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REVIEW

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THE COST OF ELECTRICITY SHORTAGE OR SURPLUS IN SOUTH AFRICA

*R K DUTKIEWICZ

To satisfy a required rate of growth in a country there must be sufficient energy available to meet demand, not only in total quantity but also of the various forms of energy such as electricity, oil, coal, etc. If there is insufficient energy available economic development will be stultified due to the inability of, for instance, the manufacturing section to supply products for sale. The shortage of energy can be translated into an economic cost by applying some relationship between energy and economy.

If however too much energy capacity is constructed there will not be a brake on economic growth but there will be an economic penalty due to the cost of idle capital capacity.

This paper proposes an economic relationship for electricity and discusses the possible cost to the country of the electricity supply system being either smaller than required for economic growth, or where excess capacity has been provided.

Arising out of the analysis it is obvious that energy supply should match the required economic growth and incorrect forecasting leads to substantial economic penalty. Forecasting a demand which proves to be too small results in a stultification of economic growth because of lack of production resources, whilst over-forecasting leads to a decrease in economic growth because of the decrease in capital available for economic activity.

KEYWORDS: electricity economics; South Africa

INTRODUCTION

There are two main factors associated with a shortage of electricity. The first concerns the psychological interpretation of a shortage, and the second refers to the economic consequences of not being able to meet a demand.

On the psychological side the effect of a brown-out or a black-out is perceived by the suppliers of electricity as a slur on their engineering ability since a shortage should have been forestalled by better design, better maintenance, or by better planning. However, the price of better planning is more reserve capacity, or smaller unit size, both of which imply more expensive electricity. From this point of view the amount of spare capacity should be analysed as a public relations exercise. The correct amount of spare capacity is available if the reaction of the press to forced outages elicits only a minimal response. If however, press comment occurs frequently, then inadequate spare capacity has been provided. Thus spare capacity is related to the amount of publicity given by the press. Consequently South Africa has a surplus reserve capacity since the only comments are on the rare occasion that there is a catastrophic failure of generating plant or distribution equipment. However the reserve capacity on the South African electricity system, and specifically within the Electricity Supply Commission (ESKOM), has been growing and requires discussion.

With regard to the economic consequences, the cost of not meeting a required demand has a deleterious effect on the country's economy, which might be estimated in financial terms.

ECONOMICS OF SHORTAGE

In theory it is possible to equate the supply and demand for electricity by suitably adjusting prices, and this is what is considered by various utilities in terms of the marginal cost concept. However it is not possible nor even desirable to adjust prices on an instantaneous basis. It is therefore necessary to maintain reserve capacity to ensure that demand can be realized with an adequate probability.

The price to be paid for providing reserve capacity could be worked out if the economic cost of being without electricity were evaluated. This cost however would vary with the length of time for which the shortage occurred, the time of the day and the time of the year at which it occurred, the amount of forewarning that could be given of an impending shortage, and on the class of consumer. Thus a short duration outage with a long period of forewarning may be no more than an irritation, whilst a long outage with no warning might well be economically disastrous. Furthermore, the cost of an outage would vary from consumer to consumer.

For the consumer to whom electricity is vitally important, i.e. in a hospital or in a computer bureau, the cost of electricity not supplied can be equated to the cost of the alternative energy sources, such as stand-by generators, which the organization is prepared to put in by itself.

Some countries, e.g. Sweden, make a distinction between a capacity shortage and an energy shortage, the former being the inability to supply because of inadequate generating equipment or distribution equipment, and the latter the inability to supply because of insufficient fuel. The energy shortage can usually be forecast well in advance and is usually due to factors such as inadequate hydro-power because of drought, as occurred in South America during the mid-1970's, or due to other causes such as strikes, as occurred in the United Kingdom during the miners' strikes in 1985. In the South African context there is unlikely to be a major energy shortage and the main consideration is the capacity shortage due to inadequate generating plant.

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Andersson and Taylor(1) have analysed the various methods of predicting the cost of an electricity shortage ranging from the opportunity cost of alternative back-up power, through the observed willingness to pay for planned production, to the basis of the losses in production value for various goods and services affected. They also raise the question of whether marginal or average costs should be used. It is apparent, in the South African context, that a shortage of capacity, as opposed to an energy shortage, would be felt mainly during peak periods when all plant is working, and therefore only average costs should be considered. Andersson and Taylor also point out that the cost of lost production should ideally equate to the other two methods of assessment since, with perfect knowledge, electricity consumers would be prepared to pay for a secure supply of the amount required to negate the loss in production. The authors also point out that the true cost of an outage will be significantly higher than the value of lost production because of the effect on the suppliers of services or goods to the consumer who experience the outage.

The cost of an outage is also dependent on the length of the outage, a factor which has been taken into account by a few studies. A recent study in Sweden, reported by Andersson and Taylor, is summarized in the Table below to illustrate the effect of a capacity shortage of various durations and to various classes of consumers.

Table 1: Cost of capacity outage for different periods — Sweden(1)

	Outage cost (US$/kWh — 1980)		
Duration	0,5h	2h	8h
Consumer			
Industry	2,41	5,55	14,75
Households	0,24	1,27	14,75
Agriculture	0,48	2,19	13,20
Offices	6,14	25,25	106,44
Commerce	5,43	14,60	51,45
Railroads	1,94	5,78	21,21
Entire country	2,08	6,42	26,38

These values are specific to Sweden, but it is reported that the magnitudes of these figures for other studies in Finland and Canada are similar to the Swedish figures. The above values are maxima, applying at the peak periods but not at other hours, i.e. outside office hours the value to the office consumer would be zero.

This analysis would yield very high costs of lost energy because of the knock-on effect described above. This is possible for limited and relatively short duration outages since an outage in one part of the country may effect sub-contractors in other parts of the country where outages did not occur. For a longer term, or more regular outages, the outage cost could be the cost of the net production loss. Telson(3) argues that the cost of loss in production is the cost of the delay in production since as soon as the outage is over the delayed production can continue. In this case the cost of the outage is the cost of salaries and wages incurred during the outage which then, in the specific accounting period, have to be written off over a smaller production output. This could be possibly the lower bound of the outage loss, but it would discount the cost of idle capital capacity. It seems therefore that a more realistic assessment would be the loss in output in terms of total cost and, in the limit, it would be the loss in Gross Domestic Product (GDP) due to the outage.

SHORTAGE IN SOUTH AFRICA

In view of the fact that it is reported that the figures quoted in Table 1 and compiled from the data of Andersson and Taylor, are of the same order of magnitude for countries as diverse in size and economic make-up as Sweden, Finland, and Canada, then, as a first estimate, it may be assumed that they will also apply to South Africa if adjusted for differing costs of power production.

It will be assumed that with a shortage of generating capacity the outages will occur at the peak demand time during the day. It is also assumed that with good overhaul planning, generating units are maintained during the year so as to follow the maximum demand curve. In this case the shortage of supply could occur during the peak demand hours on any working day throughout the year.

The figures in Table 2 below have been adjusted for the difference in economic activity between Sweden and South Africa. They have also been adjusted for the exchange rates. The resulting cost of outage in terms of Rand per kilowatt when plotted on log-log paper exhibit an exponential form, and it is possible to determine the relevant costs for various periods of outage.

Table 2: Cost of outages for different periods — South Africa

Duration of Outage — Hours	R/kWh (1980 values)
0,5	1,7
1,0	2,6
1,5	5,1
2,0	6,9
4,0	8,9
8,0	19,0

The cost penalty for not meeting the desired load can now be calculated using the above figures and by truncating the load demand curve for the country. It is assumed that the load demand curve for ESKOM in 1983(4) can be assumed correct for the whole country. If the load-demand curve is progressively truncated at various distances from the top, the amount of energy lost in the truncated section can be determined. The total time during which the outage occurred can also be determined. Using the outage costs as a function of time, as determined above, and the known lost units of electricity, the total cost of an outage can be evaluated.

It is assumed that for a shortage of capacity, i.e. a forecast which resulted in an installed capacity lower than that which would have been required for the unfettered growth of the economy, the lost units are calculated by the difference between the normal load-demand curve and the truncated curve. If, moreover, the calculations are carried out on a normalized load-demand curve, then the results can be used for predicting future outage costs.

The results of such a calculation procedure are shown below using the 1980 Rand as a basis and expressing the results for the year in which the maximum demand for the whole country rose to 20 000 MW (approximately in 1986). The GDP was then R61 334 M (1980 values). The results have been expressed in terms of a percentage shortage in the forecast for the maximum demand and the resulting cost and its value expressed as a percentage of the GDP.

Table 3: Annual cost of various levels of capacity shortage in South Africa

Shortage as a %age of the maximum demand	Yearly cost of outage	
	R Million (1980)	%age of GDP
1	640	1,0
2	2 330	3,8
3	10 260	16,7
4	17 990	29,0

As discussed above, this would be an extreme case and strictly only applicable to a short duration outage, although in the Table above the calculations have been made on the basis of a regular daily shortage. The analysis will now be repeated using the Telson criteria of the losses in salary and wages, and then using the criteria that the outage loss is reflected in a loss in the total output from the country, i.e. a proportional loss in the GDP.

In this latter calculation it will be argued that it is possible to use the value of the country's energy intensity ratio, i.e. the ratio of energy used per unit of GDP, and the number of units of electricity which could not be provided during the outage to determine the financial effect of an outage. During 1980 the energy intensity for South Africa was 7 kWh per Rand of GDP. This, however, is for total energy usage. It is reasonable to assume that with an electrical outage all industrial activity would cease since the use of other energy forms is almost always linked to the use of electricity. Thus an establishment operating coal-fired boilers relies on electricity for fans, stokers, etc. If this is considered, then the energy intensity for this calculation comes out at 1,8 kW per unit of GDP.

Table 4 summarizes the cost of electrical outages of the type caused by miscalculation of load growth and are presented in terms of the percentage of maximum demand by which the installed capacity is below the required demand, i.e. the error in the assessment of the forecast maximum demand. The calculation has been made on the basis of the year in which the maximum demand reaches 20 000 MW. Once again the monetary values are based on the 1980 Rand.

