co-ordination at all levels of planning, decision-making, costing, budgeting, implementation, and research and development. Proposals are to be made for feasible adaptations of existing institutional structures or the creation of new institutional structures to expedite the energy policies and programmes. Appropriate funding principles and mechanisms should also be established to support the effective implementation of the energy policies and programmes adopted.

Strategy evaluation

The evaluation of the energy strategy implemented seeks to identify the extent to which specified objectives are being achieved or have been achieved, its impacts on the target group and any unintended consequences. It should be a continuous process and the strategy should be adjusted if required.

It is suggested that four main components should be incorporated in an evaluation(5):

- a review of performance, providing the formal measure of the extent of implementation of the strategy;
- an impact analysis to establish how far the various policies and programmes have been successful in meeting energy and development objectives;
- an appropriate assessment to see how well the strategy components equate with the needs and priorities of the targeted consumer groups;
- an institutional evaluation focusing on the organisational structure, including grass roots as well as higher level institutions involved in the provision of energy services.

Conclusion

In this paper an attempt is made to provide a strategic frame of reference for energy strategy formulation. This conceptual framework highlights the need for energy planning, the approach to and process of energy strategy formulation.

It is anticipated that the conceptual framework will be translated into a more practical learning process once a specific energy strategy formulation project is undertaken. This framework can then form the basis of the project description for such a project.

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*Renewable sources of energy in Africa: Status of development and future contribution to the energy mix

**P N MWANZA AND **Y V PASHKOV

Renewable sources of energy in Africa are widely regarded as alternatives to fossil fuels. Being an abundant indigenous reserve, they offer considerable savings of foreign exchange. Also, they are usually regarded as environmentally friendly and thus do not contribute significantly to the greenhouse effect. However, present contributions of renewable energy to the African energy supply remain negligible despite substantial claims often made about the potential scope for renewable energy forms.

This paper is based on a comprehensive study undertaken by the United Nations' Economic Commission for Africa (ECA) in 1993-1994. The assessment of renewable energy contributions to the energy mix has been made based on data obtained from African countries. A formula reflecting new and renewable sources of energy (NRSE) utilisation was developed and an attempt was made to delineate some zones with identical patterns of NRSE utilisation. Some of the difficulties encounterred in the dissemination of NRSE technologies and incentives introduced by African countries are also discussed.

The conclusion reached is that African states acknowledge the role of NRSE in the development of future world energy systems. Yet the probability of NRSE assuming a greater share in energy supplies within the next two decades in Africa is doubtful.

Keywords: new energy sources; renewable energy; environment; sustainable energy; Sub-Saharan Africa; energy mix

Introduction

A fundamental requirement for economic development in Africa is an adequate energy supply, and prospects for economic growth are closely linked to the provision of affordable and reliable energy. In the majority of African countries current per capita energy consumption levels are very low. However, demand for energy has been increasing rapidly and further growth in energy requirements are predictable in the near future.

At present the energy mix in Sub-Saharan Africa is characterised by a predominance of fuelwood in the domestic sector, cottage industries and agriculture, while industry and transport are strongly dependent on petroleum-based products.

For a number of years, and especially after the UN Nairobi Conference on New and Renewable Sources of Energy held in 1981, the search for less costly and more environmentally friendly and renewable sources of energy has long been a major concern of African countries.

New and renewable sources of energy (NRSE) are widely regarded in African countries as suitable alternatives to fossil fuels. These energy sources, such as solar, biomass, wind and geothermal energy, could ensure the provision of affordable energy and lead to considerable foreign exchange savings in Africa.

The main problem with assessing and monitoring the prospects and progress of NRSE in Africa is the incompleteness of the available data and the scarcity of comparable national statistics covering various types of NRSE and time periods. In most publications the data on NRSE are largely aggregated (e.g. hydro, geothermal, solar together; or hydro and geothermal together; biomass and peat are sometimes included into the solid fuels category, etc.). Information is also inadequate on the final end-use of renewable energy (e.g. heat, electricity) and the categories of consumers (e.g. industry, households, etc.).

For the study on NRSE in Africa described in this paper, a comprehensive questionnaire was developed in co-operation with the Energy Division of United Nations Economic Commission for Europe (ECE)and distributed to all African member states. Table 1 lists the countries which responded to the questionnaire or were visited by ECE staff in 1992-1993. The data collected were analysed and the report(1) compiled.

From the map of Africa (Figure 1) it can be seen that the respondents were the least developed, land-locked and island countries in Sub-Saharan Africa, as well as the relatively developed countries of North Africa. South Africa was not included in the study. The results have taken into account the different levels of development in the countries concerned, as well as the need to reflect on the specifications of the different subregions of Africa.

Despite the fact that most African countries lack the data for a realistic assessment of the present and future rule of NRSE in the energy mix a great deal has recently been spoken of and written about the NRSE potential. Few efforts have been made to take careful stock of the availability and distribution of national resources for the production of energy from biomass, solar radiation, wind or small-hydro sites.

This paper attempts to introduce some quantitative parameters to differentiate African countries on their usage of NRSE and to suggest a certain zonation of the continent on this basis. However, systematic efforts to fill the serious data gaps are a prerequisite for moving beyond this pilot stage. The purpose of such a study would be to address NRSE growth opportunities from the continental and long-term perspective (to the year 2020) and to present scenarios of the possible and desirable development of NRSE in Africa.

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[*] Based on the paper submitted to the Third World Renewable Energy Congress held in Reading, U.K., 11-16 September 1994. The paper was accepted for publication in the Proceedings of the Congress but was not published due to a late submission.

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Renewable energy technologies in use in Africa

The rising costs of conventional energy and the need for environmentally sustainable energy supplies warrant a significant strengthening of the efforts to improve NRSE technologies in terms of technical and economic performance. However, the present cost of generating energy from NRSE sources has been the main hindrance in the more extensive use of these sources in Africa.

In light of Agenda 21 adopted by the Rio Conference, the most attractive feature of NRSE is that they usually do not contribute significantly to the greenhouse effect and could thus be considered as environmentally benign . It is believed that every kWh produced from the sun or wind prevents the introduction of one kg of CO_2 into the atmosphere. This is sufficient motive for the preferential usage of NRSE, besides conserving conventional energy sources.

There are two broad groups of technologies which, in spite of the low budgets allocated for their development, have already demonstrated their viability in the short and long term. The development of these NRSE technologies towards marketability has made substantial progress in relatively few years. These two groups of NRSE technologies are commercially available in Africa. They include solar power for water-heating and small photovoltaic systems, small wind power systems, conventional geothermal technologies and biomass combustion technologies. This paper is not intended to be a comprehensive discussion of the technology options, since there are many excellent references on this subject(3,5,7). However, a summary review of the basic technologies, their current status and momentum, as well as the important lessons learnt in the process of their application will be included in the paper. An overview of the technology options suitable for establishing the basis for subsequent discussion is presented here below.

Economically attractive technologies

Biomass, including fuelwood, charcoal and biogas

The first category of NRSE sources includes economically attractive technologies. These are already cost-effective in some African countries and seem likely to make a significant contribution to African energy supplies. They should be encouraged for development on a commercial scale by the end of this century. These NRSE sources are listed in Table 1 (columns 1 to 5) as inputs into the energy mix.

The world already derives 14% of its energy from biomass, which represents about 25 million of barrels of oil equivalent per day or 55 EJ per year. In Sub-Saharan Africa biomass accounts for 90% of energy use in the rural areas but it also provides an important fuel source for the urban poor and for many small- to medium-size industries based in the rural areas.

Diversity in the types of biomass makes this form of renewable energy fundamentally different from other NRSE sources. However, biomass is mainly used inefficiently, thus there is great scope for improving biomass-based technologies used (e.g. cooking stoves, gasifiers, etc.).

The most successful projects on biomass technologies are those being undertaken in Kenya, Ethiopia and Zimbabwe, and their success is partially attributed to local participation and control from the outset. The biomass in these projects is converted into conventional energy carriers, such as electricity, liquid fuels and biogas. Biogas technology has matured in Africa and the number of biogas digesters of the family and communal type is on the increase in Africa.

Solar technologies: Active solar designs, solar water heating, photovoltaics for water pumping and telecommunication

Daily average solar radiation in Africa is between 5-6 kWh/m^2. Assuming a 10% conversion efficiency, one square kilometre of land in Africa may provide 500 MWh electricity per day.

In solar thermal energy systems there are some well-developed technologies ranging from the solar efficient design of buildings (e.g. in the Ivory Coast, Senegal) to the provision of domestic, commercial and industrial hot water in many African countries. The latter technology is well-known and there are already many local firms manufacturing solar water heating equipment.

Photovoltaic (PV) panels are widely used in Africa for water pumping and telecommunications(7). The application of PV systems for electricity generation is limited by the high cost of imported components, basically the PV panels, and the initial cost of domestic configurations is usually beyond financial capability of an average African family, both in the urban and rural areas. PV use for electricity generation is discussed further in a later section.

Wind energy in coastal areas

Wind energy technology may seem deceptively simple and, together with the wind power use in the past, may explain some of wind energy's credibility. Wind technology has been used for many years in Africa for water pumping and there are some original designs of windmills which have been developed in African countries.

The establishment of wind farms for electricity generation requires strong and steady winds, which usually blow in the coastal areas. Sophisticated and often imported equipment is also necessary, as well as the back-up of an electric utility, to make the wind farms economically viable.

Small-scale hydropower

This technology is well-established and proven in Africa, as well as considered reliable and secure. Most small-scale hydropower projects are "run-of-the-mill", adapted as accurately as possible to short- and long-term variations in the flow. The basic mechanical equipment (turbines and generators) is still imported. However, there is a local capability in the majority of African countries to manufacture all the components of small-hydro power schemes.

Unfortunately, despite their abundant small-hydro power potential, African countries have not taken advantage of this cheap and reliable electricity source. The ECA recently undertook a study on the possibility of the development of a local industry for the manufacture of standardised turbines and generators for small-hydro power. This technology would be and should be made locally, tailored to the special requirements of each country that wishes to utilise it.

Geothermal energy

Geothermal energy is used as a reliable energy source for electricity generation in those countries with geothermal resources. Geothermal plants are in operation in 21 countries around the world and have a combined installed capacity of more than 6 000 MW. Kenya is a pioneer of geothermal programmes and has an installed capacity more than 30 MW at the Olkaria plant. Ethiopia and Djibouti have already completed studies and implemented pilot projects on utilising geothermal energy.

Existing technology now permits the utilisation of a broad range of geothermal resources from moderate-temperature to hypersline brines, as well as natural steam with high levels of non-condensable gases. In comparison with alternatives, geothermal plants are among the most environmentally benign. However, the technology is still very capital intensive and needs to be imported into Africa.

Promising but uncertain technologies

Included under this category are *promising but uncertain technologies* which are likely to become competitive if predicted costs can be achieved or if fuel prices rise in real terms. These technologies should be further supported to bring about improved performance and lower costs.

