REPORT NO. GEN 130

FINAL REPORT

OFF-GRID SMALL POWER SUPPLY OPTIONS FOR RURAL AREAS

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September 1989

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1.1.86 - 31.12.87

PREPARED FOR THE NATIONAL ENERGY COUNCIL
BY

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This report was prepared as a result of work sponsored by the National Programme for Energy Research (NPER). The report has been submitted to, review and accepted by the NATIONAL ENERGY COUNCIL (NEC), into which the NPER was absorbed in April 1988, as part completion of the project requirements. However, the view or opinions of authors expressed herein do not necessarily confirm or reflect those of the NEC. Material in this report may be quoted provided the necessary acknowledgement is made.

CERTIFIED AN OFFICIAL FINAL REPORT

.... 89-08-01

for NATIONAL ENERGY COUNCIL DATE

EXECUTIVE SUMMARY

Introduction

This report examines the needs, current practices and future prospects for power supply in remote areas. Included in this are a consideration of the technical and financial aspects of available technologies.

The current predominant method of power generation in remote areas is by diesel gensets. However, it is evident that this is, in general, of a poor standard. Costs of generation are high and reliability is low. Much of the problem in achieving reliable and cost effective power supply lies in the poor match between load demand and the generator system. In addition, the costs of equipment and fuel are constantly rising.

For the above reasons, alternative power generation technologies such as solar, wind and hydropower are thought to be becoming increasingly competitive. The objective of this project was therefore to determine the real costs of generating power using diesel, and to then investigate the economic and technical potential for using the alternative technologies in South Africa.

Initial survey work involved visits to all Eskom regional offices, the Division of Agricultural Engineering, Transkei Electricity Supply Corporation (Tescor), Transkei Department of Works and Energy, Somerset East Municipality, the South African Agricultural Union and the Natal and National Parks Boards. In addition some 1 000 questionnaires were sent to farmers throughout the country. The object of this survey was to establish exactly which areas are at present off-grid and are not likely to be connected into the national grid within the short to medium term.

It is apparent that there are still fairly significant areas of the country reliant on self-generation of power, or without any power generation facilities. Current off-grid power users can be categorised as follows:

- Commercial farmers
- "Homeland" areas
  - Clinics
  - Schools
  - Industries
  - Hotels
  - Small businesses
- Small demands
  - Telecommunications
  - Navigational aids

Rural Electrification

In the past, many small towns and villages generated their own power, making use of diesel generators. Subsequent to the petroleum price increase of 1973 and because of continued escalating fuel costs, pressure was placed on Eskom to connect them to the national grid. This has resulted in significant extensions of the grid over the last decade, to the extent that there are now virtually no towns or villages outside the "homelands" which do not have Eskom power. This extension of the grid to these settlements has made it possible to now supply many remote rural consumers located along the route of the power lines.

The South African Agricultural Union has also been instrumental in applying pressure on both the State and Eskom to have the grid extended into the developed rural areas. This extension has, however, been very limited in the less developed, mainly black areas.

The following two tables give an indication of the tempo of rural electrification for the period 1978 to 1985 (Evkom, 1985). These figures include supplies to smallholdings which are used primarily for farming purposes, but they exclude large power user supplies to farms, which totalled 2026 at the end of 1985.

ESKOM RURAL SUPPLIES 1978 - 1985

REGION	TOTAL 12/78	RURAL SUPPLIES CONNECTED DURING: 1979	1980	1981	1982	1983	1984	1985	TOTAL 12/85
W CAPE	9246	227	544	586	556	536	701	832	13228
NATAL	8077	334	712	1036	1365	1373	1411	1826	16134
RAND & OFS	12656	564	1028	1461	1248	1866	2001	3205	24029
N CAPE	2831	318	652	521	165	587	186	235	5495
E CAPE	1746	77	201	215	354	554	934	771	4852
E TRANSVAAL	5608	298	589	508	1092	1287	956	835	11173
TOTAL	40164	1818	3726	4327	4780	6203	6189	7704	74911
CUMULATIVE TOTAL		41982	45708	50035	54815	61018	67207	74911	