Table 4: South Africa: Financial penalty per year of a loss of electrical capacity

Loss of capacity as a %age of the maximum demand	Financial penalty in terms of Rand Million (1980 value)	
	Lower limit (wages & salaries)	Upper limit (effect on GDP)
1,0	19	54
2,0	56	157
2,5	89	249
3,0	129	362
3,5	171	480

In the case of South Africa at present, and in the medium term, manufacturing capacity will remain idle during an outage and its cost must be included in the outage cost. It is therefore considered that the upper bound, i.e. the cost of lost GDP, is the more applicable for the financial analysis.

The calculation is based on a maximum demand of 20 000 MW, therefore the 1% shortage represents a 200 MW shortage on the system.

The cost of erring on the conservative side and supplying more than sufficient plant is the yearly capital cost of the excess generating plant installed. Using 1980 values and the cost of generating plant from the de Villiers Report(5), then the cost of the excess plant at an annual charge of, say, 15% is as given below.

Table 5: Cost of having excess electrical plant on the grid — South Africa

Excess plant as a percentage of maximum demand	Yearly cost of surplus	
	R Million (1980)	%age of GDP
1	14	0,02
2	28	0,05
3	42	0,07

For ease of comparison the cost of surplus capacity and the cost of a shortage of capacity is given in the next Table where the outage or shortage capacity is based on the GDP value, i.e. the upper limit in the Table above. The values have also been converted to a percentage of the GDP.

Table 6: Summary of yearly cost of shortage or excess of plant on the electrical grid

Shortage or surplus plant as a % of max. demand	Yearly cost of shortage or excess			
	Rand Million		%age of GDP	
	Shortage	Surplus	Shortage	Surplus
1	54	14	0,09	0,02
2	157	28	0,26	0,05
3	362	42	0,59	0,07
4	480	56	0,78	0,09

This calculation demonstrates the importance of correct forecasting since the financial effects of being wrong, in either direction, are large. It also demonstrates the vital role of electricity in the economic activity of the country. The cost of providing insufficient capacity is the resultant decrease in the productive output of the country. It is apparent that it is preferable to err on the surplus side of the forecast since excess capacity will have an economic effect until the load growth meets the required demand. However, a decrease in the economic activity takes many years to recover, as the picture of the growth of economic activity after the war years will testify.

RESERVE CAPACITY

The tendency in electrical utilities is to provide sufficient reserve capacity so that black-outs never occur. That black-outs and brown-outs still occur is due to normally unforeseeable catastrophic failures which take place in spite of adequate spare capacity and are more often the result of technical failure in the distribution system than a lack of generating equipment. This is also true of other countries. Telson(3) reports that a United States Federal Power Commission showed that ". . . almost all of the incidents reported over the past few years were due to distribution system, rather than generation system, failure". However, in South Africa recent reasons for capacity shortages have been the poor availability of new large units on the system and the longer than anticipated teething problems of large power units. This is illustrated in Figure 1 which shows the changing percentage of reserve capacity from 1950 to 1989. From a low base of 11% reserve capacity it has now climbed to 33%.

Telson quotes USA experience (in 1968) of a reliability

FIGURE 1. RESERVE CAPACITY ON THE ESKOM SYSTEM AS A PERCENTAGE OF INSTALLED CAPACITY (3-PT MOVING AVERAGE)

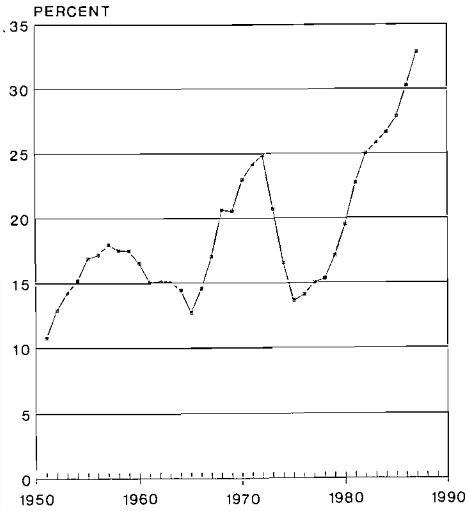


FIGURE 2. GROWTH IN TURBO-GENERATOR UNIT SIZE ON THE ESKOM GRID

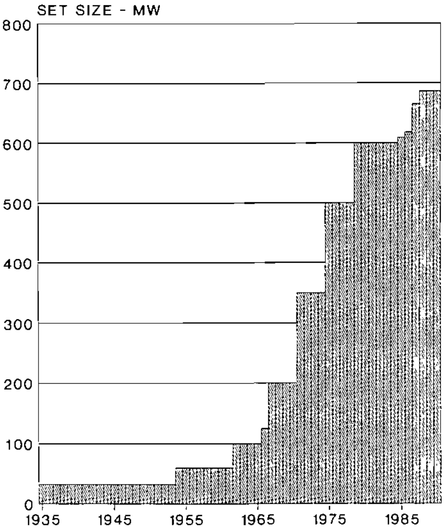
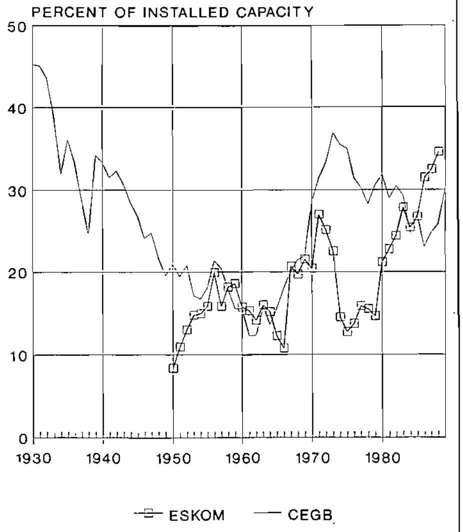


FIGURE 3. RESERVE CAPACITY ON THE ESKOM AND CEGB SYSTEMS



of 99,98%. The equivalent figures for the next highest countries, France and the United Kingdom, were 99,93% and 99,8% respectively. This approximates to a reserve capacity of 28%(3). Telson maintains that this level of reliability is inordinately high and a reduction would lead to significant financial savings. However this cost saving spread over all the consumers is relatively invisible, whilst the power interruptions are highly visible.

In part the decrease in the availability of units on the South African grid system, and in other countries as well, has been due to the rapid increase in set size and the inability of research and development to keep up with the technical problems in moving to larger units.

The increase in set size is illustrated in Figure 2 which shows the growth in size from 1935 onwards and indicates that during the period 1960 to 1980 the growth in set size was exponential with an increase of 12% per annum. This growth rate has decreased in recent years due to poor plant availability and the coincidental decrease of energy growth rates world-wide because of worsening economic conditions. This decrease in growth rate has resulted in a decrease in the need to increase set size by turbine and boiler manufacturers.

The question remains as to the required amount of reserve on a system. Other countries have been through the same learning process in determining the optimal reserve capacity. The similarity between the reserve capacities on the ESKOM system and in the United Kingdom's CEGB is illustrated in Figure 3.

ESKOM has consistently had a lower reserve capacity compared with the CEGB. From a high reserve of over 45% of installed capacity in 1929 the CEGB reserve dropped and during the period 1955 to 1970 the amount of reserve was the same on the two systems.

During the next 12 years, until 1983, ESKOM had a lower reserve than the CEGB. From 1983 the two systems again show identical reserves. Whilst it is difficult to compare the need for reserve capacity on two different systems, it does appear that both systems required large reserve capacities at periods when the availability of new large units was poor. In recent times the reserve capacity has been dictated more by a poor correlation between forecasted and actual demand, rather than because of unit operating problems.

CONCLUSION

An analysis has been made of the economic cost to the country of the under or over supply of electricity capacity. The analysis is based on the electricity intensity in South Africa and assumes that there is a direct relationship between economic growth and the demand for electricity. Use has been made of the work of the research work carried out in other countries which is considered adequate for the purpose of a first attempt at determining the economic cost but it does indicate that more work needs to be carried out in the South African context. The cost figures derived should be looked on as pessimistic values since a serious shortage of electricity could be partly alleviated, in economic terms, by measures such as rationing, brown-outs on a rotating basis, etc, as occurred in South Africa during the World War II days.

Because of the economic down-turn in South African and the resultant lack of growth in electrical demand, Eskom has a large reserve capacity on the grid, amounting to 48% in 1989. There is a financial penalty that has to be paid for this spare capacity. However there is sufficient capacity to allow for growth over the next 6 years without any detrimental effect on economic growth.

ACKNOWLEDGEMENT

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ASSESSING THE ENERGY POTENTIAL OF A LANDFILL SITE

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The exploitation of methane gas from landfill sites is extensively practised in both the USA and Europe. The same is not true of Southern Africa, but with the call for alternative energy resources, there is a rapidly growing interest in methane from landfill. This paper presents a method, including some novel aspects, which can be used for predicting the energy potential of landfill sites. Data from the Grahamstown landfill site have been used as an illustration.

KEYWORDS: landfill; methane

INTRODUCTION

The natural biological decay of organic matter inside a landfill site, under anaerobic conditions,** leads to the formation of landfill gas (LFG), which is largely a mixture of methane (CH_4) and carbon dioxide (CO_2)(1). The methane component is combustible and burns in air, producing heat. It is this energy that can be commercially exploited.

PROPERTIES OF METHANE GAS

Methane gas is, in many respects, a pollutant. The gas is explosive at concentrations of between 5% and 15%, by volume, in air, making it a dangerous gas. The reaction concerned is:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \quad \Delta H = -890\ \mathrm{kJ\ mol^{-1}} \quad (1)$$

and will take place only if the mixture is activated by a spark. If methane is not burnt, it generally remains intact in the lower atmosphere. It reacts readily, however, with ozone (O_3) in the upper atmosphere(2) and hence can be termed an ozone unfriendly gas. Methane is also an effective greenhouse gas(2,3,4) and, like carbon dioxide, it absorbs the longwave infrared radiant energy leaving the earth. Adsorption is by the bonding electrons which bind the carbon and hydrogen atoms in CH_4. With four C-H bonds, methane is a more effective greenhouse gas than carbon dioxide. It has been estimated that by the middle of next century, the contribution of methane to the greenhouse effect will be one quarter of that due to carbon dioxide(4).