Energy forestry

Energy forestry is sometimes treated jointly with biomass. Also, it is not only undertaken in developing countries. Some Nordic countries, Sweden in particular, cultivate short-rotation energy plantations of trees, and the establishment of energy forests on farmland receives a direct subsidy from the government. Sweden is phasing out their nuclear power stations and is keen to develop various alternative forms of energy to compensate for this loss to their total installed capacity.

However, Africa could achieve greater success in energy forestry. The ultimate goal of energy plantations in African countries is to substitute all currently burned conventional fuels with fuelwood and charcoal. Many African countries turned to energy forestry after the first "oil crisis" in the 'seventies.

The best known examples of national energy forestry programmes in Africa are from Kenya, the Sudan and Tanzania.

Photovoltaics (PV) for electrification

This type of solar technology is ideally suited to the desert or semi-arid regions of Africa which enjoy clear skies for most of the year. One of the great advantages of PV technology is that the basic units are modular and can be installed as and when the power demand requires system augmentation.

Photovoltaic arrays have proved to be economically viable for electricity generation in rural areas for both cottage industries and domestic uses. These uses of photovoltaic technology have the potential to permeate most aspects of electrical equipment use and to widen the market spectrum considerably for this type of solar technology.

However, PV arrays are still prohibitively expensive in Africa. The project of the Global Environment Facility in Zimbabwe estimated the cost of providing 1 watt from a PV system to be about US$6,2, taking into consideration the cost of panels, power electronics, import and shipping costs. These costs are expected to fall considerably to about US$2,50/WP by the year 2000. Dissemination of PV technologies in Africa and their future are presented in a recent paper by Karekezi *et al.*(7).

The share of renewable energy in the African energy mix

The current status of NRSE development in Africa is encouraging, as most of the sources (biomass, solar, wind, small-hydro and geothermal) are now widely used, and reliable and competitive technologies have been developed for the conversion of these sources into energy. African countries now regard NRSE as a priority in the energy sector but in the majority of the cases no quantitative targets are set. Hence estimation of the present share of NRSE in the African energy mix is guesswork as there are no reliable figures available showing the share of renewable sources in the energy mix.

While substantial claims are often made about the potential scope of renewable energy forms, some recent assessments(2,3,4,5) were rather sobering. Reviews have been conducted on the outlook for economic contributions to the national energy supplies of the principal renewable energy sources considered as alternatives to conventional energy sources. With regard to the present overall technical and economic status of the technologies classified, the studies concluded that remarkable progress had been made since the mid-1970s to develop these new technologies and that they will continue to make an increasing contribution to energy supply. However, at least 30 years may be needed for these technologies to achieve a significant market penetration, even with substantial support for development.

The United Nations Committee on NRSE and on energy for development in their recent report(2) has estimated that "truly" new and renewable sources, such as biomass, solar, wind, small-hydro and geothermal, contribute only 1,6% to the world's energy supply. However, if NRSE sources are expanded to large hydropower schemes, this contribution may amount to about 18% or 1,6 billion tons of oil equivalent (btoe).

The projections for the future contribution of NRSE to the energy mix may vary widely since they are based on different assumptions. For instance, the UN *ad hoc* Solar Energy Group in 1992 estimated that by year 2020 NRSE could supply about one third of the world's energy consumption. The World Energy Council (WEC)(4) forecasts that by the year 2020 the current contribution of 18% will be only slightly increased to about 21% (large hydropower schemes and traditional biomass included).

The NRSE utilisation formula for African countries and the continent's zonation

For the purpose of qualitative assessment, NRSE sources in African countries have been divided into five groups (Table 1). Some relevant information on current percentage share of NRSE in the energy mix has also been included in this table.

Each and every country listed in the table was awarded a NRSE "utilisation formula" which was compiled on the basis of the relative share of the various NRSE sources in the respective countries. The authors realise the conditionality of this formula and its limited applicability for the purpose of Africa's zonation. However, one example could be given to attest to the relative validity of the formula. If one considers two neighbouring countries, Ethiopia and Kenya, their formulas are different because Kenya managed to develop its geothermal potential to such an extent that this energy source is a substantial contributor to the power sector.

From the African renewable energy scheme (Figure 1) two separate zones of NRSE utilisation could be delineated.

These two zones roughly coincide with the geographic areas of the East and West African subregions respectively. From the scheme it can also be concluded that the North African countries have their own set of formulas and that the development of solar energy is a priority in this subregion.

From Table 1, on the basis of which the renewable energy scheme was plotted,

COUNTRY	PLANNING PERIOD	% SHARE NRSE	BIOMASS (1)	SOLAR (2)		WIND (3)	HYDRO POWER (SMALL-SCALE) (4)	GEO-THERMAL (5)	NRSE FORMULA	SOURCE
				PV	THERMAL					
Algeria	To 2000	3,0	500 Biodigest.	7MW	10 000 M^2	1 000 units	–	10^5 SER	252	
Angola	Open	54,0	64 000TJ			<3kJ	<1,0%		123	
Benin	Open	87,0	85,0	0,6		0,15	1,0		124	
Botswana	1991-97	NQT	Y	Y		Y			122	
Burkina Faso	1991-95	21,5	11,5	1,3		0,3	7,7		242	
Burundi	1990-2000	NQT	Y	Y			10,0		124	Country
Cameroun	1988-2010	55,0	45,0	3,5		0,5	4,0		122	
CAR	1994-99	20,0	5,0	3,0			11,0		412	
Congo	Open	<1,0	Y	Y			Y		241	
Equatorial Guinea	1985-95	57,0	Y	2,0			55,0		421	
Ethiopia	1990-2010	94,0	$1,9 \times 10^7$ TOE	$0,4 \times 10^2$ TOE	$2,0 \times 10^3$ TOE	$2,7 \times 10^2$ TOE	$4,2 \times 10^2$ TOE	$3,4 \times 10^3$ TOE	142	Cessen-Ansaldo study
Gabon	Open	NQT	24 KTOE	410 TOE			2 400 TOE		421	
Gambia	1980-2000	12,0	10,0	1,0		1,0			123	
Ghana	Open	NQT	Y	Y	Y	Y	Y		122	
Guinea	1989-2005	5,0	1,0	1,0	0,5	0,5	2,0		412	Country
Kenya	1994-99	NQT	Y	Y	Y	Y	Y	YY	512	
Lesotho	To 2010	80,0	79,0	0,2	0,05		0,7		142	
Madagascar	To 2010	83,5	3 316 TOE	4 TOE	4 TOE	4 TOE	86 TOE		142	
Malawi	1988-97	95,0	93,0	<1,0	<1,0		4,5 MW		142	
Mali	1984-2000	85,0	80,0	3,0	1,0	0,5	0,5		122	
Mauritius	1992-94	40,0	35,0	0,5	1,0	0,5	3,0		142	
Morocco	1993-95	0,2	1 223 TOE	1 377 TOE	4 554 TOE	3 080 TOE	46 TOE		232	
Namibia	1990-2000	37,0	13,4	0,1		0,13	23,3		412	Country
Niger	1994-98	3,5	0,1	3,1	0,2	0,1			232	
Nigeria	Open	NQT	Y	Y	Y	Y	Y		123	
Rwanda	1992-94	95,0	94,0	0,1			0,9		142	
Sao Tome	To 2010	60,0	5,0	5,0	Y	Y	50,0		421	Country
Senegal	1990-94	69,0	850 KTOE	3,0			Y		124	
Seychelles	1990-94	NQT	Y	Y	Y	Y	Y		212	
Sudan	1992-2003	1,0	Y	Y	Y	Y	Y		142	
Swaziland	1994-97	45,0	22,25	18,25		2,25			123	
Tanzania	Open	90,0	60,0	10,0	5,0	5,0	8,0	2.0	142	Country
Tunisia	2001-2010		50 KTOE	5 MW	200 KTOE	20 MW			213	Country
Zimbabwe	Open	NQT	Y	Y	Y		Y		123	Country

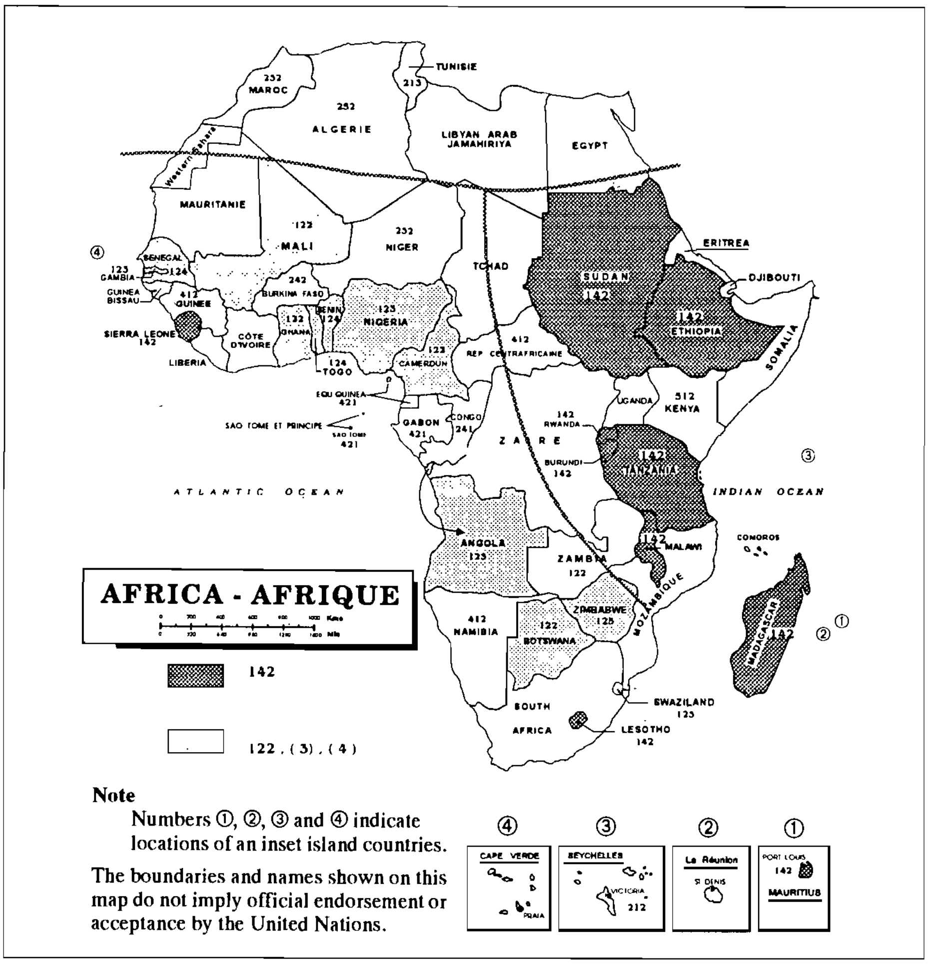
NQT - NO QUANTITATIVE TARGETS; 80,0%, IF UNIT IS NOT SPECIFIED;

Table 1: African NRSE formula: 1994

some interesting observations could be made. For instance, Namibia indicated that the utilisation of NRSE sources in the primary energy supply by the year 2000 is forecast at 36,9%. Hydro resources in this country contributed about 12,8% to the electricity supply in 1990, but are expected to contribute 36,4% by the year 2000.