PROGRESS WITH SUPPLY BY ESKOM TO RURAL CONSUMERS - 1985

	W CAPE	NATAL	R&OFS	N CAPE	E CAPE	E TVL	Eskom TOTAL
Supplies connected	832	1826	3205	235	771	835	6869
Under construction	305	112	1437	5	100	60	1959
Approved not begun	401	285	4135	47	678	0	5546
Supplies applied for:							
Being investigated	50	0	157	91	64	0	362
To be investigated	0	0	250	815	423	0	1488
Total to be supplied	756	397	5979	958	1265	60	9355
POWER LINE LENGTH (km)							
Erected	956	3210	6171	390	1371	1005	12098
Length per supply	1,15	1,76	1,93	1,66	1,78	1,20	1,76
Planned length	905	3000	5050	341	1100	1550	10396

The Electricity Amendment Act No 50 of 1985, was introduced as a result of the the recommendations of the De Villiers Commission of Inquiry into Electricity Supply in South Africa. The most important impact of the Act insofar as it affects rural consumers is that it dispenses with the need to identify the costs of supplying individual groups of consumers in distinct geographical areas. This has enabled Eskom to accelerate the gradual equalisation of electricity supply costs, a process which has been ongoing for several years.

The most significant effect of this restructuring of Eskom's rural supply tariffs has been to make connection to the grid much more attractive for a large number of presently unconnected rural users. A secondary effect has been to increase the cost of power for those rural consumers who had long been connected to the grid, and were thus paying low or no extension costs. These users are now effectively subsidising the capital costs of the more recently connected consumers, and those in the process of being connected to the grid.

Diesel-Powered Electricity Generation

Current practice for generating power in remote off-grid areas of the country can only be described as the sum of many individuals' attempts to meet their needs for electrical power. Systems range from 32V DC wind-powered generators with ancient single-cylinder slow-running Lister engine backup, through to modern 25 kVA, and larger, turbo-charged diesel gensets which run for 16 hours or more per day. Maintenance is also just as varied, and generally sub-standard.

Based on information received from the various surveys conducted, both by questionnaire and interview, a somewhat sketchy picture of diesel generator usage was obtained. Nonetheless, it was possible to establish an idea of the areas still reliant on self-generation of power and, in addition, the costs being incurred by users.

The following table shows the response to the ± 1 000 questionnaires distributed to farmers. The regions, in the Cape in particular, are based roughly on those used by the Department of Agriculture.

Table 5.1 Questionnaire Respondents

Region	Total	Escom	Gensets
Winter Rainfall	87	77	13
Eastern Cape	88	34	55
Natal	40	38	6
Karoo	129	22	95
Orange Free State	4	0	4
Highveld	50	45	10
Transvaal	14	9	7
	412	225	190

The range of type, size and quality of diesel installation is wide. Some users claim satisfactory performance from 4 kVA plant while others have installed 25 kVA units. By far the most common is the 8 kVA two cylinder plant, although most consumers would agree that this is a compromise between meeting peak loads of 10-12 kVA and keeping down fuel usage. As a comparison, similar homesteads in areas now serviced by Escom now have 15-25 kVA power supplies.

Considering that there are about as many operating modes of diesel gensets as there are gensets themselves, it would be impossible to determine a typical load profile for a self generation power supply. Thus in order to determine the real costs to the consumer of diesel power generation, two approaches were taken. Firstly, a simple micro-computer based diesel genset model was developed, and secondly field monitoring of a limited number of diesel genset systems was carried out to determine real operating fuel and power consumption.