Although the formation of methane gas under anaerobic conditions is a natural process which has been occurring spontaneously for millions of years, it is nevertheless a noxious gas. Attempts to reduce the concentration of methane in the environment should therefore be encouraged. According to Pearce(3), 500 million tonnes of methane are produced globally each year, from cattle, bogs and marshes, rice paddies, the burning of forests and grasslands, termites, and landfill sites. Landfill sites are thought to contribute some 6%-18% methane to total world production(4).

LANDFILL PRACTICE

The successful exploitation of the methane in LFG entails, first and foremost, that the gas be efficiently contained within the site. The simplest manner of doing this is to cover the landfill surface with a clay or soil layer which has a thickness of between 20 cm and 100 cm.*** This will not completely prohibit the loss of methane by diffusion from the site, but it will reduce oxygen ingress by minimising air infiltration. Anaerobic conditions, essential for methane production, are thus maintained, and the enclosed refuse site can be considered a large anaerobic bioreactor.

It is accepted landfill practice to compact and cover all incoming refuse on a daily basis. The resulting honeycombs of refuse and cover material are known to be as high as 400 m and are often above ground rather than in disused quarries and pits. These man-made mountains are usually constructed with great care and their impact on the environment, from a pollution perspective, can be negligible. The landfill sides are usually planted with grass, and walls (2 m to 3 m high) surround the working floor of the site, in order to hide the refuse and prevent it from being blown about by wind.

The LFG can be extracted by using a vacuum pump to draw the gas from vertical perforated pipes sunk deep into the landfill site. The gas can be used in a variety of ways and applications include boiling water(5), space heating(5), brick baking(6), production of electricity(5), the propulsion of vehicles(7), and use as a chemical feedstock(8).

The rate at which gas is pumped out of the site must not exceed the normal rate of LFG production(9). In the event of excessively high pumping rates, large quantities of air are drawn into the bioreactor and the anaerobic methanogens are consequently poisoned.

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**The production of methane from the organic component of refuse, can only occur if no oxygen is present (anaerobic conditions). If oxygen is present (aerobic conditions) the methane-forming bacteria (methanogens) cannot exist, and the aerobic bacteria produce carbon dioxide, by oxidation of the organic refuse.

***The researchers have found that a multilayer of soil and clay, with good grass cover, provides a better top-capping than soil or clay alone. This is relatively impervious to gas leaks and does not crack in dry weather.

THE MAXIMUM POSSIBLE ENERGY AVAILABLE FROM LANDFILL

Simple calculations from the following equation show that 120kg of organic material (considered to be dry for the purposes of these calculations) will produce 0,416 m^3 CH_4 gas at NTP:

$$(CH_2O)_n \rightarrow (n/2)CH_4 + (n/2)CO_2 \qquad (2)$$

The organic material (food residues, plant material and paper) is considered to be composed of carbon, hydrogen and oxygen in the ratio of 1:2:1. This is a reasonable assumption as most of the organic material in municipal solid waste (MSW) is composed of carbohydrate compounds, such as cellulose(10).

The combustion of CH_4 gas, as shown in Equation (1), will produce (890/0,025) kJ of energy per cubic metre of CH_4 at NTP. Combining this result with the previous calculation shows that 1 kg of dry organic material will produce $14,8 \times 10^3$ kJ [$(890 \times 0,416/0,025)$ kJ] of energy. Dry organic material comprises only some 35%(11) of landfill material, so that a metric tonne of refuse will produce $5,18 \times 10^3$ kJ of heat.

Unfortunately, due to loss by diffusion(12) and non-methanogenic reactions at the landfill surface(13), not all of the methane produced can be captured. Furthermore, in order to collect the total amount of methane produced by the refuse, the gas needs to be extracted over the entire period required for decomposition, which may be as long as 30 years.

In order to predict the methane capacity of a landfill at any time, a knowledge of the size of the landfill is therefore not enough. Information regarding rates of refuse decomposition and knowledge of the history of the landfill is also necessary.

A Simple Kinetic Model for LFG Production

The rate at which LFG is produced is a direct function of the decomposition rate of the organic material in the landfill. The decay of MSW, and hence CH_4 production, can be assumed to be a simple, first order process(14,15).

$$dP_t/dt = -kP_t \qquad (3)$$

where: P_t = quantity of degradable material at time t (kg),
k = degradation rate ($years^{-1}$), and
t = time (years)

The integration of Equation (3) gives rise to an exponential term:

$$P_t = P_o \exp(-kt) \qquad (4)$$

where P_o = quantity of degradable material at time t = 0.

Differentiating (4) with respect to time leads to:

$$dP_t/dt = -kP_o \exp(-kt) \qquad (5)$$

Now given that gas production is dependent on the decomposition of organic material:

$$\alpha dP_t = -d[CH_4] \qquad (6)$$

where $[CH_4]$ = quantity of gas produced,
and $\alpha = 0,416\ m^3/kg$.

Using Equations (5) and (6):

$$d[CH_4]/dt = \alpha k P_o \exp(-kt) \qquad (7)$$

where k is dependent on the nature of the organic material and is a function of its half-life (the time for half the material to decompose):

$$k = \ln 2/t_{\frac{1}{2}} \qquad (8)$$

Substituting for α and k in Equation (7), the rate equation becomes:

$$d[CH_4]/dt = (0,416 \times 0,693 \times P_o/t_{\frac{1}{2}})\exp(-0,693xt/t_{\frac{1}{2}}) \qquad (9)$$

The potential methane production (in m^3/hr) can hence be calculated over the lifetime of a landfill, provided that the amount of dry biodegradable refuse deposited in the site each year and the half-life of the refuse is known. In addition, the following assumptions are necessary:

(i) Ideal conditions for LFG production exist in the site, i.e. all the biodegradable refuse will eventually decompose, producing 0,416 m^3 of methane per kilogram of dry material.

(ii) There have been no landfill fires on the site. Fire will significantly reduce the quantity of starting material available for CH_4 production as well as the CH_4 already produced. Landfill fires are a common occurrence in South Africa due to dry climatic conditions, the dumping of hot coals, and poor landfill site management.

(iii) The half-life of the various refuse types is known. Hoeks(14) classified degradable refuse into three categories: readily degradable food wastes ($t_{\frac{1}{2}}$ = 1 year); moderately degradable soft plant wastes ($t_{\frac{1}{2}}$ = 5 years); slowly degradable paper and wood ($t_{\frac{1}{2}}$ = 15 years). Half-life values for paper are extremely difficult to assign because degradation is very sensitive to climatic conditions. Under very wet conditions the half-life is possibly as low as 5 years compared to the half-life value of 15 years used by Hoeks(14). It is probably much longer under very dry conditions.

A Theoretical Assessment of the Methane Potential of a Landfill Site

An estimate of the LFG potential of a landfill, using the kinetic model discussed above, can be made based on a detailed inventory of the material in the site. To illustrate this, the researchers have chosen to model gas production, based on recent data, from the Grahamstown landfill site. The results are probably comparable to any other well-managed South African landfill site serving a population of 70 000 (20 000 white and 50 000 black).

Table 1: Analysis of refuse deposited at the Grahamstown landfill

(j)	WASTE TYPE	$t_{\frac{1}{2}}(j)$ (YEAR)	MATERIAL DEPOSITED (TON/YR)	WATER CONTENT (%)	$P_{o(j)}$ (DRY TON/YR)
(1)	food	1	2424	63	897
(2)	garden	5	2718	50	1359
(3)	paper, wood	15	2874	23	2213

Amounts of dry biodegradable refuse ($P_{o(j)}$), and the relevant half-lives thereof, entering the Grahamstown site, are detailed in Table 1. Using these values and assuming that tipping takes place at the same rate each year, the total rate of methane production from the 3 types of refuse at any time t after the first refuse is deposited, is given by Equation (10).

$$d[CH_4]/dt = \sum_{t=1}^{t=t} (0{,}416 \times 0{,}693 \times 897 \times 10^3)\exp(-0{,}693 \times t) +$$

$$\sum_{t=1}^{t=t} (0{,}416 \times 0{,}693 \times 1359 \times 10^3/5)\exp(-0{,}693 \times t/5) +$$

$$\sum_{t=1}^{t=t} (0{,}416 \times 0{,}693 \times 2213 \times 10^3/15)\exp(-0{,}693 \times t/15) \qquad (10)$$

The result of tipping at this rate for 50 years is obtained by adding each year's contribution and has been graphed in Figure 1. The model indicates that after 5 years of landfilling, the situation at present, methane will be produced at a rate of approximately 83 m³/hr or 29 m³/dry biodegradable tonne/year from the Grahamstown landfill. If tipping were to continue indefinitely at the same rate, a steady rate of methane production, 240 m³/hr, would eventually be realised. In the event of tipping being discontinued after the 50th year, the model indicates that methane will still be produced in the 100th year at the rate of only 15 m³/hr, or 0,5 m³/dry biodegradable tonne/year.

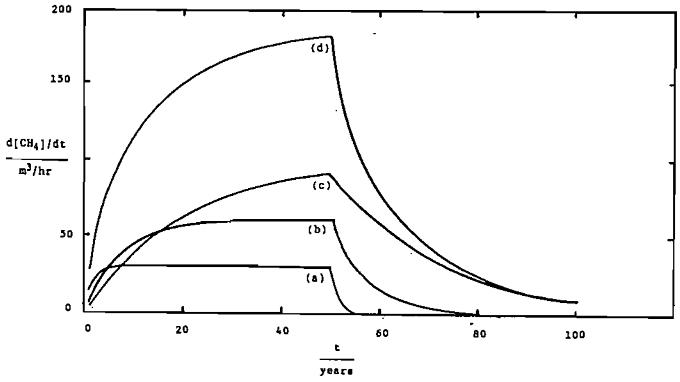

Figure 1: Methane production from the Grahamstown landfill site using data in Table 1 and equation (10). (a), food wastes; (b), garden wastes; (c), paper and wood; (d), sum of (a), (b) and (c).

An Empirical Assessment of the Methane Potential of a Landfill Site

Gas pumping experiments are commonly used to determine gas production rates(16,17,18). The results of these experiments should confirm the gas production rates predicted on the basis of simple kinetic modelling. The pumping is conducted using a vacuum pump on perforated pipes sunk vertically into the refuse (see Figure 2).