Tunisia has set a target of 5,2% of NRSE utilisation in the future energy supply mix. The government of Tunisia has an energy policy which combines energy conservation and efficiency measures with the introduction of renewable technologies. As a result Tunisia's marginal energy intensity dropped from 1,3 in 1985 to 0,8 in 1989, which is attributable in part to these efforts.

Back in 1982, Egypt formulated a national strategy for the development and utilisation of NRSE which envisaged that 5% of the country's energy needs will be supplied through the application of modern NRSE technologies, with particular emphasis on wind power. The Egyptian government embarked on a well-conceived programme of integrated development of NRSE which aimed at harnessing geothermal power resources, solar energy for domestic use, and wind farms for electricity generation.



Note

Numbers ①, ②, ③ and ④ indicate locations of an inset island countries.

The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

Figure 1: African renewable energy scheme 1995: NRSE formula

Incentives for NRSE development

In constructing alternative scenarios for the development of NRSE in Africa it is important to take into account many indicators. This, however, poses the problem of the selection of an indicator with which to compare scenario outcomes. For this study, the indicator selected was the availability of incentives for R&D and their use for NRSE. With regard to critical uncertainties, it was decided to emphasise (a) the evolution of science and technology and availability of technical innovations in African countries; and (b) the lack of investment capital for the development of NRSE.

Since the Nairobi conference on NRSE, African governments have realised that NRSE could contribute to the aims of energy and environmental policies. Hence, they supported the development of renewable technologies and their utilisation. The development of NRSE for commercial marketing required funding over a long period of time, and new technologies have received limited backing from the private sector in the majority of African countries.

The issue of government incentives and subsidies for the development of NRSE is not new in Africa. In the national policies and programmes on NRSE development, governments have envisaged subsidies for research, development and demonstration (RD&D), the creation of institutional infrastructures, support for marketing, and the promotion of economic competitiveness.

The subsidies and incentives for the development of NRSE are not necessarily characteristic of the developing world. For example, the government of the United Kingdom recently announced that, as part of its proposals to privatise the electricity supply industry, there will be an obligation on the electricity supply companies to generate up to 600 MW capacity from renewable energy sources.

The aim of subsidies should be to encourage viable industries and development without encouraging dependency, and possibly to foster some degree of competition and market behaviour. In African countries which have a largely state-driven electricity supply industry, the state may express a clear policy preference for the utilisation of renewable energy through subsidies. In a competitive market, subsidies can be used to the advantage of the preferred sources of energy. Basically, two methods are employed in subsidies: (i) reducing capital costs by various means, and (ii) the paying of a premium price for electricity. It is worth considering the different methods of subsidisation for NRSE in some African countries and how successful they have been.

The utilisation of NRSE in conjunction with the national programmes for enhancing energy efficiency is economically attractive to African countries. Deployed on a commercial scale and with subsidies, NRSE may have immense benefits to offer African populations, especially in the rural areas and to all who use NRSE, and that means everyone on the continent.

Most of the RD&D programmes for the development and utilisation of NRSE in Africa started, as in Europe and the rest of the world, as a result of the first increase in oil prices in 1973. A steady increase has been noted up to 1977 and a new peak occurred immediately after the Nairobi Conference on NRSE. The gap between research, industrial development and commercialisation was bridged only recently, However, the levels of government support for NRSE have not always been maintained.

Some African countries (e.g. Senegal, Zimbabwe) gained experience in providing incentives for RD&D and the use of NRSE over a period of more than 15 years (Tables 2 and 3). This experience could be usefully shared with the other African countries. Unfortunately, government support for NRSE has decreased sharply as a result of low oil prices and budgetary constraints. This decline in government interest has discouraged industry in the development of NRSE.

Difficulties in the dissemination of NRSE technologies

In disseminating NRSE technologies African countries are faced with quite a number of difficulties. The major problems are financial and institutional in origin. In African countries there is a lack

INCENTIVES FOR R&D	BURUNDI	SAO TOME	SENEGAL	ZIMBABWE
Financial	An amount of US$40 000 is yearly allocated to NRSE RD&D by the government. Funds are also provided by EEC.	International, bilateral and multilateral technical assistance is provided.	Financing of the national energy programme includes allocations for NRSE development. Multilateral co-operation in financing of projects is sought.	R&D section under the DOE budget is allocated funds for NRSE promotion. Grants from EEC, UNIDO for NRSE pilot projects. GEF grant for PV utilisation, German grant for PV pumping on 15 sites.
Administrative	N.A.	Training of manpower is regulated by the government.	R&D in NRSE is supervised by the Ministry of Technology.	Solar manufacturers have established an association which, together with the standard association of Zimbabwe, will look into issues of codes of practice and conduct for their members. For other NRSE technologies there are no such guarantees.
Legal	N.A.	Favourable legislation aimed at facilitating R&D for NRSE technologies was inserted into the goverment-sponsored programme.	The government assumes responsibility for developing NRSE. The regulations are in force encouraging the establishment of private companies. The National Committee on Energy is co-ordinating the NRSE programme.	Embodied in the objectives of the energy policy. Emphasis is on research, development and promotion of NRSE.
Fiscal	N.A.	NRSE technologies are exempted from all taxes.	In 1991 the Interministerial Council lifted all taxes on solar equipment.	Discussions already underway to reduce/remove taxes, duties levies on NRSE components, especially on imported NRSE technologies. Some NRSE technologies (PV, biogas) are subsidised by government.

Table 2: Incentives for R&D in selected African countries

of investment capital for the development of NRSE and, moreover, their use in rural and remote areas is inhibited by the inability to deal with the sophisticated equipment. These impediments to the development and use of renewable sources of energy contrasted with the significant growth potential to be derived by the cost reduction due to technical improvements, mass production and international co-operation in the development of NRSE and their further use in recognising the environmental and ecological advantages of these sources.

Many African countries also lack suitable institutions that can serve as focal points for planning strategies for NRSE, devising and supporting RD&D programmes, and promoting commercial applications.

There is a feeling that the production and management of NRSE should be more centralised and industrialised for both rural and urban areas, and that it should be used as part of an integrated production system. In this way, advanced technologies could be used to increase production and financial returns and thus will have greater appeal to African people.

Regional co-operation in Africa in the development of NRSE is extremely limited. There are few examples of joint projects, and a great deal of effort is wasted because activities are not co-ordinated at the subregional or regional level. The establishment of the African Regional Centre for Solar Energy (ARCSE) in Burundi has not fulfilled the high expectations of African countries, since the limited financial allocations from these countries could not provide even for the basic requirements for research and development in NRSE. Consequently, the institution and its operational activities are facing closure due to a lack of finance.

Lack of adequate technical capabilities is another obstacle to the implementation of NRSE projects. This also creates difficulties in identifying suitable NRSE technologies, as the selection, installation and adaptation of equipment requires expertise in the field as well as well-trained manpower.

Weaknesses in the industrial infrastructure is also a problem in several African countries. Implementation of NRSE projects, including those carried out for research and demonstration purposes, requires equipment and components which cannot be provided locally. Apart from biogas and some components of solar and wind energy systems, expensive equipment and materials are often imported, with the total cost of the project ending up, in some cases, out of all proportion to the benefits. In addition, many NRSE projects have ended in complete failure due to the transfer of inappropriate technologies and the lack of industrial know-how for their adaptation to local conditions.

In several cases, lack of awareness of the importance of NRSE from policy-makers and substantive ministries in African countries is an additional obstacle hinde-

INCENTIVES FOR USE OF NSRE	BURUNDI	GUINEA	SAO TOME	SENEGAL	TUNISIA	ZIMBABWE
Financial	Biogas digesters are built at government expense, and the cost is recovered from the beneficiary (with subsidies) on installment. Funds are provided by GTZ.	Public projects get government support, private companies get financing from private banks.	N.A.	Non-reimbursable loans for projects on NRSE assured by the Government. Government subsidies are in place for solar energy technologies.	Soft loans for NRSE projects in priority areas.	Government grants, donor funds under bilateral/multi-lateral agreement. Soft loans for end-users are envisaged under GEF and local financial institutions.
Administrative	N.A.	N.A.	N.A.	Adequate structures for administrative incentive schemes are being developed.	Demonstration projects are subsidised up to 50%, with ceiling set at US$23 000.	Under the GEF programme, a solar PV system promotion campaign is envisaged together with the establishment of codes of practice and conduct for manufactures to install, guarantee, test etc. An awareness and information programme, promoted.
Legal	N.A.	The participation of private sector in NRSE development is encouraged by the government.	A legal framework is being worked out ensuring equal opportunities for consumers in the public and private sectors.	Code of investment into the development of NRSE adopted. Provisions are in favour of establishing private solar companies.	Government regulated minimal customs duties for imported NRSE and VAT exemption. Law No. 90-62 of 22 July 1990 on energy matters.	Policy on NRSE is in place. Communal Lands Act deters people from cutting down trees, and any violation of the Act is liable to fines.
Fiscal	N.A.	All charges and levies on importation of NRSE equipment in the public sector were lifted.	N.A.	No taxes on import of solar energy equipment or materials.	Fiscal allowance for NRSE equipment for 3 years.	Levies/duties and surcharges which are usually passed on to the end-users, are lifted/reduced under the GEF programme. This will provide incentives for the use of NRSE.

Table 3: Incentives for the use of NSRE in selected African countries

ring the development of NRSE and frustrating efforts to promote the implementation of NRSE projects. This has clearly manifested itself in the collection of data for this publication when the ECA Secretariat spared no effort in developing and distributing a comprehensive questionnaire to which few countries bothered to reply.

In spite of all these problems, the prospects for NRSE development in Africa are highly promising. The feedback from the number of regional meetings held by the ECA on NRSE was encouraging. With a more concerted effort and closer co-operation, programmes for resource evaluation, manpower development and the identification of suitable technologies may be implemented without much difficulty. This has provided a solid background for improving the present status of NRSE in the African region and for launching more appropriate NRSE projects.

Recommendations for priority actions

The following is a list of recommendations proposed by African countries at the various meetings on NRSE organised by the ECA.

(1) *Improving the statistical database on NRSE.*

Because of deficiencies in the existing database and the lack of international comparability, it is difficult to assess the growth prospects and to monitor the progress of NRSE. The development potential of NRSE and achievements already made are believed to be underestimated because of the lack of internationally comparable technical and economic performance indicators. An African regional data bank for NRSE should be established to cover installed energy generating capacity; primary energy and electricity production; end-uses, etc.