SUMMARY OF POWER COSTS DETERMINED BY USING THE COMPUTER MODEL

DIESEL COST	0.55 RAND/l
MAINTENANCE	50.00% OF CAPITAL COST SPREAD OVER ENGINE LIFE
DISCOUNT RATE	5.00%
ESCALATION	0.00 % PER ANNUM
ENGINE LIFE	15000 HOURS

USE OF POWER	MAX DEMAND [kVA]	RUNNING TIME/DAY [hrs]	POWER/ DAY [kWh]	COST/ kWh [c/kWh]	CAPACITY FACTOR
DOMESTIC 1	2,5	5,75	11,50	53,91 - 86,65	0,31 - 0,54
DOMESTIC 2	3,5	5,75	14,75	52,39 - 93,98	0,29 - 0,52
DOMESTIC 3	4,0	5,75	10,35	75,84 - 136,06	0,20 - 0,30
DOM & WKSHP 1	10,0	11,50	68,98	42,35 - 76,29	0,24 - 0,47
DOM & WKSHP 2	15,0	11,50	85,23	51,00 - 65,89	0,21 - 0,35
DOM & DAIRY 1	16,5	9,50	95,55	40,88 - 54,77	0,24 - 0,40
DOM & DAIRY 2	25,5	5,50	137,00	26,73 - 36,14	0,39 - 0,82
DOM & PUMP 1	10,0	13,00	100,35	35,14 - 64,23	0,31 - 0,61
DOM & PUMP 2	20,0	13,00	190,35	31,19 - 47,37	0,29 - 0,55
PUMPING	50,0	9,00	450,00	21,25 - 27,49	0,40 - 0,77

It is evident that the costs of diesel power generation are high. The costs calculated by means of the model, summarised above, are probably the optimum that can be achieved under the given conditions, and can be regarded as the best case. As the field tests have shown, the real costs incurred are always higher, in some cases by as much as 45%. The following table gives a summary of the costs determined from the field measurements, together with theoretically achievable costs, i.e. if the gensets were well maintained and run at optimum under the same load conditions.

SUMMARY OF POWER COST DATA FROM FIELD TESTS

	GENSET RATING [kW]	RUNNING TIME/DAY [hrs]	POWER/ DAY [kWh]	COST/ kWh [c/kWh]	CALCULATED COST/ kWh [c/kWh]	CAPACITY FACTOR
1	9,40	6,00	14,13	84,66	83,61	0,24
2	9,00	8,00	16,44	90,80	89,68	0,34
3	4,90	4,00	5,07	114,42	95,20	0,25
4	7,50	4,00	5,58	120,95	113,93	0,23
5	7,50	8,00	9,42	124,21	124,22	0,20
6	3,70	6,00	5,37	145,61	101,01	0,30
7	7,50	8,00	8,37	145,50	135,59	0,17
8	3,70	8,00	4,32	158,75	148,58	0,18
9	7,50	6,00	6,22	171,11	136,62	0,17

Despite the theoretical power generation costs being calculated on a best-case basis, it is apparent from these figures that, even at best, diesel is an expensive source of energy for the remote small power user. When the actual costs incurred are determined, on the basis of field data, they are found to be much higher.

Photovoltaics

More recently, the conversion of sunlight to electricity has captured the interest of many scientists and engineers. This has promise as an effective decentralized power generation system, and can basically be achieved through two fundamentally different methods - solar thermal and photovoltaic. Naturally, because of the need for power at times when there is no insolation, all solar power generation systems require some form of storage, usually in the form of chemical or thermal energy. Because solar thermal power generation is not yet commercially viable on a small scale, this report concentrated on the economic evaluation of solar photovoltaic power systems.

Comparison of radiation figures for South Africa with those of other countries reveals how this country is blessed with high levels of solar radiation. On an annual average basis ±6 000 $Wh/m^2/day$ is received over the whole world. This includes the poles as well as tropical and humid regions, where solar radiation is rapidly attenuated. The annual average for South Africa is ±5 280 $Wh/m^2/day$ compared to the United Kingdom with an annual average of ±2 400 $Wh/m^2/day$ and the USA with ±3 600 $Wh/m^2/day$. Looking at the above figures for the Cape, even the July value is higher than the annual average of the UK.

The economics of photovoltaic generated power is dominated by the high initial capital cost of the equipment. Despite the sustained efforts of cell manufacturers to bring their costs down, they are still not competitive with diesel power generation in many remote applications.

The following table is a summary of the costs of photovoltaic generated power from the same system sited at Bloemfontein, Cape Town, Grootfontein (Cape), Port Elizabeth, Nelspruit, Pretoria, Windhoek and Upington. To allow comparison with the diesel systems, these have been named using the same nomenclature as was used in the previous section.