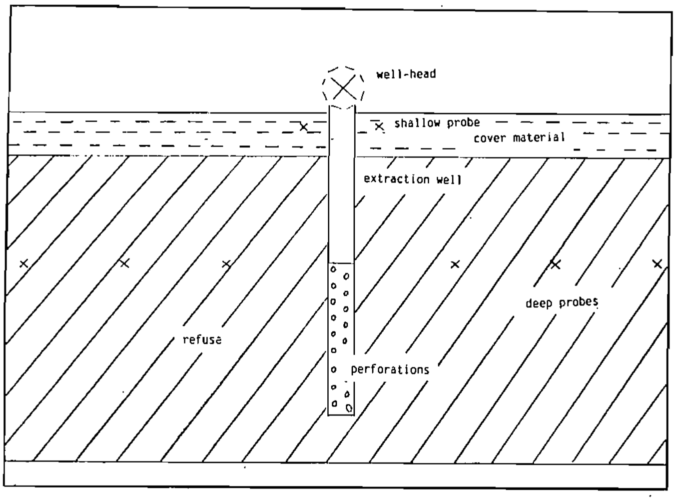

Figure 2: Cross-section of gas extraction well and pressure monitoring probes installed in a landfill.

The U.S. Environmental Protection Agency (EPA) has developed a method for the determination of LFG production flow rates, based on the concept of the "radius of influence" of an extraction well. Their method is used to determine the present, but not the future, methane potential of a landfill. The approach is to withdraw gas from a well in the landfill and attempt to identify the volume of refuse from which the gas is being extracted. The method entails the use of pressure monitoring probes. The application of vacuum on the extraction well, results in a decreased pressure at points in the landfill close to the well. The further the distance from the well, the less the pressure change, until at some distance no change is detected. The point at which this occurs defines the "radius of influence" for the well in question and the vacuum applied. Knowledge of the "radius of influence" is necessary for the proper design of a landfill gas wellfield. Costly sinking of unnecessary wells is thereby avoided, as is the incomplete extraction of gas due to installation of wells that are not sufficiently close together.

The EPA(16) suggest, in the method known as Method-2E, that gas extraction wells be installed in a cluster of three in a triangular arrangement, as detailed in Figure 3. The wells should be sunk in an area of the landfill judged to be typical with regard to site characteristics, such as compaction and refuse composition. Sinking three wells, rather than only one, is an attempt to overcome the effects of the heterogeneity of the refuse material.

Two types of pressure monitoring probes are used (Figure 3).

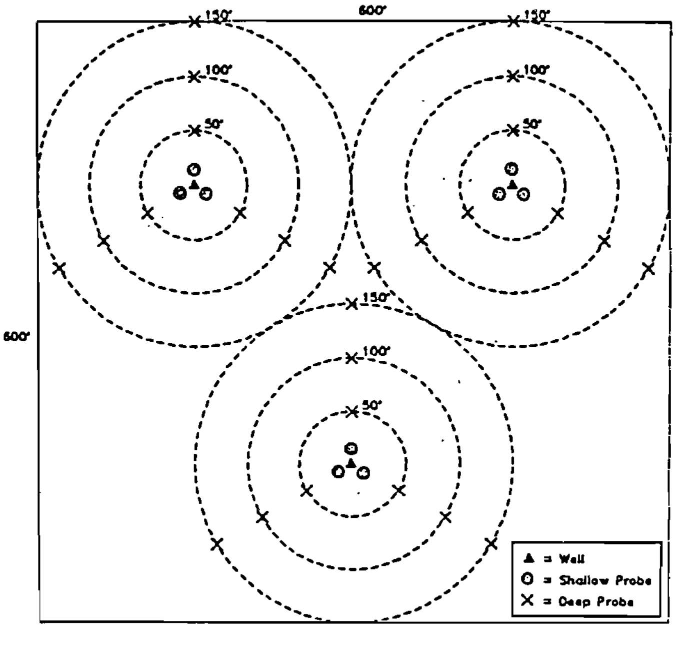

Figure 3: Layout of extraction wells and pressure probes(16)

The first type of probe should be located close to each individual well (≈ 3 m) and should penetrate the cover material, but not the refuse itself. The second type of probe (called deep probes) should be installed in the refuse, at the level of the first perforations in the vertical pipes. Testing is carried out as follows:

(i) The natural flow rate Q_i of the gas leaving each well (no pumping) and its methane content is determined. The static pressures (P_i) in the pressure monitoring probes are measured.

(ii) The wells are pumped from, collectively, at twice the natural flow rate ($2Q_i$) for 24 hours.

(iii) To check for air ingress, nitrogen concentrations in the gas are measured and the pressure (p_g) in the shallow monitoring probes is recorded.
(iv) If nitrogen concentrations are less than 1% by volume and no negative pressures are detected in the shallow monitoring probes, the pump flow rate is increased to $4Q_i$ and the infiltration tests repeated.
(v) The pumping procedure is repeated at $6Q_i$, etc. until nitrogen concentrations exceed 1% and/or a negative pressure is detected in any one of the shallow probes.
(vi) The pump vacuum is then slowly decreased until nitrogen concentrations are less than 1% and no negative pressures are detected in the shallow probes.
(vii) At this flow rate (Q_e), the deep pressure probes are monitored. The distance from the well at which no pressure difference between the initial static pressure (p_i) and the probe pressure (p_f) exists, $\Delta p = 0$, is then the radius of influence (R) for the particular flow rate Q_e.

The authors have developed a modification of the method put forward by the EPA(16) for determining gas flow rates. It does not require the use of expensive pressure probes or nitrogen detection equipment. In order to assess the ingress of air (see (iii) above), we have used an oxygen detection system which is simpler and less costly than the nitrogen method. The authors maintain that the possible ingress of air is rapid, with the pumping rates employed, so that oxygen will be drawn through the system before it has time to react.

Yet another method which can be used instead of (iii) above, is to place containers of a highly volatile and odorous chemical (e.g. thiophene) in positions just below the landfill surface in the cover material. The immediate detection of this characteristic smell in the LFG being pumped from the extraction well, signals the ingress of air into the landfill. The researchers have also used thiophene for determining the radius of influence. Instead of using costly probes (see (vii) above), thiophene is placed in the refuse at some distance from the extraction well judged to be the maximum possible radius of influence. LFG is extracted at the rate determined by infiltration testing (Q_e) and smelt in order to determine whether or not it has been contaminated by thiophene. If not, the thiophene probe is installed closer to the well, and the smell detection test repeated. The distance at which the smell is immediately detected indicates a minimum value for the radius of influence. The suggested thiophene probe is a metal pipe fitted with a spike and many perforations. The pipe is driven into the refuse below the cover material, and the sides covered with wet clay. The thiophene vial is dropped into the pipe which is then sealed.

If the radius of influence, determined by either of the two methods above, is projected onto the whole site, the total number of wells required to extract all the methane from the site (q) can be calculated. The total flow of LFG from the site at time t is then given by qQ_e. The methane flow is mqQ_e (equated to Q_t in the following equation) where m is the percentage of methane in the LFG. This quantity should be equal to the value $d[CH_4]/dt$ predicted on the basis of kinetic modelling in the previous section (Equation 10).

Assuming:

$$d[CH_4]/dt = mqQ_e = Q_t \qquad (11)$$

then

$$Q_t = \sum_{j=1}^{j=3} \sum_{t=1}^{t=t} (0{,}416 \times 0{,}693 \times P_{o(j)}/t_{½(j)})\exp(-0{,}693 \times t/t_{½(j)}) \qquad (12)$$

where $_j$ refers to the refuse type.

It must be noted that the rate of methane production must take into account $P_{o(j)}$ for each year of deposition. For the sake of simplicity $P_{o(j)}$ is considered here to be a constant.

If the values obtained by the two means (theoretical and experimental) are identical, it is possible to use Equation (12) for predicting future methane flow rates. However, it is unlikely that the two values will be the same because of the uncertainty in the $P_{o(j)}$ and possibly also in the three $t_½$ values. The value for $P_{o(j)}$, taken from refuse inventories, may indeed be too high because some of the organic refuse material may not end up as methane. This could be due to aerobic decomposition (which produces only CO_2) of some of the refuse and also the total absence (e.g. under very dry conditions) of some of the refuse. By applying a correction factor V to $P_{o(j)}$, it is possible to use Equation (13) for predicting future methane flow rates from an experimental Q_t value and the $t_½$ values estimated by Hoek:

$$Q_t = \sum_{j=1}^{j=3} \sum_{t=1}^{t=3} (0{,}416 \times 0{,}693 \times V \times P_{o(j)}/t_{½(j)})\exp(-0{,}693 \times t/t_{½(j)}) \qquad (13)$$

This one parameter equation provides a simple method for predicting the future methane potential of a landfill.

It is also possible to simplify Equation (13) by using a composite $t_½$ value for the three types of refuse material, and again applying a correction factor, V, to P_o. Equation (13) then becomes:

$$Q_t = \sum_{t=1}^{t=t} (0{,}416 \times 0{,}693 \times VP_o/t_½)\exp(-0{,}693 \times t/t_½) \qquad (14)$$

Again this equation must take into account P_o for each year of deposition.

Two values of Q_t are now required to solve for V and $t_½$. These can be taken at an interval of one year. The parameter V will take into account the problem of combining three types of refuse material into one value for P_o. It will also take into account the other major limitation with this approach, namely, that some of the refuse material does not in fact end up producing methane.

COMMENTS

The rate of energy production from landfill can be readily calculated from the value of Q_t and the enthalpy of combustion of methane given in Equation (1). For the Grahamstown site, our theoretical model (Figure 1) shows that Q_t will reach 150 m^3/hr after 20 years of refuse disposal. This is equivalent to 1,48 MW of energy. Unfortunately, experience shows that not all the methane can be captured and 50% at best can be harnessed. If the resultant heat energy is converted into electricity, a further loss is experienced. A reasonable electric generator could operate at 30% efficiency. Overall, the electrical energy expected from 150 m^3/hr of methane amounts to 223 kW. This is about 2% of the peak demand of a non-industrial city the size of Grahamstown.

The prediction of methane flow rates from the decay of MSW is of course a hazardous process. The landfill is a heterogeneous medium and precise values of P_0, R and even $t_{\frac{1}{2}}$ are not possible. The researchers have presented two semi-empirical methods, and it is perhaps best to consider the parameters V and $t_{\frac{1}{2}}$ as simply constants in an equation [Equations (13) and (14)] which can be used for predictive purposes, rather than give these parameters any physical meaning. This is analogous to the case of van der Waal's coefficients in the description of non-ideal gases.