(2) *To establish a regional NRSE network, and to improve and consolidate subregional networks.*

A lack of information about developments underway and experiences gained with NRSE is hampering their use and further development in African countries. Regional and subregional networks should be created or consolidated for the purpose of exchanging experiences, sharing research, training and marketing facilities, and promoting the development and use of NRSE.

(3) *To compile and publish a compendium of incentives for NRSE.*

Many countries have gained experience in the use of various incentives for NRSE over a period of more than 15 years and this experience could be usefully shared with other countries. Such a publication prepared by an organisation such as the ECA, which lists the types of forms of incentives and assesses the results achieved in a comparable format, would encourage an exchange of views and improvements in this area (Tables 2 and 3).

(4) *To integrate NRSE in policy-making documents and in the agendas of all meetings concerned with the environmental sustainability of energy development in Africa.*

NRSE has an important role to play, not only in energy planning, but also in the attainment of environmental goals. To fulfil these potentials, NRSE must be integrated into all environmental and energy policies, as well as included in all discussions relating to sustainable development and environmental protection.

(5) *To promote trade and inter-African industrial co-operation in NRSE in line with the Abuja treaty.*

For this purpose, surveys of joint venture opportunities should be carried out and the information widely disseminated in order to facilitate intra-African trade in NRSE equipment and the transfer of NRSE technologies. This will in turn create larger markets, encourage standardisation and mass production, reduce costs, improve the knowledge of market opportunities and build an intra-African trade infrastructure for NRSE.

Conclusions

In order to assess the contributions that NRSE may make in the future to Africa's energy supplies, the ECA analysed performance data collected from African countries through questionnaires and field trips to selected countries. This data were produced by research and development programmes implemented by African countries against a range of future fuel price scenarios.

The results of this analysis were used to assign each renewable energy source and related technology to one of two broad categories:

(i) economically attractive;
(ii) promising but uncertain.

Economically attractive technologies, i.e. those that are already cost-effective in some African countries, are likely to make a significant contribution to African energy supplies and should be encouraged commercially. Promising but uncertain technologies are those which are likely to become competitive if predicted costs can be achieved or if fuel prices rise in real terms, and which should be further supported to bring about improved performance and lower costs. An attempt has also been made to work out the formula of NRSE utilisation in some African countries (Table 1).

The development of renewable energy technologies in Africa goes hand-in-hand with measures to improve energy efficiency, for there is little point in increasing the available range of energy supplies without taking steps to make the best use of them. Africa has the potential to cut its annual energy consumption by as much as 20%, or approximately US$100 million a year. Savings are attainable in every sector of the African economy.

In the light of this analysis, it seems probable that from 1995 onwards renewable energy will be making a small but useful and growing contribution to Africa's energy supplies. By 2025, if all goes well, NRSE could be producing substantial amounts of energy both in the form of heat and electricity.

The actual contribution, of course, is ultimately unpredictable since it will depend on how economic circumstances evolve in Africa and more especially, on the movement of international energy prices. What is certain, however, is that the promise of NRSE will only be fulfilled if appropriate steps are taken now. From the early 1980s much of the work was concerned with science and engineering. The utilisation of the more promising NRSE sources are now moving out of the research stage towards commercialisation.

The ECA Secretariat and other regional, subregional and national institutions are seeking increased collaboration with manufacturers and potential energy users in African countries in order to encourage technology transfer and effective marketing. The aim is that ultimately industry should take full responsibility for NRSE technologies and that they should be allowed to prosper according to commercial forces.

Given the weak basis from which the region's renewable energy resources will develop, this paper argues for a need for African countries and the donor community to work together in properly addressing these issues in order to harness Africa's major renewable resources so that solid bases for the growth of the energy sector can be provided.

This paper has attempted to show that NRSE cannot be considered as a single homogeneous entity in assessing the possible medium-term impacts upon Africa's energy supply/demand balance.

There are still arguments over NRSE's power economics. The point is that in assessing the potential of renewables, absolutely objective comparisons are hard to come by. It is also difficult to know where to draw the boundaries of economic appraisal. Renewable energy produces no emissions and no greenhouse gases yet currently receives no credit for this. Attention has recently started to focus on the relative social or external costs of energy, although the problem of quantifying these accurately still remains.

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Energy and monetary savings for developed households in South Africa

*M KLEINGELD, *E H MATHEWS, *W F FULS AND *A SHUTTLEWORTH

The domestic sector is a major energy consumer and contributor to peak demand. It is claimed that an awareness campaign to save energy will address these problems. Such a campaign is expected to have a wider impact, since people who save energy at home will save energy at work. The multiplication effect is thus incalculable. Such a campaign was initiated by the Department of Mineral and Energy Affairs.

In order for the campaign to succeed, it is important to motivate households to participate. The best motivator is probably extra money in the pocket. However, no published data were found which gave monetary values for different energy-saving suggestions. This article presents these values for South Africa.

The energy-saving suggestions of the campaign were rated according to the monetary value and the ease of implementation. To keep the results independent of inflation, the time it takes to save for a cinema ticket was used as the monetary unit. This unit is easily understood by people of all ages and cultures.

Only the best energy-saving suggestions were used in the campaign.

Keywords: energy conservation; energy efficiency; domestic energy; South Africa; monetary values

Introduction

Energy is an important topic world-wide. Many countries have initiated campaigns to promote energy conservation and several have focused on the domestic sector. In South Africa the Department of Mineral and Energy Affairs (DMEA) started a similar campaign.

It is postulated that people who save energy at home will also save energy at work. Furthermore, if children learn to save energy at home, they are likely to save energy when they become the leaders in commerce and industry. The DMEA campaign is therefore expected to have a wide impact.

The domestic sector is one of the largest contributors to peak electricity demand(1). This sector also contributes to 15% of South Africa's electricity consumption(1). Thus energy savings will be of benefit to this sector.

The success of a campaign to encourage the use of domestic energy more effectively will depend on the successful motivation of the public. The most effective motivator is probably money in the pocket. Energy savings should therefore be expressed in monetary terms. No calculated values for specific energy savings could be found for South African conditions. This article presents these monetary values. These monetary values must also be independent of inflation if they are to remain valid in the future. An idea for such a monetary unit to be used in this campaign was a cinema ticket as it is easily understood by people of all ages and cultures.

Energy saving suggestions may result in large monetary savings, yet may be difficult to implement. However, the time, money and effort needed to realise these suggestions, together with the monetary savings, must be taken into consideration, as they will determine which suggestions are acceptable to households.

Therefore the saving suggestions were rated according to their ease of implementation and potential monetary savings. Only the most realistic suggestions were used in the DMEA campaign.

Important assumptions and limitations

Households in the developed sector of South Africa use electricity for more than 93% of their energy requirements(2). This article therefore emphasises only suggestions which will save electrical energy.

The rating of these energy-saving suggestions is very subjective. Each person is unique and has his/her own preferences. Therefore there could be differences of opinion over the ratings suggested. In this campaign, it was attempted to give ratings that will be acceptable to most people.

The study was conducted using an average monthly electrical energy consumption figure of 1 150 kWh(2). The rate of 17,1c per kWh for Pretoria was used. This converts to a monthly account of R197. This amount does not take into account the fixed levy paid for electricity supply.

The energy-saving hints in this article will not necessarily have the savings effect as claimed in this paper for various reasons. A household with an electricity account of R197 per month may already be relatively energy efficient. Failure to apply the hints given could thus lead to an increase in energy consumption. It would thus be incorrect to add all the savings to obtain a total monthly saving. This total could be more than the monthly energy account!

The household assumed in this study would typically consist of two adults and two children, in the medium- to upper-income bracket. They would be earning in excess of R2 000 per month in 1992 terms(2). This is why saving suggestions for a swimming-pool, dishwasher, tumble-drier and other luxury equipment are included.

The energy usage patterns of household equipment as determined by Eskom(3) were utilised to predict realistic savings. The calculation of the monetary value, namely, the price of a cinema ticket, was assumed to be R10. The details of all the calculations are described in more detail in a report to the Department of Mineral and Energy Affairs(4). Only the final results are summarised in this article.

Water-heating

It has been estimated that the hot water system of an average household accounts for 40% of the annual energy consump-

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	+SUGGESTION	SAVING/MONTH (R)	++SAVING TIME IN MONTHS
1	Shower instead of taking a bath	14,40	0,7
2	Do not rinse dishes under running hot water	3,42	2,9
3	Avoid using the hot water tap for small amounts of water	6,84	1,5
4	Plug bath/basin before hot water tap is opened	1,37	7,3
5	Repair leaking hot water taps	6,84	1,5
6	Set geyser thermostat between 50-60 degrees C	10,26	1,0
7	Insulate geyser and the first 1,5 m of the hot water pipes	3,95	2,5
8	Switch geyser off when away from home for more than 3 days	3,99	2,5
9	Fit flow restictors to shower heads	5,47	1,8

+ The saving suggestions were rated according to the monetary value and ease of implementation.

++ This is the time it takes to save enough money to buy a R10 cinema ticket.

Table 1: Water-heating savings suggestions

tion in developed households(1). Hot water savings should therefore have a visible effect on the monthly electricity account.

Many of the suggestions made in this campaign relate to habits that can be changed. They are therefore more important than retrofits. It is suggested that the less effort, money and time required to change these habits, the more likely the suggestion will be implemented.

Table 1 presents a summary of some of the most realistic saving suggestions for water-heating, each discussed in more detail below.

It is claimed that the easiest habit to break is to shower rather than to bathe. It may be inconvenient the first few times but should become a habit very quickly. Besides being easy to implement, a relatively high saving of R14,40 per month can be achieved. However, if the shower takes more than ten minutes it will be more cost-effective to bathe in a half-filled bath. Also, it is often dangerous for elderly people and small children to shower because of a slippery floor. The use of a rubber non-slip shower-mat will solve this problem. Small children also have difficulty in reaching the taps.

Another common habit is to rinse dishes under running hot water. It is suggested that it would be more cost-effective to to use a filled basin for rinsing the dishes. This also is not considered a difficult habit to break, especially when the estimated saving is R3,42 per month.

The hot water tap is often used for small amounts of water, for example, filling the kettle. It may save time but it costs an extra R6,84 per month for the geyser to regain that lost heat. It will thus be cheaper to fill the kettle with cold water rather than lukewarm geyser water.

A basin or bath should be plugged before the hot water tap is opened. Usually the water becomes too hot and cold water must be added afterwards anyway. Thus the cold water entering the basin initially will compensate for this. Although this is not a significant saving, it is easy to implement and will save money and water.

The following suggestions require some handyman abilities. In some cases an investment in other appliances and the need for professional installation will be required. This could result in a certain reluctance to implement these saving suggestions.

Apart from the water loss incurred, leaking hot water taps could cost nearly R7,00 per month in wasted energy. Fortunately it is not too difficult or expensive to repair.