COMPARISON OF VARIOUS SITES - ALL AC, BASED ON DOMESTIC 3

		BFN	CTA	GFN	PLZ
Insolation	[$kWh/m^2/day$]	5.87	3.93	5.23	4.47
Required array power	[W]	3047	4825	3549	4250
Required batt. storage	[kWh]	37	85	47	66
System life-cycle cost	[R]	118687	206338	140019	173867
Annualised cost/kWh	**[c/kWh]**	223	388	263	327

		NEL	PTA	WHK	UPN
Insolation	[$kWh/m^2/day$]	4.71	6.00	6.00	4.83
Required array power	[W]	4012	2952	2952	3896
Required batt. storage	[kWh]	59	36	36	56
System life-cycle cost	[R]	161746	114856	114856	156085
Annualised cost/kWh	**[c/kWh]**	304	216	216	293

Wind

The wind data measured by the S.A. Weather Bureau at various weather stations has been evaluated (Diab, 1979). This report is somewhat misleading in its findings, as it was reliant on very few recording stations, with a poor spatial distribution over the country. Nonetheless, indications are that the coastal regions of the country generally experience the highest wind speeds, but that there are also isolated pockets of strong wind potential in the interior.

The cost of wind power is governed by a number of considerations. Firstly, power will only be available inasmuch as the generator is able to extract it from the wind. If the supply of and demand for power are not well matched there will be times of shortfall and others of excess. In times of shortfall the consumer must either do without power, draw from energy stored during times of excess, or make use of some backup system such as a diesel genset. The economics of wind power are obviously dependent on the system chosen. As with all self-generation systems, as a general rule, the cost increases in direct proportion to the increase in reliability of the system.

The following table allows comparison with those in the previous sections. The load characteristics are similar to those of DOM & WKSHP 1 and 2 in the section on diesel power cost. The capacity factors chosen are within the bounds of possibility for a site in South Africa. It is of interest to note that the battery storage capacity is in both instances nearly twice that specified in the PV systems. Analysis has shown that each day of battery storage adds ±40c to the unit cost of power. Thus, were another two days of storage required for the wind systems i.e. 5 days of autonomy, the unit cost of power would be almost as high as that from the PV systems.

HYPOTHETICAL WIND-POWERED SYSTEMS - ALL AC

Peak load	kVA	10.00	15.00
Daily consumption	kWh/day	67.20	86.40
Capacity Factor	%	14.00	12.00
System autonomy i.e. Battery storage	days	3.00	3.00
Required battery storage	kWh	504	648
System life-cycle cost		555776	718066
Annualised cost/kWh	**c/kWh**	161	162

The following table gives the unit power costs in c/kWh for 24-hour continuous power supply. The effect of capacity factor is evident.

Rating kW	Capacity Factor 15%	Capacity Factor 30%	Diesel
1.00	214.09	170.63	
2.00	195.95	161.05	36.00
5.00	176.68	151.92	30.50
10.00	166.50	146.83	28.20
20.00	158.53	142.84	
30.00	154.68	140.92	22.70
50.00	150.52	138.84	21.11
75.00	147.68	137.42	
100.00	145.89	136.52	17.97

Hydro

Given the climatic characteristics of the country, large basin schemes for the generation of hydro-electric power (HEP) have been discounted as a source of power in South Africa, except for the limited peak power generation capacity installed on the Orange River. Nonetheless, in a 400 km wide strip along the east coast, extending northwards from East London, and in parts of the Escarpment, the mean annual runoff (MAR) is sufficient to warrant investigation of small, mini and micro scale HEP potential. Although extensive hydrological studies have been carried out by various researchers, these have focussed mainly on the quantification of surface water resources for agricultural, industrial and domestic purposes.

A number of micro hydro schemes are in use by farmers in the Eastern Cape. These have all been built either by the farmers themselves or by local contractors and are either run-of-river (ROR), or make use of minimal impoundment. Two of the turbine manufacturers were visited during the course of the project, and data on their various installations were collected. The plant ranged in size from 0,25 kVA to 54 kVA, are all robust in design and construction, and entirely appropriate to the technological skills of their operators.