CONCLUSION

In this paper the researchers have shown how it is possible to assess the "energy from methane" potential of a landfill site. Firstly, the EPA(16) method of determining the methane level in a landfill has been modified by using a low-cost technique which uses a highly odorous chemical. Secondly, the researchers have taken a well known first-order theoretical model and developed simple one and two parameter equations to predict future methane yields.

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ENERGY FOR DEVELOPMENT: PARTICIPATORY RESEARCH IN NAMAQUALAND

*A A EBERHARD, *M L BORCHERS and *F M ARCHER

A research project on energy consumption patterns and energy supply options in Namaqualand is described and analysed in relation to two main issues. First, the relation between energy and development is examined. The provision of adequate and affordable energy for all households is seen to be part of a development strategy aimed at meeting the basic needs of the poor. However, new energy supply schemes may be inappropriate and may even be resisted by local communities if they are not part of the process of development planning — which leads to the second main issue examined in this paper. The participation and support of local people in development projects is greatly facilitated if they are part of the project from the beginning, including the research phase which identifies problems and needs and explores alternative solutions. The participatory research process and main findings of this project are described. Finally, some subsidiary points are made about economically viable and appropriate energy supply options for remote areas.

KEYWORDS: energy consumption; energy planning; participatory research

INTRODUCTION

The availability of adequate and affordable energy supplies has always been a necessary precondition in support of economic development. Energy is required for production, the basis of material development. It is also essential to social reproduction, i.e. it is part of the package of basic needs of households for survival. Energy is needed for cooking, keeping warm and lighting. It is also important for saving labour and freeing time for productive activities or for rest, leisure and entertainment which in turn often rely on one form of energy or another. Most current development strategies recognise the importance of meeting basic needs, particularly of the poor, and energy supply is an integral component of such strategies. Resources are allocated directly to the alleviation of poverty and the improvement of material and social well-being. The expectation is that more even development is promoted, that in the long term there could be benefits to the wider economy through a healthier, more educated work-force and that demand (and hence increased production) would be stimulated.

However, the provision of new energy supplies as part of an initiative to promote social and economic development is not unproblematic. It is difficult to demonstrate a direct, causative relationship between improved energy supplies and economic development (even though countries with higher levels of economic output generally use more energy per capita than less developed countries). Moreover, new energy supplies may be resisted for a number of reasons including economic and socio-cultural factors. For example, households which rely primarily on wood may not easily afford to convert to gas or may be reluctant to forego the social function of a fire.

It is thus important that development planners carefully research current household reproductive patterns to identify constraints and needs. It is also important that they understand local perceptions and preferences and the way in which development projects, such as improved energy supplies, can affect lifestyles, values and material well-being. If this understanding is to be thorough and useful, research should be undertaken with the participation of the affected people and research findings should be fully discussed with these communities.

Participatory research emphasizes the co-operation of "researchers" and "subjects", i.e. those affected by the research influence directly each stage of the research process: defining the problem, how the problem is to be studied, data analysis or establishing the meaning of the data, and how the findings can be used.

This paper describes a research project which sought to work with communities in six "Coloured" rural reserves in Namaqualand (Figure 1) in order to understand current energy usage patterns and to assess alternative energy supply options which would result in affordable and adequate energy for all in the area. The researchers describe the process of the research, the main findings and recommendations, and end with a discussion on the relevance of participatory research to development planning.

THE RESEARCH PROCESS

The project arose after publicity surrounding legal proceedings in the Supreme Court in which residents in the reserves successfully challenged a "development" scheme by the administrative authority (the House of Representatives) which sought to divide communally-held land into a limited number of "commercial" units. The scheme was based on questionable assumptions and it would have enriched (probably temporarily) a few residents who, at the expense of the majority, would have lost traditional rights to grazing and other natural resources(1). One of the outcomes was a suggestion that independent studies on development options for the region should be undertaken. The Energy for Development Research Centre (EDRC) of the Energy Research Institute took the initiative in proposing two of these research projects, one on water supply options and the other on energy supply options**, the topic of this paper.

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**Both of these projects were funded by the National Energy Council.

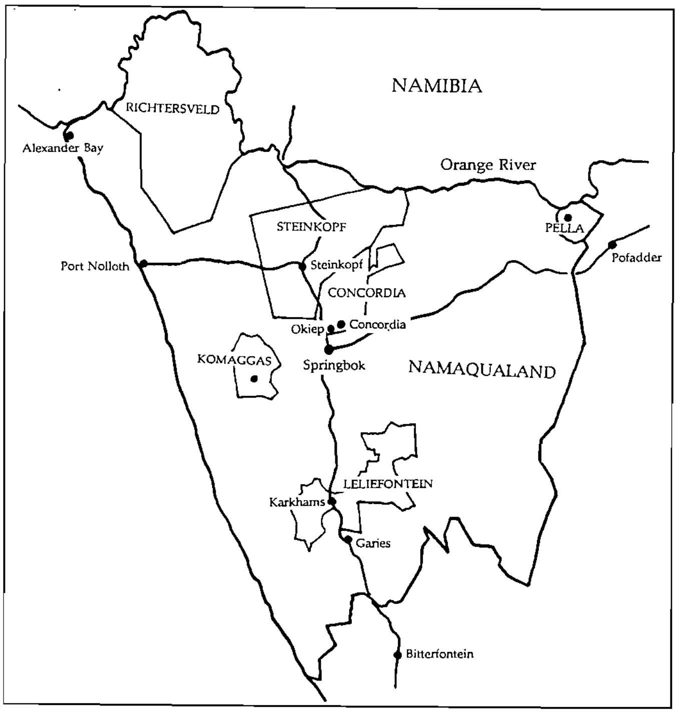

Figure 1: "Coloured" rural areas in Namaqualand

While relying on many traditional research techniques such as questionnaires and interviews, the researchers also sought to involve the communities in the various aspects of the research process. Seven field trips were undertaken, some lasting for over a month. One of the researchers had lived previously with families in the reserves and played a vital role in establishing and consolidating an ongoing relationship with the communities. This was not always entirely unproblematic, as organisations are weak and some of the communities in the reserves are divided. Some towns are divided according to religious allegiance. The local Management Boards are generally unpopular, but in some areas they retain a measure of support. However, the researchers' experience was that those members of the community who became involved in this energy research project adopted an explicitly non-sectarian role and realised the potential benefits of adequate and affordable energy for all. Some areas formed "energy committees", while in other areas the local civic organisations took the lead in involving members of the community in the project.

Meetings were held to talk about the aims and methods of the research project. An initial questionnaire was piloted and changes were made in response to this experience. Some questionnaires were administered by the main research worker, others (following suggestions made at community meetings) were filled out in groups while discussing the various questions. In other areas, local enumerators undertook to administer the questionnaires. A total of 450 questionnaires were completed, with the most comprehensive coverage occurring in Leliefontein Reserve in order to obtain a measure of diversity within one area. Interviews included questions on problems, needs and preferred solutions. Data were coded and analysed statistically with microcomputer packages, and supply alternatives were evaluated with the aid of design and costing tools developed at the EDRC. Provisional findings, conclusions and recommendations were summarised and translated and these were discussed in meetings in each of the reserves to ensure that the opinions of the communities were reflected adequately. Recommendations were adjusted accordingly, and a final report and translated summaries were sent to each of the communities. Committees in these areas have been discussing the report and have been examining ways in which the recommendations for improved energy supplies may be implemented. The report was also sent to the funding agency, the National Energy Council, who has established a working group to evaluate the recommendations. Pressure is growing from the communities for representation on development planning committees and institutions.

It should be clear from the above that while the researchers sought the involvement of local communities, the research process was not fully participatory in the ideal sense defined in the introduction above. While the communities did partially suggest the research topic, influence the research method, participate in data collection, comment on the meaning of the data, and actively engage in deciding how the research findings could be used, the research staff at the EDRC played a dominant role in all stages of the research project, particularly in the analysis of the data from the questionnaires and in the evaluation of supply alternatives. The latter was accomplished with the aid of accumulated knowledge and experience embodied in a computer-based design and costing package.

The researchers experienced, thus, the common dilemma of this type of inquiry. Research skills and relevant technical knowledge were not readily available in the Namaqualand reserves, yet their input and full participation in the project was recognised as being critical. It is problematic to suggest merely that the scientific and "objective" knowledge of experts should be integrated with the "subjective" knowledge and values of local communities. There is an intellectual tradition which would assert that all knowledge is related to interests and values(2). The researchers do not pretend to resolve, or even to contribute to, these theoretical debates here, but rather to demonstrate below that greater community participation in the production and evaluation of knowledge is favourable to it being assimilated, owned and acted upon. The benefits for development initiatives should be obvious.

BACKGROUND TO THE AREA

Namaqualand lies in the north-west corner of South Africa bounded by the coast and the Orange River Namibian border. It is popularly associated with small mining activity and the spectacular wildflower displays in spring. It is an extremely arid region and agricultural potential is limited. Within the region lie six "Coloured" rural areas, or reserves: Leliefontein, Komaggas, Concordia, Steinkopf, Pella and the Richtersveld. These have their origin in mission stations which were established in the early 1800's. With the encroachment of white settlers, the original Nama-speaking Khoi inhabitants, many of whom had settled around the stations, were granted a form of land tenure. Today's inhabitants are mostly descendants from these clans, and they currently number close to 24 000 out of a total Namaqualand population of 63 000. The reserves comprise roughly a quarter of the total land area of 47 700 km^2 of Namaqualand.

The Khoi were nomadic pastoralists. Pastoralism remains important in the area, but the traditional house structure, the "matjiehuis", is fast disappearing and, in terms of energy supply, gas and other commercial fuels are substituting for fuelwood for cooking.

Employment opportunities are limited. Most available work is on the mines outside the reserves, forcing many residents into a migrant lifestyle. The median household monthly income is around R600.

RESEARCH FINDINGS

The research generated an enormous amount of data which has been reported in Borchers *et al.*(3). A very brief overview is presented here.

Energy use patterns

Grid electricity is available only in the towns of Leliefontein, Karkhams, Concordia and Steinkopf, and to less than a fifth of the households in these settlements. Only 9% of all households in the reserves have electricity.