Setting the geyser's thermostat to between 50°C and 60°C may be difficult since geysers are often located above the ceiling. However, reducing the geyser's thermostat has the advantage that extra cold water need not be added for bathing or showering. When considering that a saving of R10,26 per month can be achieved, it may be worth the effort.

Related to the previous suggestion, another energy-saving measure is to insulate the geyser and the first 1,5 m of the hot water pipes. The estimated payback period for this type of insulation is 13 months.

Switching the geyser off when going on holiday may be inconvenient, especially on returning home. This problem can be overcome by installing a time-switch which could result in a monthly saving of R3,99. However, an initial expense may be incurred as time-switches are expensive to install. If it is decided not to install a time-switch, savings can still be achieved if the geyser is switched on when one arrives back from holiday, as it only requires two to three hours to heat up the water.

Flow restrictors, a device for reducing the flow of hot water, can be fitted to any shower head or hot water pipe. Such restrictors are very cheap and could result in savings of up to R5,47 per month on the electricity bill.

South Africa is a country with limited water resources. It is claimed that the implementation of these energy-saving suggestions will also reduce overall water consumption.

Space-heating

It has been estimated that interior heating (or space-heating) consumes 12% of domestic energy consumption annually(1). Saving suggestions for space-cooling were omitted in this campaign because only 3% of the households surveyed had air-conditioners(1).

Table 2 lists the ten most appropriate energy-saving suggestions for space-heating.

It is important that people dress according to the climate of the country or region. It is better to wear insulating clothing, such as woollen jerseys, as this would mean that thermostat settings can be lowered and less use will be made of heaters. It would therefore be more cost-effective to use more blankets rather than heaters. It is unnecessary to heat the entire room when only the bed needs to be warm. Blankets are usually cheaper than heaters, and a saving of R6,84 per month can be achieved in this way.

Energy can be saved by keeping the doors to heated rooms closed. This will reduce the load on the heater and ensure a smaller temperature gradient throughout the room. A wasteful habit is to keep the heater on when the room is unoccupied. Also, some heaters may be hazardous if left unattended. By implementing this suggestion it will be possible not only to save money but also to reduce the risk of fire.

Preventing draughts through the house presents a potential saving of R8,55 per month. Only a few windows or a strategically placed door inside the house need be closed to stop a draught. It will also be beneficial to seal the gaps beneath doors and around window frames.

A saving suggestion that requires some effort is the insulation of the roof. Installation is often done by professionals, thus making it even more expensive. On the other hand, insulated roofs offer a potential saving of R10,02 per month. To reduce costs, possibly only the large living areas should be insulated.

As previously mentioned, electric blankets should be used instead of heaters ensuring that heat is localised to heating only the bed. Electric blankets are expensive but the saving of R6,16 per month will result in a short payback period. For safety reasons, only high quality blankets (i.e. those approved by the SABS) should be used.

With regard to heaters, it is more efficient to heat the person than the air. Convective heaters cause warm air to rise to the ceiling where heat is lost. On the other hand, radiative heaters eliminate this problem because they heat the person and not the air. Thus radiative heaters are more efficient than convective heaters. However, some radiative heaters are hazardous because of open elements.

A common mistake often made is to overheat the room. By experimenting with different thermostat settings the most comfortable setting can be found. If no thermostat is available, it is suggested that heaters be used in cycles.

Use of glass windows and doors result in major energy losses. This problem can be solved by using thick curtains as a form of insulation. Pelmets should also be closed at the top in order to prevent energy losses.

	+SUGGESTION	SAVING/MONTH (R)	++SAVING TIME IN MONTHS
1	Dress according to the interior climate	5,13	1,9
2	Use blankets rather than electric blankets	6,84	1,5
3	Close the doors of heated rooms	7,78	1,3
4	Switch heaters off when the room is unoccupied	3,42	2,9
5	Draughtproof the house by sealing windows,doors	8,55	1,2
6	Insulate the roof	10,20	1,0
7	Use electric blankets rather than electric heaters	6,16	1,6
8	Use radiative heaters rather than convective heaters	8,55	1,2
9	Do not overheat the room. Lower the thermostat setting or switch off the heater	3,08	3,2
10	Use thick curtains & pelmets closed at the top to insulate windows and glass doors	5,13	1,9

\+ The saving suggestions were rated according to monetary value and ease of implementation.

++ This refers to the time it takes to save enough money to buy a cinema ticket of R10.

Table 2: Space-heating energy savings suggestions

The kitchen and laundry

Various energy-consuming appliances are used in the kitchen and laundry. Significant energy savings can be made if these appliances are used correctly. Table 3 lists these savings rated according to their relevance for the household.

	+SUGGESTION	SAVING/MONTH (R)	++SAVING TIME IN MONTHS
1	Sun-dry the washing	11,08	0,9
2	Load the tumble drier and dishwasher to full capacity	12,83	0,8
3	Use the economy cycle on the dishwasher (least water at the lowest temperature	8,12	1,2
4	Use small appliances (kettle, frying pan, pressure cooker, etc.) rather than the stove	9,20	1,1
5	Do not open the fridge or oven unnecessarily or for extended periods	3,94	2,5
6	Check the door seals of the fridge, freezer and oven	5,71	1,8
7	Set the fridge at its warmest possible setting	4,23	2,4
8	Defrost foods before cooking	2,57	3,9
9	Leave lids on pots while cooking	2,17	4,6
10	Do not over-dry washing in the tumble-drier	2,05	4,9
11	Use a microwave oven rather than a stove	9,04	1,1
12	The bottoms of pots should be the same size as the plate	1,02	9,8

\+ These savings suggestions were rated according to monetary value and ease of implementation.

++ This refers to the time it takes to save enough money to buy a cinema ticket of R10.

Table 3: Kitchen and laundry energy savings

South Africa is a country with abundant sunshine. By sun-drying the washing, the use of a tumble-drier can almost be eliminated. This could result in a saving of R11,08 per month, which should outweigh the effort involved. It is unnecessary to over-dry the washing in the tumble-drier, but it may be inconvenient to frequently check on the clothes. Initial experimentation will help in choosing the shortest time cycle.

Also, it is important to fill the dishwasher and tumble-drier to their maximum capacity without overloading them. The potential saving of R12,83 per month ought to be a good motivator. This suggestion only applies to relatively large families. In general, small families do not usually have sufficient laundry or dishes to warrant the efficient use of tumble-driers and dishwashers. It would mean

	+SUGGESTION	SAVING/MONTH (R)	++SAVING TIME IN MONTHS
1	Switch off household appliances, lights and power tools after use	R6,06	1,7
2	Install movement sensors on security and other exterior lights	R35,91	0,3
3	Rely on daylight rather than artificial lighting	R4,92	2,0
4	Use fluorescent tubes instead of normal incandescent bulbs	R4,93	2,0
5	Use low wattage lamps for interior and exterior lighting	R2,82	3,5
6	Minimise the use of a hair-drier by using a towel	R0,96	10,4
7	With area bound chores, use task lighting	R0,68	14,7
8	Clean and service the pool pump and filter regularly	R18,46	0,5
9	Reduce the cycle time of pool pumps	R10,26	1,0

\+ The savings suggestions were rated according to monetary value and ease of implementation.

++ This is the time it takes to save enough money to buy a R10 cinema ticket.

Table 4: Other appliances

that the washing and dishes will have to accumulate over too long a period before the respective appliances can be filled to capacity.

Also, many dishwashers have a short economy wash setting that could result in a saving of up to R8,12 per month.

Small appliances, such as kettles, toasters, frying pans and pressure cookers, should be used in preference to using the oven, as these appliances are generally faster and more energy-efficient. This could result in a potential saving of R9,20 per month.

Browsing through the fridge or freezer, where the door is left open for a long time, should also be discouraged. Opening the door unnecessarily also leads to energy losses. It is not necessary to have the fridge set to a very cold setting as this will only cause milk and other liquids to freeze during a cold night. On the other hand, setting the fridge too warm may cause some foods to spoil.

By defrosting food, cooking times will be reduced. This requires that frozen foods be taken from the freezer long before cooking. To reduce health risks, food can be defrosted in the fridge. The planning of meals will also help to solve this problem.

The door seals of the fridge, freezer and oven should all be checked annually. Perished seals could add an extra R5,71 to the monthly electricity account. Although the inspection demands little effort, repairing a faulty seal could be expensive and difficult for some equipment.

Cooking with lids on pots and pans will save energy and time. Peeks into the pots and pans to check on the food should be kept to a minimum. A problem may occur when cooking times are unknown. One solution is to use transparent lids. The bottoms of pots and pans should be the same size as the stove plates to prevent unnecessary loss of heat. Pots and pans should also have thick flat bases to heat the food evenly.

Although microwave ovens are expensive, about 54% of households already own one(1). Apart from being faster and more convenient they are also more energy-efficient than a conventional stove, and should therefore be used as often as possible.

Other energy-consuming appliances

This section discusses electrical appliances not mentioned in the previous sections. These are lights, power tools, other small appliances, and swimming-pool pumps. Saving suggestions for this category are listed in Table 4.

A habit that should become second nature is to switch off electric household appliances, power tools and lights when not in use, as this could save at least R6,06 per month on the electricity bill.

Many houses have security and other exterior lights. It is usually unnecessary to keep them burning throughout the night as the movement sensors connected to these lights will come into operation when required. Thus the estimated household energy saving could be R35,91 per month.

The sun is a free light source that should be used more often. It is easy to arrange furniture for optimal use of sunlight, for example, placing a desk near the window. However, direct sunlight may be uncomfortable, even damaging to furniture. The use of inside net curtains or exterior shading may solve this problem.

It is more energy-efficient to use task lighting with area-bound chores. For example, desk lamps are cheap and easily available. Unfortunately the energy saving is small - only R0,68 per month.

A new trend is to use fluorescent tubes rather than normal incandescent bulbs as fluorescent lighting is more energy-efficient. Although these units are expensive, their expected life-span is six times longer than for normal incandescent bulbs. It is also unnecessary to always use high wattage bulbs. For example, 100 W bulbs can be substituted with 60 W bulbs where bright light is not needed.

To minimise the use of a hair-drier, a towel can be used. However, this may not be acceptable to those whose hair styles require blow-drying.

Approximately 25% of households in the developed sector have swimming-pools(1), but the cleaning and servicing of the pump and filter are often neglected. If undertaken on a regular basis, this could result in a saving of up to R18,46 per month. Also, swimming-pool pumps normally have an adjustable time cycle. If a reduced cycle is used, a further saving of R10,26 per month is possible. During summer the cycle can be reduced to 6 hours/day, and in winter to 4 hours per day.

It is important to bear in mind that not every household has all the above-mentioned appliances. However, remarkable savings can still be achieved by implementing these suggestions where applicable.

Designing or buying a house

Energy savings in existing houses are the responsibility of the home-owner and his family. It would be their prerogative to change wasteful habits and to possibly undertake modifications to ensure greater energy efficiency. However, when designing a new house, energy conserving measures can be planned beforehand. Some of these measures are given in Table 5.