The costs of power from these plant is the cheapest available in remote areas over most of the 1 - 100 kW range, as is shown by the following table. The unit power costs given here are in c/kWh for 24-hour continuous power supply. As can be seen the unit cost is very much dependent on the load factor under which the plant operates.

Rating kW	Load Factor 20%	40%	100%	Diesel
1.00	106.23	53.12	21.25	
2.00	58.90	29.45	11.78	36.00
5.00	23.44	13.63	4.64	30.50
10.00	13.29	7.66	2.66	28.20
15.00	9.61	5.48	1.92	26.86
20.00	7.64	4.33	1.53	
30.00	5.53	3.10	1.11	22.70
40.00	4.40	2.45	0.88	
50.00	3.69	2.05	0.74	21.11
60.00	3.19	1.77	0.64	20.46
80.00	2.54	1.40	0.51	18.82
100.00	2.13	1.17	0.43	17.97

Bioenergy

Various biomass derived feedstocks can be used to fuel conventional or modified internal combustion engines. The fuels discussed in this report include gas derived from both the gasification of biomass such as wood, maize cobs and other agricultural residues, and the gas, also known as biogas, derived from anaerobic digestion of manure and other agricultural residues.

The use of producer gas or biogas has been shown to have some merit in South Africa. However, as the following tables reveal, the advantages of producer gas are only really apparent in larger systems with high capacity factors, while biogas has the edge over diesel for all system sizes. The main disadvantages of these systems are their initial capital costs, and the necessity for additional O & M. Their real benefits will begin to emerge as the cost of diesel fuel increases. The costs of power from straight diesel-powered gensets is included for comparison purposes.

SUMMARY OF UNIT POWER COSTS USING PRODUCER GAS

SYSTEM	DUAL-FUEL COST/ kWh	DIESEL COST/ kWh	CAPACITY FACTOR
	c/kWh	c/kWh	
DOMESTIC 1	104.47	63.22	0.44
DOMESTIC 2	86.03	59.21	0.52
DOMESTIC 3	130.48	80.90	0.27
DOM & WKSHP 1	44.68	49.19	0.45
DOM & WKSHP 2	46.36	53.53	0.33
DOM & DAIRY 2	24.41	29.55	0.74
DOM & PUMP 1	36.22	42.06	0.53
PUMPING	16.65	27.49	0.77

SUMMARY OF UNIT POWER COSTS USING BIOGAS

SYSTEM	DIGESTER COST	DUAL-FUEL COST/ kWh	DIESEL COST/ kWh	CAPACITY FACTOR	INDIAN DIGESTER COST	UNIT POWER COST
	RANDS	c/kWh	c/kWh		RANDS	c/kWh
DOMESTIC 1	2646	49.24	63.22	0.44	1409	46.86
DOMESTIC 2	3394	42.43	59.21	0.52	1706	39.89
DOMESTIC 3	2382	69.47	80.90	0.27	1299	67.15
DOM & WKSHP 1	15873	34.43	49.19	0.45	5577	31.12
DOM & WKSHP 2	19613	37.69	53.53	0.33	6561	34.29
DOM & DAIRY 2	31526	19.22	29.55	0.74		
DOM & PUMP 1	23092	29.02	42.06	0.53		
PUMPING	103551	14.31	27.49	0.77		

Hybrids

In many remote areas the levels of available power from an alternate resource such as solar radiation, wind or water may be insufficient to meet the full needs of the consumer. In other cases the cost of the equipment needed to meet the full power needs at desired level of reliability may be prohibitively high. To overcome these problems, the consumer should consider the use of an hybrid power generation system making use of a combination of power sources, exploiting the strong and avoiding the weak points of the technologies available.

Clearly, there are no easy rules to follow in selecting an autonomous power system. Almost every application requires careful analysis. This involves the examination of the energy resource to be used, investigation of the competitive technologies, and the evaluation of the total costs over the lifetime of the system. A few hybrid combinations are PV-Diesel, Wind-Diesel and the genset-plus, which combines a diesel genset with battery storage.