In common with many other rural areas of South Africa, most families use wood and candles(4). However, unlike the designated African "homelands" and even many informal shack settlements around the metropolitan centres in the rest of South Africa, most households (over 80%) use gas and although a significant proportion of households use paraffin (Figure 2), quantities consumed are relatively small.

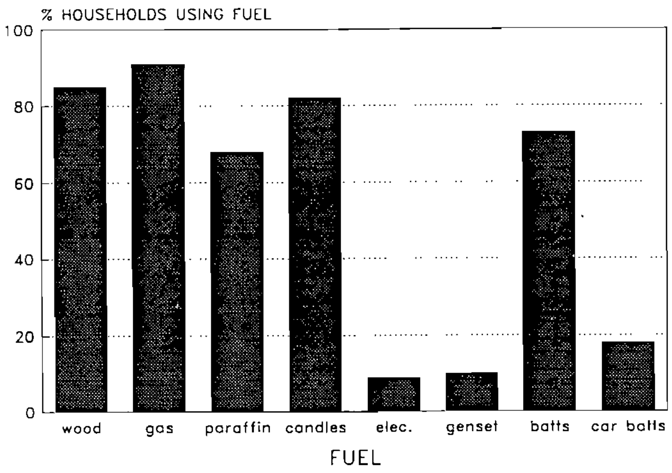

Figure 2: Percentage of households using each fuel

Gas is difficult to obtain but is preferred over other available fuels, apparently because of its greater convenience as a cooking, lighting and refrigeration fuel. A significant number of households still cook daily with wood, particularly in Leliefontein, Pella and the Richtersveld and to a lesser extent in Concordia. Most wood is gathered from natural woodland, but increasing numbers of households have to use transport to fetch wood or have to pay for it, indicating its growing scarcity around settlements. Woodfires are still an important focal point of social activity, but there is a discernible transition to gas usage which is often associated with building and moving to more modern brick houses.

In terms of overall energy used, wood contributes nearly two-thirds. However, because of the greater efficiency of gas appliances, gas actually contributes more useful energy (Table 1).

Table 1: Contribution of each fuel to average monthly household net and useful energy consumption in the Namaqualand reserves

Fuel	Average net energy use (MJ/house/month)	Average useful energy (MJ/house/month)
Wood	2 856	286
Gas	1 152	806
Paraffin	316	174
Candles	49	25
Generators	12	10
Electricity	90	72
TOTAL	4 475	1 373

Note: Details on net/useful energy conversion given in Borchers *et al.* (1990)

Average household monthly energy expenditure varies between R51 in Leliefontein and R166 in Komaggas. There is a clear trend of higher income groups spending more on energy (R100-R200 per month (pm)), while poorer households with incomes less than R300 pm (a quarter of the total) typically spend less than R40 pm.

Perceived problems and solutions

Residents expressed widespread dissatisfaction with the affordability and availability of fuels. The poor in particular face a difficult situation of greater reliance on fuelwood. They either have to devote greater time and effort to providing household energy or have to commit a higher proportion of their income. The great majority of households expressed a strong preference for electricity as a supply option. Interest was also expressed in arranging cheaper gas distribution and in planting woodlots to increase the availability of wood.

Energy supply alternatives

Based on the above, the energy supply options investigated in more detail were:

(i) Electricity from the national grid and independent stand-alone decentralised generators such as diesel plants and photovoltaics, but not hydroelectricity (which has no potential in the area) and wind energy (as insufficient data is available).
(ii) Improved gas distribution.
(iii) Various strategies to improve the supply of fuelwood.

Photovoltaic, diesel and grid-connected systems were sized and costed with the aid of POWERCOST, a microcomputer program which has been described in Eberhard and Borchers(5).

Figure 3 indicates electricity costs for diesel generators at different capacity factors, diesel generators supplying a small local grid network, petrol generators and photovoltaic systems with different loss-of-load probabilities (or levels of reliability).

A detailed estimate of grid-connected electrification costs was also undertaken. Table 2 shows that if all homes in the reserves (excluding remote individual homesteads) were electrified, the average unit cost would be of the order of 24c/kWh.

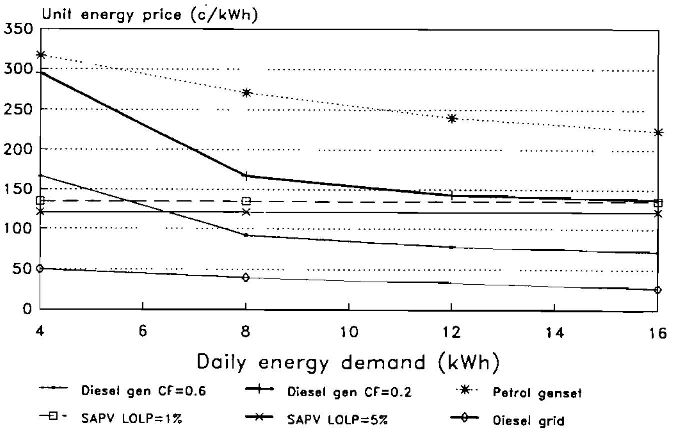

Figure 3: Unit energy cost from power supply options

Table 2: National grid electricity costs averaged over all six Namaqualand reserves

Total number of houses	4632
Total grid extension cost	R5 223 000
Total internal settlement reticulation cost	R10 338 277
Average internal reticulation cost/stand	R2 232
Total extension + reticulation cost	R16 459 237
Average total cost/stand	R3 553
Monthly capital recovery charge (1,35%)	13,5c/kWh
Average c/k	Wh 24c/kWh
Monthly payments:	
120kWh pm (lower income group)	R29
240kWh pm (middle income group)	R58
480kWh pm (higher income group)	R116

If allowance were taken of ESKOM's excess generating capacity and ESKOM agreed to sell electricity at generation, operating and maintenance costs only, the delivered unit energy cost could be as low as 16c/kWh.

It is clear from the above that grid-connected electricity is cheaper than all the other generating options considered in all the villages in the reserves (with the exception of 4 small remote settlements in the Steinkopf reserve). If estimated monthly electricity expenditures are compared with current household expenditure on energy, then it is clear that most households will be able to afford electricity.

The next cheapest option is a local grid supplied by a diesel generator. Stand-alone photovoltaic systems are generally cheaper than diesel and petrol generators at most of the loads considered (except at high diesel capacity factors) and are the most cost-effective options for isolated homesteads with small electrical demands. These systems, however, are still very expensive (>120c/kWh) and would not be affordable without subsidisation.

A significant barrier to further electrification in those few towns which already have electricity in Namaqualand has been the connection fee and the cost of wiring houses. The use of ready-boards and a nominal connection fee would make this option affordable to many more people. Another barrier is the cost of switching to electrical appliances and it is likely that, in the short term, transitional fuels such as gas will continue to be used.

The possibility of providing a cheaper gas supply by arranging more direct supply routes from Cape Town was investigated, but scope for savings appeared to be only marginal.

Fuelwood will probably remain an important energy source for the very poor⁽⁶⁾. Two approaches were explored to improve the supply of wood. Firstly, the riverine areas in the Leliefontein Reserve could be encamped in order to protect saplings from stock grazing and to promote natural wood growth. This suggestion came from local residents and is likely to receive general support.

The second strategy for improving wood supplies is the development of woodlots. This may seem to be an inappropriate recommendation, given the low rainfall of the area and the fact that there are very few examples worldwide of successful woodlot schemes in arid regions. However, a few woodlots do exist in Namaqualand and reasonable growth has been achieved with *Eucalyptus* species. These schemes unfortunately have been useless in providing fuelwood. There has been no community participation, existing stands have been poorly managed, and communities have not had regular access to wood harvesting; in fact, most of the stands have not been felled at all. These issues of involvement of local communities in woodlot management would need to be resolved if a woodlot programme were initiated. There would also appear to be some potential for managing the utilisation of local wood species: *viz. Acacia karroo* (indigenous) and *Prosopis spp.* (exotic) which is particularly prolific around Pella.

Detailed recommendations were developed from these research findings, including the immediate electrification of most of the settlements and the implementation of a number of other complementary energy supply strategies.

CONCLUSION

The findings of this research project on energy supply options in the reserves of Namaqualand have been significant in terms of content, the process of research, and the implications for development planning in the region.

Namaqualand has the most favourable solar energy resource in the country. Yet it has been shown that grid-connected electricity is currently very much more economical than photovoltaics in all of the villages in the reserves. This probably indicates that photovoltaics will not be cost-effective in any villages in South Africa in the immediate future and that their only rational application for home power would be remote individual homesteads.

The process of undertaking this research has been illuminating. Many of the recommendations were made on the basis of accumulated "technical" knowledge at the EDRC, which has been embodied in a computer-based rational decision-making tool. This aspect of the research did not involve community participation and communities experienced some difficulty initially in understanding and appreciating all the research findings. However, other recommendations were based on the suggestions of residents.

The involvement of affected communities was vital to the quality, relevance and potential application of research findings. It provided a clearer understanding of existing problems with energy use, as well as a clear expression of preferred supply options. Most importantly, their involvement (albeit limited) in the research process lays the basis for their participation in the formulation and execution of development plans. The potential exists for their empowerment through assimilating new and relevant knowledge on energy supply options. Residents in some of the reserves have begun this process by meeting and discussing the research findings. They are beginning to consider ways in which preferred and recommended supply options can be realised and, if they are given the opportunity of participation in the development of the region, the potential for success is enhanced.

The importance of this issue is demonstrated in a current electrification programme in O'Kiep township in Namaqualand where communities were neither adequately consulted nor provided with the opportunity of participating in the planning of the project. The result has been widespread dissatisfaction and even resistance to the electrification scheme, the technology used, the manner in which it is being executed, and the proposed service charges. This experience has the potential for prejudicing any other proposed electrification scheme in the area.

The experience of this research project, however, has indicated the exciting potential for participatory research which facilitates the empowerment of poor communities and encourages their involvement in shaping the nature and direction of development initiatives.