	⁺SUGGESTIONS	SAVINGS/MONTH (R)	⁺⁺SAVING TIME IN MONTHS
1	Insulate the roof	19,97	0,5
2	Plan light fittings for the most economic lights: • Fluorescent lights • Large bulbs	 4,93 5,10	 2,0 2,0
3	Draughtproof the house during the building stage	8,55	1,2
4	Design the house to be in ground contact	9,44	1,1
5	Insulate the geyser	3,95	2,5
6	Plan the house to face north	4,90	2,0
7	Install the geyser as close as possible to areas of major use	2,08	4,8

\+ These savings suggestions were rated according to monetary value and ease of implementation.

++ This is the time it takes to save enough money to buy a R10 cinema ticket.

Table 5: Suggested energy savings in the design or purchase of a new house

It should be noted that some of the saving suggestions have been mentioned in some of the previous tables. The discussion will however differ because of changed circumstances.

Insulation of the roof can result in an estimated monthly saving of R19,97. It is also easier to insulate during the construction stage than afterwards.

As previously mentioned, it is important to choose the correct light fittings when designing a new house. Changing to more economical and energy-efficient lights later on is expensive and sometimes difficult. The best choice may be fluorescent lights. Although these fittings are expensive, it may result in a monthly saving of up to R4,93 in the long run. The second best choice would be to rather install one large incandescent bulb rather than two small ones.

Draughts can quickly introduce cool air into a house. Properly sealed window frames and doors that seal could prevent such draughts. This will also prevent rain from entering during a violent storm.

The earth is an effective heat capacitor. If the house is in contact with the ground, indoor air temperature fluctuations will be minimised. Rooms supported on pillars will be very cold on a cold day. However, if these rooms were in contact with the ground, the temperatures would be more moderate.

Since water-heating is costly, geyser losses should be kept to a minimum. As previously mentioned, insulation of the geyser and the first 1,5 m of warm water pipe is easy to implement during the building phase. Left-over pieces from the roof insulation can be used. The geyser should be installed as close as possible to the major areas of use. Shorter hot water pipes will reduce heat losses. Although the monthly saving is small, less money will also be spent on hot water pipes. A square floor plan should make this suggestion easier to implement.

The orientation of a house also has a considerable effect on the interior temperature. Houses facing north are much warmer during the winter due to solar heating. This natural heating will save R4,90 per month in electricity. Apart from the saving, the house will also be lighter inside compared to a south-facing house.

When buying an existing house, all the above-mentioned suggestions should be considered.

In addition, it is also a good practice to replace or service old appliances. Due to their age, old appliances can be very energy-inefficient. For instance, an old geyser could waste up to R18,55 per month.

Other suggestions included previously should also be considered when upgrading the house.

Conclusion

This national campaign was initiated by the Department of Mineral and Energy Affairs (DMEA) in order to create an awareness among people to save energy at home. To motivate people to implement these savings, they have to be made aware of the benefits to themselves. The potential savings for the given energy-saving suggestions were calculated. These values were also converted to a monetary value that is independent of inflation.

It is claimed that people will only do something if the benefits for them are greater than the effort needed to do it. Therefore the saving suggestions were rated according to the ease of implementation, together with the monetary saving. However, too many suggestions will lower the retention of information. The rating helped to filter the best suggestions for each category. These suggestions will be used by the DMEA in pamphlets and brochures produced as part of their energy conservation awareness campaign.

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Energy in the new South Africa: An international perspective

*M A OUKI

Keywords: South Africa; energy sectors; economics

The fundamental importance of energy supplies in the South African economy made energy and especially petroleum issues a principal objective of control and regulation during the apartheid era. Now that a Government of National Unity has been in place for more than a year and the economy is opening up to the world, the unravelling of outdated controls in the energy sector is of major and urgent importance. Equally important is the requirement to bring in new thinking, new capital and new enterprise to the supply and distribution of all forms of commercial energy as a crucial factor in revitalising the whole post-apartheid economy.

As South Africa continues to restructure its political and economic spheres, the following significant aspects of the existing energy sector and expected energy developments have been identified in a recent analysis of each major sub-sector**.

Coal

South Africa's energy scene is largely dominated by its abundant low-cost coal resources. In addition to its direct uses, which account for more than a third of the total final consumption of commercial energy, coal is the main fuel in the production of electricity, synthetic fuels and synthetic gas. The power sector is the country's largest user of coal. It accounts for 35% of the total production of coal and about 60% of the country's internal consumption of coal, excluding coal discards.

With the opening of its economy to the rest of the world, South Africa, with its large coal-fired electricity generation component, is expected to come under international pressure to reduce emissions generated mainly through this extensive use of coal. However, it is unlikely that environmental considerations will significantly affect coal consumption by the power sector within the next ten years.

It is important to note that all the current proposals for the restructuring of the various segments of South Africa's energy sector due consideration is given to environmental aspects. But, given the tremendous challenges facing policy-makers in terms of wealth redistribution and affordable access to energy to all South Africans, it is doubtful that environmental considerations will have a significant impact on coal use before the end of this decade, other than the development of improved clean and efficient coal technology. Thus, in the medium term, coal is expected to continue to play a major role in South Africa's energy balance.

Petroleum industry

Following a long period of political and economic isolation and without significant hydrocarbon resources, South Africa developed a unique and highly regulated petroleum industry. Petroleum products are sourced from conventional crude oil-based refineries and from synthetic fuel plants using indigenous coal and some natural gas as feedstock. This unique feature is well illustrated by the fact that at present synthetic gasoline accounts for 46% of all gasoline sales.

The current situation in the South African petroleum industry is dominated by the ongoing debate on its deregulation. This debate is mainly concentrated on three fundamental issues: (i) the reform of the petroleum product pricing system, (ii) the future of the retailing regime, and (iii) what to do with the synthetic fuel industry. The deregulation process will have to start with a full assessment of the future role of synthetic fuel production. The issues of product pricing and the future of the retailing regime, *inter alia*, are linked to whether or not government protection of the synfuel industry will continue and on what basis.

The deregulation debate has up to now focused too much on the sensitive issues of job losses and the country's foreign exchange savings. It is important that efforts are made to determine the impact of deregulation on employment and balance of payments aspects. But, in an economy such as South Africa's, which is considered today as a developing emerging market, the main drive should be the re-energising of the economy to generate foreign exchange revenue and stimulate employment. This should replace the now outmoded, inward-looking concept of foreign exchange savings and government protection of local industries through import substitution.

The restructuring of the petroleum industry is a long process that will require gradual transparent adjustments before a stable transition to an open environment with minimum government intervention is ensured. This does not, however, mean a piecemeal deregulation, as all the existing regulatory measures are closely interlinked and must be changed in unison.

Power sector

The power sector in South Africa is characterised by the main electricity utility, Eskom, which accounts for 98% of all electricity sales. Eskom generates more than 50% of all the electricity on the African continent and is the fourth largest electricity utility in the world, in terms of installed capacity. However, at present its national grid provides electricity to only 36% of the country's households.

The power sector's biggest challenge will be to meet the Reconstruction and

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** The present article is based on a recent study, *Energy in the new South Africa*, conducted by Penspen Economics in association with the Energy Research Institute of the University of Cape Town. For more information on this study contact: Penspen Economics, Darpen House, Citadel Place, Tinworth Street, London SE11 5EH, U.K., Tel.: +(44) 171 582 557, Fax.: +(44) 171 587 0288

Development Programme's (RDP) goal of doubling the number of households with access to electricity by the end of this century. The full implementation of this electrification programme will have significant financial requirements. Given the relatively limited availability of financial resources in South Africa, the issue of sustainable methods of funding this programme is of crucial importance.

Although prices of delivered coal are very high on the country's southern and western coasts because of high rail transport costs, within the next ten years coal is expected to remain the main source of primary energy for the generation of electricity.

Gas developments

South Africa has a small gas industry based on synthetic gas, or Gaskor gas, produced from Sasol's synthetic fuel plants. This gas is used mainly in Gauteng and projects are currently underway to transport this gas to the Kwazulu-Natal region by converting Petronet's spare pipeline capacity.

Imports of natural gas from Namibia and Mozambique into the South African energy scene will depend on various factors. The main barrier to the penetration of natural gas is the presence of large reserves of low-cost coal close to South Africa's major industrial region. As explained above, within the next ten years, it is unlikely that natural gas will be able to compete against coal by relying solely on its environmental advantages. It is expected that natural gas will be able to fully penetrate the market for electricity generation around 2005-2010 when Eskom will start facing capacity shortages and when the use of cleaner and cost-effective alternative generating fuels will need to be developed.

An important aspect of the development of potential regional supplies of natural gas for the South African energy market is the crucial involvement of local key energy players. Without the securing of significant potential markets in South Africa the mobilsation of the large financial resources required for the development of these gas projects will be very difficult. However, these projects, which represent an important element of Southern Africa's regional economic integration plans, benefit from strong government support from all the relevant SADC member countries.

Overall policy issues

The current debate on the restructuring of the petroleum and electricity industries should be considered within an overall integrated national energy planning exercise for the whole of South Africa(1,2,3). Energy planning should be an essential part of the country's macroeconomic planning. This does not, however, mean a rigid centralised energy policy as conducted in the former centrally planned economies of Eastern and Central Europe. At the implementation level policies should be based on market incentives and decentralised competitive forces.

Because of the many interactions among various energy sub-sectors at one level and the energy sector and the rest of the economy at a higher level, and the need to optimise the use of all available resources, the concept of integrated national planning is an important framework to address the socio-economic development objectives of the new South Africa.

Finally, the new South Africa faces formidable challenges not only in the energy sector but on all economic and social fronts. It has the means to address these challenges - the country has significant potential natural and human resources, and several segments of its economy are very well developed with a degree of sophistication approaching that of developed countries. But, to restructure its energy sector and its economy in general, a transparent, consistent and pragmatic policy approach to all these issues will be crucial in a world characterised by limited capital and the existence of increasingly attractive terms for foreign investments in emerging economies around the globe.

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COMPARATIVE ENERGY COSTS IN SOUTH AFRICAN CITIES RELATED TO HEATING VALUE

SEPTEMBER 1995

Energy source	Consumer prices			Cost of energy (c/MJ)			*Relative heating costs			Heating value	
	Coast	Inland	Units	C.T.	Jhb	Dbn	C.T.	Jhb	Dbn		
Coal A (Peas)	274,17	83,22	R/Ton	0,98	0,30	0,64	3,29	1,00	2,15	28,0	MJ/Kg
Elect.	21,47	24,43	c/kWh	5,96	6,79	5,68	20,07	22,84	19,11	3,6	MJ/kWh
Heavy Furnace Oil	63,06	78,96	c/litre	1,54	1,93	1,54	5,17	6,48	5,17	41,0	MJ/litre
Illum. Paraffin	88,63	100,53	c/litre	2,40	2,72	2,40	8,06	9,14	8,06	37,0	MJ/litre
Petrol (Premium)	178,00	188,00	c/litre	5,13	5,42	5,13	17,26	18,23	17,26	34,7	MJ/litre
Diesel	145,90	155,90	c/litre	3,76	4,02	3,76	12,65	13,52	12,65	38,8	MJ/litre
Power Paraffin	90,00	102,30	c/litre	2,40	2,73	2,40	8,07	9,18	8,07	37,5	MJ/litre
LPG	108,00	123,10	c/litre	3,94	4,49	3,94	13,26	15,12	13,26	27,4	MJ/litre
Gas											
Cape Gas	45,60	–	R/GJ	4,56	–	–	15,34	–	–	–	–
Gaskor	–	17,16	R/GJ	–	1,72	–	–	5,77	–	–	–

This table shows comparative energy costs (in SA cents/MJ) in selected South African cities (coastal and inland) based on a range of energy sources. The following criteria were taken into consideration in the calculation of the cost of energy:

(1) Transport costs for coal were obtained from Spoornet. Railage of coal was calculated from Saaiwater to Cape Town and from Saaiwater to Durban respectively.

(2) The energy cost has been calculated on the bulk delivered price for consumers, i.e. includes 14% VAT and other charges.

(3) All figures for electricity have been based on energy requirements for large commercial users.

(4) Electricity prices have been based on typical monthly accounts for large users (see Table 5 in the Energy Price List in *Selected Energy Statistics: South Africa*).

(5) A 75% load factor has been used in the calculation of the Gaskor prices.

(6) *The relative heating costs are shown in relation to the cheapest source, i.e. coal in Johannesburg.

(Source: *Selected Energy Statistics: South Africa*, No. 34, August 1995)

Energy news in Africa

Electricity

Ghana

A US$414 M project was recently approved to provide reliable electricity supply, resources for demand-side management, conservation and efficiency, and which is expected to lay the groundwork for private sector involvement in Ghana's power industry. Since embarking on its ecnomic recovery programmein the mid-1980s, Ghana's annual growth has been 5%. Over the past three years, domestic load (which forms 40% of total demand in Ghana, has increased by 14%/year, and the Volta River Authority's (VRA) hydroelectric capacity is being outstripped by demand. The situation has been exacerbated by poor inflow into the Volta reservoir.

The VRA is now turning to gas turbines and oil-fired steam plant for its short- to medium-term power needs. By the year 2000, electricity demand is expected to be about 8 000 GWh. To meet this demand, the VRA is developing the 300 MW Takoradi combined cycle plant which will consist of two 100 MW gas turbines and one 100 MW heat recovery steam generator, which will be commissioned in 1997/98.

Another source of energy will be the 130 MW gas turbine plant being developed by Ghana National Petroleum Corporation using natural gas from the developing offshore field in the Tano Basin.

The Ghanian government is implementing a national electrification project, which aims to supply electricity to the whole of Ghana from the national grid by 2020. Under Phase I, due to start in September, the VRA will be connecting 19 district capitals to the grid within the Brong-Ahafo, Northern and Upper East regions. In Phase II, programmed for 1996, the VRA will provide electrification to 124 towns and villages along the transmission lines built under Phase I.

The costs in UScents/kWh, based on 1994 estimates for various existing and projected power stations are the following: Akosombo (1,5 UScents/kWh), Bui (300 MW option) (5,5 UScents/kWh), Aboadse (5 UScents/kWh), the 90 MW hydro project (8,1 UScents/kWh), and the Tema diesel-powered station (13 UScents/kWh). It was also confirmed that Ghana will continue to buy supplies from the Ivory Coast.

Tenders have been received and are being considered by the Electricity Corp. of Ghana, for a transmission-distribution project, which are concerned with boosting and extending the 33 kV systems in Accra, Kumasi and Tema, including transformer substations.

(Source: Modern Power Systems, June 1995
Africa Energy & Mining, 19 July 1995)

A study on a high-voltage interconnection between Ghana and Burkina Faso that forms part of Sonabel's internationally-financed investment programme was recently submitted to donor institutions, the Burkina Faso utility and Ghana's VRA. The overall project also includes a line between the Ivory Coast and Burkina Faso.

(Source: Africa Energy & Mining, 19 July 1995)

Ivory Coast

The World Bank's affiliate IDA recently approved its $80 M loan towards the Ivory Coast's Private Sector Energy Programme.One of the clauses of the loan involves the preparation of a second independent (private) power station project after Vridi II. The new programme, which forms the core of the co-financing package for the second section of Vridi II, will last until 1999.

The cost of the second phase has been estimated to be $87 M. The production units will cost $48 M. A 90 kV line between Treichville and Plateau will be undertaken; there will be replacement of a 15 kV underground line over 2 x 60 km, and other extension and reconstruction projects, which will cost about $26 M.

The study concerning a restructuring of the sector to simply the role of government services will be awarded in October. A demand forecast study will follow next January along with another concerning bidding process preparation for the second private power station. In June next year, a hydrocarbon sector will be developed which will entail production planning and distribution and the development of the butane market. Lastly, a financial management analysis and rates adjustment study will be awarded in January 1997.

(Source: Africa Energy & Mining, 5 July 1995)

Mauritius

The Central Electricity Board (CEB) in Mauritius claims that the Centrale Thermique Union Saint Aubin (CTUSA) project for a coal-sugar cane waste power station is not viable in the long run. The CEB claims that the project would cost 1 billion rupees more over 25 years than a diesel-powered unit.

Presently there is no question of privatising electricity distribution in Mauritius, and that the "sugar estates" are likely to provide supply for most of an expected increase in consumption. This will double by the year 2010 compared to the 600 GWh provided by existing facilities.

(Source: Africa Energy & Mining, 2 August 1995)

South Africa

After undertaking the Khayelitsha project near Cape Town under an agreement with Eskom, Electricité de France (EdF) has become interested in other schemes with Eskom. These are electricity generating schemes and small networks in a series of regions and towns too isolated to be hooked up to major grids at reasonable cost.

With regard to electricity production, Eskom estimates that it should be able to generate 6 000 MW more than at present by the year 2000 to meet the rise in demand expected as more consumers are connected to the grid under Eskom's "Electricity for All" programme.

Hydro power on a regional level, starting with the 950 MW that will be received from Cahora Bassa, should be sufficient to meet the need. Coal will encounter ever stiffer environmental obstacles but since the benchmark oil price remains low, coal will stand in the way of gas imports (from Pande in Mozambique and Kudu in Namibia) for more than 10 years.

Also, there is considerable uncertainty over the number of mothballed coal-fired power stations that could be put back into service. Four are to be dismantled but the decision on that involved the units generating the most expensive kWh, and the cost of restarting the others would escalate in keeping with the work required to commission them, including systems to desulphurise the emissions.

(Source: Africa Energy & Mining, 2 August 1995)

Zimbabwe

While waiting for the interconnection with South Africa via Bulawayo to enter service in six or seven month's time, the Zimbabwe utility ZESA received permission in July to double the capacity to 300 MW put at its disposal by Zaire's SNEL via Zambia and by Zambia's ZESCO. ZESA is facing a major hydraulic deficit, as in 1992, because of drought. The Zambesi River Authority (ZRA) recently announced that the water level at the Kariba dam had fallen so low that fears were expressed over whether a minimum operational level could be maintained between now and the end of November. Thus it was decided to reduce production by a third, leaving Zambian and Zimbabwean companies the alternative of boosting imports.

(Source: Africa Energy & Mining, 2 August 1995)

Hydro-electricity

Ethiopia

The Ethiopian utility EELPA recently awarded the study on a project for a dam to be used for hydroelectricity at Gilgel Gibe to two Italian consultants. The contract is worth $6,7 million.

EELPA wants to ensure that at least one turbine will be in service by 1999 and the second shortly after the year 2000. However an important aspect is whether EELPA will obtain the large loan ($270 million) for the project from the World Bank.

(Source: Africa Energy & Mining, 5 July 1995)

Malawi

The capacity of the Tedzani and Nkula dams on the Shire river in Malawi has been reduced because of excessive silt, and the national utility, ESCOM, is seeking $1,5 million to undertake dredging operations. The problem has occurred as Malawi is preparing to start work in early 1996 on the Kapichira hydro project, following Phase III equipping the Tedzani site. The two power stations, Tedzani I-II and Nkula, which have been operational since 1966 and 1980 respectively, have a capacity at present of 120 m^3/second instead of the usual 250 m^3/second. ESCOM is also looking for funding for certain parts of the Power 5 programme based on Kapichira. These include bolstering the Lilongwe-Blantyre line ($14,3 M), urban networks ($19,8 M) and Malawi's part of the future Cahora Bassa-Malawi interconnection.

(Source: Africa Energy & Mining, 19 July 1995)

Fluidised beds

A 4 600 kW fluidised bed hot-gas generator is to be designed and manufactured in Cape Town by John Thompson Africa (JTA) for the Hartley platinum mine, some 150 km southwest of Harare, Zimbabwe. It will supply hot gas for drying the platinum concentrate in a flash drier. The R1,3 million plant is due for commissioning in January 1996.

The design for the platinum mine in Zimbabwe incorporates a fluidised bed located within a refractory-lined enclosure. A rotary feeder meters the fuel which is pneumatically spread above the bed. Most of the ash is entrained in the off-gases leaving the furnace, and the coarse ash which remains in the bed is automatically removed by in-bed classifiers. These classifiers provide for ash removal without operator intervention, while automatically maintaining the size distribution of the inert material within acceptable limits. A programmable logic controller enables the fluidised bed to be operated from a remote control room.

Start-up is achieved by means of two above-bed oil burners. Controls are provided to maintain bed temperatures, furnace draught and load matching, with the furnace being loaded from the drier outlet temperature signal. The gas velocity in the flash drier is maintained between preset limits by bleeding air upstream of the drier.

(Source: Mining Mirror, July 1995)

Statistics

According to figures compiled by Enerdata, an agency linked to the Grenoble-based Institut d'Etudes d'Economie de l'Energie (IEPE), overall energy consumption in Africa during 1994 amounted to 1 218 Mtoe (million tons of oil equivalent) compared to 214, 3 Mtoe in 1993. Coal made 40% of the supply, oil a further 40%, 16% from natural gas, and the remainder from renewable energy (mainly hydropower) and nuclear power from South Africa. Sectoral energy consumption was as follows: industry 37%, transport 34%, domestic use and services 23% and 6% for non-energy uses (e.g. chemicals).

The total output of crude oil and LNG (liquefied natural gas) for 1994 in Africa was slightly lower than for the previous two years. The 1994 figure was 324,5 Mt, with 326,1 Mt in 1993 and 333 Mt in 1992. In 1994, Africa imported 28,2 Mt and exported 244,5 Mt oil and gas. Gas production in 1994 dropped by 4,4% to 76 billion m^3 and exports by nearly 10% to 33,2 billion m^3. This was influenced mainly by the provisional drop in Algeria's capacity with the renovation of liquefaction lines.