ACKNOWLEDGEMENT

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PERSPECTIVES ON A NATIONAL ENERGY STRATEGY FOR SOUTH AFRICA

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An energy strategy, which is a plan to achieve specific energy-related goals within a given time frame, is an essential component of a national development plan. The framework of a national energy strategy for South Africa, in the form of emerging schools of thought around economic restructuring, and the experience of Africa in planning development, is presented. The broad context in which an energy strategy for South Africa will operate is considered. The energy sector is analysed and a categorisation in terms of fuel group characteristics of consumers suggested. This categorisation into modern, transitional and traditional components provides a new perspective in which the focus is the consumer rather than the commodity consumed. Aspects of an energy strategy are examined, and a governing paradigm, as well as goals for the components of the energy sector, proposed.

KEYWORDS: energy strategies; energy policies; energy planning; South Africa

INTRODUCTION

As energy costs increase, resources dwindle and energy policy becomes more sophisticated, the need for a coherent national energy strategy becomes increasingly apparent. As the manner in which energy is obtained and used directly influences the economy, the environment, and human welfare, improvements in economic performance, environmental quality and social well-being may be gained through the modification of energy usage. This modification may be achieved by a range of policy measures, by market forces, and by the education of both consumers and suppliers.

An energy strategy is a plan to achieve a set of goals within the framework of a variety of constraints and within a specific time frame, by means of the instruments of modification mentioned above. To be effective an energy strategy needs clear and meaningful goals which are derived from a framework of broader national objectives. The formulation of an energy strategy requires an understanding of the social, economic and technological contexts in which it is to operate. The deeper questions of social policy and national security that may be skirted at the policy level, have to be considered at the strategic planning stage. It is axiomatic that the formulation of an energy strategy must also be based on a detailed understanding of the energy sector itself.

This paper briefly explores the context and development framework of an energy strategy for South Africa. The energy sector is then analysed in some detail and a categorisation suggested that may aid in the formulation of the strategy. Finally, some elements of the strategy are presented.

THE DEVELOPMENT FRAMEWORK

A national energy strategy will require integration into broader national goals. No national development plan has as yet been formulated, although a vigorous polemic has begun around developmental issues(1,2). Two schools of thought are developing in South Africa around economic restructuring. The first is "growth through redistribution" which envisages growth stimulated by active policies of redistribution of income and the factors of production. Secondly, there is a stimulated growth school which sees social upliftment as a corollary of faster economic growth. The basic difference in these schools of thought is the role of the market. Despite this there is convergence on issues such as increased social spending for the amelioration of poverty. Can there also be convergence on energy-related issues?

While the "development challenge"(1) is being fleshed out, lessons can be learnt from Africa which is addressing problems identical to those in our developing areas. Two recent strategies are of interest: one prepared by the U.N. Economic Commission for Africa, and the other by the World Bank.

The Economic Commission for Africa(7) proposed an alternative framework for Africa. This plan involves "adjustment with transformation" of the societies in question(5). It stresses the human dimension and has as its major development objective the alleviation of poverty and raising the welfare of the people. It aims to do this by developing self-sustaining economies, integrating economies, and evolving participatory political systems. The framework is presented only in broad terms and it is left to each country to develop its own policy package.

The World Bank(10) has proposed a broad development strategy for Sub-Saharan Africa entitled "Sub-Saharan Africa: From Crisis to Sustainable Growth". The core of the plan is sustainable growth with equity. The main focus is on human resources, technology, regional co-operation, self reliance, and respect for African values. The plan sees agriculture as the main foundation for growth in Sub-Saharan Africa. Here structural transformation is seen as essential in improving the productivity of labour, capital, and natural resources. A vital benchmark is that economic growth must exceed population growth. The World Bank strategy is more detailed than the ECA framework and deals with a number of key issues, one of which is energy. However, the strategy is not well formulated in this regard. It recognises the key role of woodfuel (and the massive problem of deforestation), but sets growth targets only for commercial energy (5% p.a.) and not for transitional fuels, or re-afforestation.

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Both of these development strategies indicate the importance of adequate data to develop full understanding of the issues, and of setting clear goals. In the case of South Africa, when the various schools of thought on development are elaborated into national development plans, the first steps will have to be the formulation and prioritisation of developmental goals. Even if the energy sector is a key component, energy-related goals will have to be subordinated to issues such as education and housing. In the case of the "redistribution" model, domestic energy supply will probably be ranked highly as it is an area of obvious inequality. In the "growth" model the expansion of energy for productive purposes is likely to take precedence over domestic supply. The key issue is that the appropriate subordinate positions of the energy components in the national strategy need to be found.

THE CONTEXT

The formulation of an energy strategy requires an appreciation of the social, economic, environmental and technological contexts in which it is to operate. This will require the in-depth investigation of areas of concern which will impinge on strategy and, conversely, where the impact of strategy is likely to be greatest. These will include the following:

(1) *Socio-political arena*: In this era of rapid change, energy provision, particularly in the form of electricity, is already an issue with a high profile. The drive for social justice and development will result in increasing calls for the provision of energy for all. Expectations that have been raised in this regard need to be quantified and prioritised. Policy-makers need to be apprised of the possibility of energy supply from a far wider range of energy options, and of the cost-benefit implications of providing certain options. The security of supply of energy on the one hand, and the potential integration of Southern African energy markets on the other, need to be assessed in the light of emergent political trends. The impact of changing regional and local forms of government on energy provision also needs to be assessed.

(2) *The economy*: South Africa is a developing country but ranks at present in the category of poor performers. Per capita GDP growth is low, the industrialisation process is stalled, inflation is above that of trading partners, and the economy is sensitive to commodity price fluctuations. Concomitant with this is the high energy intensity of the country due to the large mining component and the advanced age of much industrial technology. Increasing demands for energy provision are being made against weakening fiscal capability to meet these demands.

(3) *Socio-economic attainment*: On any measure South Africa ranks highly in terms of inequality. Incomes, educational levels, mortality rates, quality of services, etc. exhibit wide ranges both racially and regionally(9). Poverty is still a pervasive phenomenon. An energy strategy may assist directly and indirectly in closing these gaps and reducing poverty levels.

(4) *Environmental considerations*: South Africa is a semi-arid country but is still host to a diverse range of ecosystems. These have been reduced by both subsistence and extensive commercial agriculture. Soil erosion is widespread. Water quality is poor in certain areas. Regional atmospheric pollution due to sulphur dioxide emissions from power stations, and urban air pollution due to vehicle and industrial emissions and coal fires, are major problems. Energy production and consumption are interlinked with all of these. Addressing these problems will be a major challenge of any energy strategy.

(5) *Infrastructure*: A sophisticated distribution network for fuels already exists in South Africa. The national electricity supply and distribution system is extensive. The potential for the extension of this infrastructure is great. This potential and the cost and social benefit of this exercise will be a cornerstone of any energy strategy.

(6) *Institutional framework*: South Africa has a developed institutional framework for financing, marketing, research and development. The effective utilisation and strengthening of these institutions are essential for the successful implementation of an energy strategy.

(7) *Technology*: Technological innovation occurs in South Africa firstly through contact with its major trading partners, and secondly through internal innovation. The system provides innovations relating almost entirely to the modern component of the energy sector. Innovations in the transitional and traditional components will have to be actively sought and the local innovation process stimulated.

(8) *Policy framework*: Policy measures are the basic building blocks of an energy strategy. Current legislation pertaining to energy is concerned mainly with regulating prices and supply processes. In almost all cases fuels are viewed in isolation. The role and effectiveness of existing energy-related policy will need to be assessed in the light of different developmental goals. Modifications to existing legislation, and new legislative and other policy measures, will have to be draughted to complete the strategy.

(9) *Resources*: South Africa has an abundance of coal. Its continued use for energy generation will be increasingly questioned in the light of environmental considerations. The country has, however, both natural resources and supply conditions that favour the use of renewables. Solar, wind, hydro and biogas technologies that are already developed may be hybridised to provide economic power for remote area applications. The present and future economics of various energy options need to be explored in the energy strategy.

(10) *Physical attributes*: South Africa is large and topographically complex. This has important implications in terms of settlement distribution, transport costs and energy distribution costs. In addition, difficult climatological conditions make re-afforestation a difficult option in many areas.

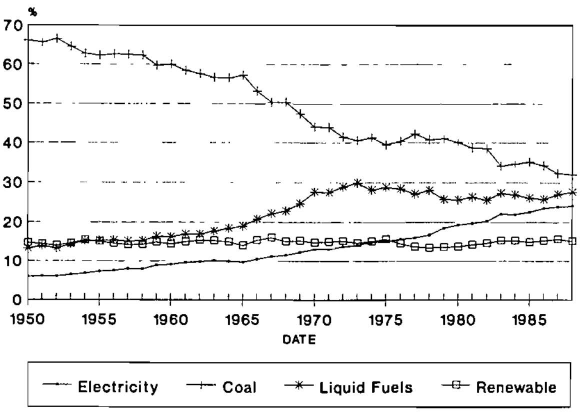
Energy planning in this context will have to follow both Third World(3,4) and First World models. It should be apparent that contextual appreciation is a difficult task, but energy is a large sector and thus the net has to be cast wide to embrace it.

THE SOUTH AFRICAN ENERGY SECTOR

A clear understanding of the energy sector is vital to the formulation of an energy strategy. The sector is a dynamic one and thus its evolution needs to be briefly set out.

The history of energy in South Africa is one of change from traditional energy sources (notably wood, wind and water) to a mix of modern, transitional and traditional energy forms. Concomitant with this change has been a radical increase in energy efficiency, a proliferation of fuel types, and the development of energy carriers such as electricity. Until recently, the process has been slow. Coal took a century to overtake wood as the dominant fuel in terms of energy consumption; from its discovery in the early nineteenth century to about 1925. The major changes in market shares of fuels have occurred only in the last four decades. Figure 1 illustrates the growth of the usage of electricity and liquid fuels and the matching decline in the use of coal.

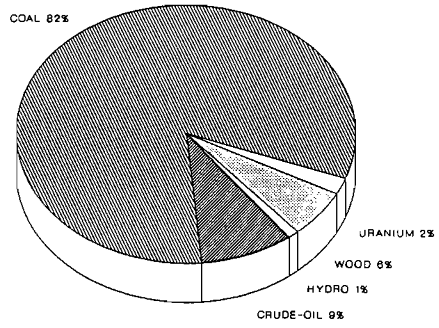
FIGURE 1: SHARE OF DIFFERENT ENERGY FORMS: 1950 - 1988



In parallel with the transition detailed above, there has been a sectoral shift in energy use, from agricultural and domestic uses to industrial, commercial and transportation uses. This shift and the consequential decline in the importance of the domestic sector have lead to the masking of underlying trends in the developing sector of the population.