Gas consumption in electricity production contiues to rise, although slowly, to 15,2 billion m^3. Coal output in 1994 contiued to climb to 195,5 Mt. Exports, largely from South Africa, amounted to 55,5 Mt.

Electricity production showed the greatest growth in 1994, totalling 348,6 TWh.

(Source: Africa Energy & Mining, 2 August 1995)

Wind energy

Morocco's Office National de l'Electricité has announced that a contract has been awarded to the French firm Tramontana and the Danish contractor Vestas (aerogenerators) for the wind energy complex at Tetouan. The windfarm forms the biggest part of a Moroccan programme involving rural electrification and renewable energy. With an expected capacity of 50,4 MW, it will generate 2% of national demand and the equivalent of 46 000 tons of fuel oil.

The wind turbines will be constructed in such a way so as not to cause damage to birds. The 600 kW generators will be placed on top of 45 metre-high masts every 100 metres, each with 20 metre-long blades. A total of 84 wind turbines will be installed with a centralised and computerised control centre that links the complex to the one grid at a cost of about $60 M.

(Source: Africa Energy & Mining, 2 August 1995)

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He is the guest editor of the *International Journal of Building and Environment* and an editorial board member of the *International Journal for Numerical Methods in Heat and Fluid Flow.* He is also an editor and editorial board member of two South African scientific journals, namely, *Aeronautica Meridiana* and the *Research and Development Journal.*

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In 1981 Dr Mwanza transferred to the United Nations Economic Commission for Africa (UNECA) to become director of the Natural Resources Division. Here he was responsible for the development and implementation of the Commission's programmes on mineral resources, water resources, marine science and technology, science and technology, the environment, cartography and remote sensing, and energy development.

At the UNECA he has also been responsible for the training of experts (engineers, planners, economists, policy executors and decision-makers) from various African countries in energy management, energy planning, environmental sustainability and energy development, and in specific areas such as, energy conservation and efficiency and the promotion of regional and subregional co-operation in energy development. He has also been the main force behind the conceptualisation and establishment of the African Regional Centre for Solar Energy (ARCSE) based in Bujumbura, Burundi. In 1982 he was asked to go to Dakar to revive the African Regional Centre for Technology (ARCT) and introduced energy development technologies as a priority programme at the Centre.

Dr Mwanza is a member of the International Energy Foundation and has a keen interest in the development of new and renewable sources of energy (NRSE).

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During the past 12 years (1983 to the present), Dr Pashkov has worked for the United Nations Economic Commission for Africa. He has been in charge of the Energy Resources Unit of the Natural Resources Division. His responsibilities include research and supervision, coordination and representation. He has travelled extensively in Africa, Europe and America.

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NOVEMBER 1995

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FOURTH INTERNATIONAL NATURAL GAS CONVERSION SYMPOSIUM Kruger National Park, South Africa

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1996

MARCH 1996

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FRIGAIR '96 Kempton Park, Johannesburg, South Africa

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APRIL 1996

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ELEVENTH INTERNATIONAL SYMPOSIUM ON ALCOHOL FUELS (ISAF XI) Sun City, South Africa

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Plumstead, South Africa

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2ND ENVIRONMENTAL MANAGEMENT, TECHNOLOGY AND DEVELOPMENT CONFERENCE
Fourways, Gauteng, South Africa

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1998

SEPTEMBER 1998

11TH WORLD CLEAN AIR CONGRESS AND ENVIRONMENTAL EXPOSITION
Durban, South Africa

Theme: Interface between developing and developed countries

Enquiries: Congress Secretariat,
Mrs Ammie Wissing, P O Box 36782,
Menlo Park, Pretoria 0102, South Africa

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Recent energy publications

BORCHERS M L and HOFMEYER I-M

Workshop report and proceedings. May-1995. 25p. + appendices.
Report No.EO9418

The overall purpose of the Workshop on Energy for Rural Development was to facilitate rural development focusing on the energy sector. The primary objectives were: to establish a rural energy policy which supports rural development needs effectively; to establish implementation mechanisms and responsibilities; to identify and prioritise research programmes to support policy formulation; to identify actions necessary to take the Workshop conclusions further. Summarises the main outputs of the Workshop in the light of the Workshop's objectives.

COOPER C J

Energy consumption statistics according to SIC. May-1995. 16p.
Report No.EG9304

Focuses on the generation of energy usage information in South Africa. The objectives of the project were to compile energy consumption data for South Africa by energy carrier, end use, SIC codes, and geographic region on an annual basis. The results have been presented as an analysis of how much, how and by which energy sectors energy is consumed in South Africa.

DICKSON B I, VAN HOREN C R and WILLIAMS A T

Low-smoke fuels as a solution to household problems: A synthesis of current research. Jan-1995. 1V.(various pagings).
Report No.ES9406

Provides a general overview of the reasons for pursuing low-smoke fuels as a potential solution to high exposures to air pollutants in South Africa. Describes the present distribution and household use of bituminous coal and related health problems. Examines the practicalities of introducing low-smoke fuels and the potential benefits of its widespread adoption. Identifies the key issues to be considered in the formulation of low-smoke fuel policy.

DONNELLY J

Sasol synfuel protection study 1995: A report to the Liquid Fuels Industry Taskforce. Jun-1995. 127p. + appendices.
Report No.EV9504

The objectives of this study were: to establish the appropriate level of protection, if any, by Sasol for its synfuel operations; to determine whether there is any evidence of cross-subsidisation between Sasol's synfuel production and its other operations, both upstream and downstream. The study would provide new, independently verified data to substantiate a change, if any in the level of Sasol's synfuel protection and the mechanism through which it is currently granted. The 5-year forecast related to Sasol's activities, as set out in the Andersen report, has been taken into consideration.

***DRACOULIDES D A and DUTKIEWICZ R K**

Air pollution modelling in Cape Town. Aug-1995. 5p.
ERI Report No. REP 060
Reprint. R5,70

Describes the work carried out on a comparison of measured pollution levels in Greater cape town with that predicted using an EPA environmental model. The chosen model for the study was the Industrial Source Complex Short Term 2 model.

***DUTKIEWICZ R K and DE VILLIERS M G**

Brown haze in Cape Town. Aug-1995. 5p.
ERI Report No. REP 059
Reprint. R5,70

Summarises some of the findings of the pilot study carried out in 1992 on the occurrence of brown haze in Cape Town and some of the causes.

***DUTKIEWICZ R K**

The effect of fuel composition on the formation of photochemical smog. Aug-1995. 5p.
ERI Report No. REP 058
Reprint. R5,70

Describes work being carried out on the effect of vehicle emissions and fuel evaporation on the formation of photochemical smog, specifically the estimation of the effect of increasing precursor level on the potential photochemical smog situation in Cape Town.

GROBLER J H

Emissions study relating to South African conditions: A summary of Phase 1. Apr-1995. 70p.
Report No.VE10/7

Summarises the results of a series of projects investigating the levels and effects of motor vehicle emissions in South Africa. Includes a study of overseas emission levels, standards and measurement technology for compression and spark ignition engines. The fuels tested include Mossgas premium, Highveld premium, Highveld regular, coastal regular and diesel fuels.

LANDY C F and WALLISER R F

Further research in detecting broken and/or cracked rotor bars in large squirrel cage machines. Apr-1995. 21p.
Report No.EL9006

Investigates the causes of problems in the present monitoring techniques to detect impending rotor cage damage, and suggests possible solutions. Discusses the results achieved, singling out four factors as the major causes of these problems. Outlines a proposed monitoring procedure.

***MEARNS A J**

Rolling road dynamometer reconstruction. Jul-1995. 40p.
ERI Report No. GEN 175
R34,20

Details the modifications made to the NEC's rolling road dynamometer during the move of the engine testing facilities of the ERI from the UCT Campus to the Diep River site. Aspects covered are driving simulation by rolling road dynamometer; rolling road equipment; rotational inertia; the control system; commissioning of the rolling road.

MORRIS G and HOFMEYER I-M

Masizakhe Energy Information Centre feedback process and workshop to determine an action plan for the future. Jun-1995. 1V.(various pagings).
Report No.EO9501

The report summarises the feedback findings on the project and provides a plan for the Centre's immediate future. Mentions that the overall need for a community-based resource centre was endorsed by the delegates. However, there was no sense of urgency on the part of the public or private sectors nor the civil society to adopt and pursue the benefits of such a centre.

STOHR H P

Low-cost timber drying kilns suited for the small sawmiller Apr-1995. 22p.
Report No.ED8901

The initial objective of this work was to provide plans and specifications of dry kilns to enable the small sawmiller to build his own kiln for drying his own timber. What was achieved was the creation of a South African kiln company, Delanco, that not only supplied the small sawmiller with affordable kilns, but ensured that the sawmiller dried his timber efficiently and at low cost. This was achieved by providing the sawmiller with turnkey drying solutions that included a choice of kilns, combustor, gas-to-air heat exchanger, stacking frames trolleys, kiln control, moisture measurement and control and training of kiln personnel. The kilns, although supplied at low cost, have a technological content comparable to that of their more expensive imported counterparts.

TRUTER R

Exposure characterization and potential impacts of domestic fuel use in homes in Khayelitsha, Cape Town. March-1995. 44p.
Report No.EO9403

The study assesses the potential health impacts of air pollution emitted from domestic fuel use in the Western Cape. The project collected data on exposures to air pollution in households using gas and/or paraffin in comparison to those using electricity, as well as risk factors related to the energy use that determine such exposures. The study consisted of a pollution monitoring survey and a questionnaire submitted to those homes selected for the survey. The pollutants measured were SO_2, NO_2, CO and TSPs. Co-located sampling was also performed in one home of each group, measuring indoor and outdoor concentrations simultaneously. The results indicate that the homes using mixed fuels had higher levels of indoor air pollution than those which used mainly electricity, or electricity and/or gas and/or paraffin. These levels were, however, low when compared to the levels in Gauteng homes which burned coal and wood. The respiratory health risks associated with the use of gas and paraffin were seen as more acceptable than those associated with wood or coal.

VAN DER LINDE H A

Wind energy test centre. Apr-1995. 48p.
Report No.EO9133

The objective of this project was to establish a wind energy test centre at the PE Technikon. This would enable wind generators to be tested, which would in turn result in data on the performance of various wind generators. Also looks at maintenance problems.

All these reports are Final Reports (unless indicated) and are the result of research funded by the Chief Directorate: Energy, Department of Mineral and Energy Affairs.

The publications can be ordered from:

The Librarian, Chief Directorate: Energy, Department of Mineral and Energy Affairs, Private Bag X59, Pretoria 0001, South Africa, unless otherwise indicated. Prices are available on request from the Department of Mineral and Energy Affairs.

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Dr. John Maree, Chairman,
Eskom Electricity Council.

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