While electricity has grown in importance, it is largely generated from coal. Similarly, a portion of local liquid fuel is derived from coal. Thus, while energy forms have changed, coal is still the basis of the energy economy. It accounts for the lion's share of primary energy use, some 88% in 1988 as illustrated below.

FIGURE 2: PRIMARY ENERGY USE IN SOUTH AFRICA IN 1988



The conventional categorisation of the energy economy in terms of either aggregate energy consumption of each fuel, or aggregate energy consumption per sector, leads to quantitative bias in favour of the large consumer of higher grade fuels. A categorisation by fuel group characteristics of consumers, which is an extension of the model suggested by Viljoen[8], provides a different perspective. A threefold system emerges.

Firstly, there is the *modern component* where a large number of 'high grade' energy forms are used in relatively efficient energy conversion devices. In this component there are a large number of institutional, commercial, industrial and mining consumers, a number of agricultural consumers, some transportation consumers, and about a third of the nation's households. The last category consumes energy within the household as well as in private vehicles and indirectly through their large stake in the formal economy. Households in this component have a high average energy consumption.

Secondly, there is the *transitional component*. Here component fuels of lower utility, although not necessarily lower calorific value, are used in relatively inefficient energy conversion devices. There are a small number of industrial and commercial consumers in this sector and a large number of households, probably also about a third of the national total. These households have limited private vehicle ownership, and a large proportion are employed in the informal sector. As a result, the direct and indirect consumption of modern fuels is small. The average energy consumption by households in this component is intermediate.

Thirdly, there is the *traditional component*. Here a few fuels of low calorific value and low utility are converted to energy very inefficiently. The consumers in this component are almost all households, mainly in rural areas, which have low mobility and a marginal association with the formal economy. These households have a small number of end-uses where energy is consumed and low average energy consumption.

The table below summarises the characteristics of the three components.

Table 1: The traditional, transitional and modern sectors

	TRADITIONAL	TRANSITIONAL	MODERN
DOMINANT SECTOR	Domestic/ agricultural	Domestic/ transport	Comm/Ind/Mine
ECONOMY	Subsist/inform.	Informal/ formal	Formal
FUELS USED	Wood/dung	Para./coal/LPG	Elec/ Liq. fuels
TRANSPORT MODE	Foot/animal	Taxi/bus/train	Pvt car/ plane
AVE EFFICIENCY*	10-15%	30-40%	60-75%
NO APPLIANCES*	2-4%	3-6%	15-20%
AVE ENERGY USE	Very low	Medium	High

* Domestic appliances only

This categorisation changes the focus to the consumer rather than the commodity consumed and is more suited to the blend of developed and developing that characterises the South African economy.

From the above analysis it is apparent that at the macro scale energy consumption differences between the components identified above are attributable firstly to their differential shares in the formal industrial economy, and secondly to differential mobility. These factors more than offset the increase in energy efficiency as the transition from traditional to modern fuels takes place. At present it is the transitional component that is growing fastest, but about which the least is known.

TOWARDS AN ENERGY STRATEGY

The preparation of a national energy strategy has yet to be undertaken. A framework has to be developed, the context of the plan understood, and the energy sector analysed in depth. Even so, at this early stage certain elements of a strategy emerge.

At the heart of a national energy strategy will be a central goal, or governing paradigm. This paradigm should have the following characteristics:

- It should take a holistic view. The energy sector in its entirety must be addressed.
- It should be concerned with the role of energy in influencing development, as measured by socio-economic attainment, rather than only economic growth, as measured by GDP per capita.
- It should be concerned with both energy demand and energy supply.

The governing paradigm could be: the optimum use of national energy resources to maximise social benefits and minimise social and economic costs to achieve sustainable development. Flowing from this would be the following:

1. Energy reduction of the whole system would be a planning principle. Energy efficiency, demand management and the substitution of more efficient energy forms would be major objectives. The management of the energy transition process is fundamental to the strategy.
2. The quantification and qualification of benefits to society and of social, environmental and economic costs would be essential requirements of all energy planning. The objective would be the determination of 'real' costs and weighing them against benefits which have distinct priorities in terms of the framework within which the strategy operates. This would permit the direct integration of the strategy with broad social policy.
3. National energy planning decisions need to be taken with sustainability in mind. Global environmental concerns will play an increasing role in national strategies, as will energy security in the emerging era of an unstable oil market.

At higher levels of disaggregation, goals will have to be formulated for each of the traditional, transitional and modern components of the energy sector.

(1) In the traditional component the focus will be on the domestic sector. The broad goals could be the provision of affordable energy supplies and the stimulation of the energy transition process. Within this component the provision and efficient use of biomass fuels by the rural poor will probably be a high priority.

(2) In the transitional component the focus will be on the domestic, transport, and commercial sectors. The broad goals could be to increase the efficiency, safety and health-related aspects of energy use, to reduce the cost of fuels by the formalisation of distribution networks, and to accelerate the energy transition process.

(3) In the modern component the focus will be on the industrial, mining, and transportation sectors. For the industrial and mining sectors the major goal will be increasing energy efficiency and reducing environmental pollution. The restructuring of urban transportation modes and patterns to permit more efficient travel are goals that this and the transitional component will probably share.

Rational planning decisions and policy measures to influence both the energy supply industry and consumers could flow directly from the broad strategy goals and those relating to the energy sector components. In the latter case real issues with clear priorities for the planning process emerge.

CONCLUSIONS

It is likely that the process of formulating a national energy strategy will be commenced within the next few years. While issues relating to the development framework of the plan are clarified, the task of collecting data relating to the context of the plan and researching aspects of the energy sector should be undertaken on a structured basis.

An energy strategy will be a vital element in the economic and social restructuring of the new South Africa. To live up to its promise, it will have to address real economic, social, environmental and technical issues. If successful, the strategy will accelerate socio-economic upliftment as well as economic growth.

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REVIEW

Overview of the World Energy Council's Regional Energy Forum for East and Southern African Countries held in Harare, 12-14 November 1990

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INTRODUCTION

The World Energy Council (WEC) as a non-government, non-commercial body is currently the only international multi-energy organisation to inform and marshal world opinion for the solution of major world energy problems. It represents 87 member countries, of which South Africa is one. The WEC maintains a substantial ongoing programme of international energy studies dealing with various energy and energy-related subjects.

As part of their scope of work the WEC has initiated a series of Regional Energy Forums, largely organised with the assistance of the local host Member Committees. The prime objective is to provide a forum for discussion of global energy matters, but in particular of local energy matters.

The Regional Energy Forum for East and Southern African countries entitled, Regional Energy Perspectives for the 1990's, was the first WEC forum to be held in Africa. This event was mainly sponsored by the WEC and its Zimbabwe WEC Committee, with considerable support by the South African WEC Committee (SANCWEC).

The attendance of 220 representatives came from 22 countries around the globe. The following African countries were represented: Angola, Zaire, Zimbabwe, Swaziland, Botswana, Tanzania, Kenya, Zambia, South Africa, Rwanda, Namibia, and Nigeria. A positive attitude was evident towards South Africa in general and a realisation of the benefits of future co-operation in all spheres of energy and economic development manifested strongly during the course of the event.

PROGRAMME

The programme for the first day covered issues such as:

— The Regional Energy Scene Today,
— World Energy Perspectives to 2020, and
— Major Energy Issues of the Developing World.

The second day was devoted to Regional Energy Resources and Issues, while the last day covered Regional Energy Co-operation and Perspectives.

The Opening Address was given by President Mugabe and other Keynote Addresses were given by officers and experts of the WEC and World Bank.

According to Ian Lindsay (Secretary-General, WEC), the following issues *inter alia* are of crucial importance to sustainable energy development in developing countries:

- The availability of finance, including the burning questions of social financing and local mobilisation of capital, and the absolute necessity — if outside finance is to be sought — for borrower countries to create the right investment environments. A catalyst to alter historic attitudes is required in both developing and developed countries if investments are to materialise in the manner and dimensions in which they are required.
- Energy efficiency, not only in terms of energy use, but of energy management and in the institutions which handle this commodity locally. The possible de-coupling of governments from the day-to-day managementof energy was supported, together of course with the necessary re-identification of government's role in the setting up ofthe framework within which local energy managements canbe held accountable for their actions in the future.
- Environmental matters. In practical terms, this must mean the solving of local problems of water and air pollution before the Third World becomes over-involved in the debate on global warming or the transfrontier issues of CO_2, SO_2 or NO_x.
- The research and development required to implement programmes, especially in rural areas, of practical and efficient renewable energy systems, together with the investment capital they will require.

Miguel Schloss of the World Bank (African Region) presented a most stimulating paper on Sub-Saharan Energy Financing — The Past and the Future: The Need for a New Game Plan. The main thrust of his paper was that the challenge for Africa lies not so much in initiating and constructing more energy projects, but in building the institutional capacity and creating the enabling environment that will get the job done.

Four Discussion Groups took place on the second day and covered the following:

- Regional Energy Issues and Resources
- Financing
- Energy Policy Management and Institutions
- Social and Environmental Issues

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MAIN CONCLUSIONS

The forum's main conclusions were as follows:

- Southern African countries will face major financial/ capital constraints in the 1990's.
- There is a dire need for less government intervention in the energy sector.
- Structural reform is of utmost importance in the energy sector in general and power utilities in particular, both at the national and regional levels.
- Intra-regional and cross-border consultation and co-operation in energy matters together with the optimal exploitation of joint energy resources have become practical necessities.
- In many instances energy projects should be given priority and investment should be channelled to maximise economic benefits to the region as a whole.
- Energy conservation i.e. the wise and efficient use of energy is as important as exploitation of new resources.
- Strategic and macro-issues pertaining to energy development are now much more important than "technical" problems *per se*.
- Education and training should be two major elements of future energy strategies for the Southern African region.
- An integrated/holistic approach to energy development is essential.
- Rural electrification is one of the key issues to be addressed in the region.
- Energy technology transfer in the region in future should be South-South, not North-South.

Copies of the proceedings can be obtained from:

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