Ancillary Equipment

Given the nature of remote area power supply systems, and in particular, those using renewable sources of energy, many such systems require ancillary equipment of various forms and degrees of sophistication. This can basically be divided into two groups, energy storage equipment and power conditioning equipment. Given its significance in alternative power supply systems, energy storage is dealt with in some detail in the report.

Conclusion

In conclusion, it is hoped that this report highlights some of the potential for the use of alternative power generation technology in South Africa. It should also be stressed that South Africa with its relatively sophisticated manufacturing industry, is well placed to develop and produce power generation equipment appropriate to the needs of rural communities.

CONTENTS

CHAPTER ONE

INTRODUCTION

South Africa is serviced by an extensive national electricity supply network under the control of Eskom. There still remain, however, a significant number of people, in urban, peri-urban and rural areas who do not enjoy the benefits of this power supply. This report will not, however, look at the situation as regards the urban and peri-urban categories, but will concentrate on remote off-grid rural areas. It should be made clear here that South Africa in this report refers to that area designated as the Republic of South Africa in 1961, i.e. including the TBVC areas and the so-called "homelands".

The cost of extending the grid was, for isolated consumers, prohibitively high prior to 1986. The cost to the consumer was mainly in the form of extension charges. With the introduction of the new Eskom tariff structure, at the beginning of 1986, these charges have fallen away for almost all users. Capital charges are however still significant for a small number of users situated more than a certain distance from the nearest grid connection point.

This report examines the needs, current practices and future prospects for power supply in remote areas. This includes consideration of the technical and financial aspects of available technologies.

The current predominant method of power generation in remote areas is through the use of diesel gensets. However, it is evident that this is, in general, of a poor standard. Costs of generation are high and reliability is low. Much of the problem in achieving reliable and cost effective power supply, lies in the present poor match between load demand and the requirements of the generator system. In addition, the costs of equipment and fuel are constantly rising.

For the above reasons, alternative power generation technologies such as solar, wind, hydropower and alternative fuels for internal combustion engines are thought to be becoming increasingly competitive. The objective of this project was therefore to determine the real costs of generating power using diesel, and to then investigate the economic and technical potential for using the alternative technologies in South Africa.

KEY QUESTIONS

The key questions can be summarized as follows:

* What are the approximate number, typical energy demands and geographical locations of off-grid users of diesel generating sets?

* What are the range of actual operating costs of diesel generating sets in remote areas?

* What is the range of capital costs and performance characteristics of locally available conventional and alternative power generation systems, and ancillary equipment?

* What are the comparative lifetime costs of power supplied in remote areas by stand-alone or hybrid diesel / battery / wind / photovoltaic and other alternative power generation systems?

* What will the effects of future cost shifts be (particularly photovoltaic module prices) on the comparative economics of alternative energy technologies for remote area power supply?

REPORT OUTLINE

The report follows the sequence of the key questions. Chapters Two and Three deal with the status quo as regards remote area power supply in as much detail as possible. Subsequent chapters deal with the technical and economic aspects of the alternative power sources available.

It is important to be constantly aware of the site specificity of many of the renewable energy resources. This factor makes it difficult to make a thorough comparison of the alternatives, and the reader should take careful note of the assumptions pertaining to each case.

CHAPTER TWO

LOCATION OF OFF-GRID AREAS

Initial survey work involved visits to all Eskom regional offices, the Division of Agricultural Engineering, Transkei Electricity Supply Corporation (Tescor), Transkei Department of Works and Energy, Somerset East Municipality, the South African Agricultural Union and the Natal and National Parks Boards. In addition some 1 000 questionnaires were sent to farmers throughout the country. The object of this survey was to establish exactly which areas are at present off-grid and are not likely to be connected into the national grid within the short to medium term.

2.1 INITIAL SURVEY

2.1.1 Electricity Supply Authorities

Because of the change in the Eskom tariff structure, which came into effect at the beginning of 1986 a significantly increased number of enquiries have been received by Eskom from potential rural consumers. During 1985 about 450 enquiries per month were being received regarding grid connections, but this increased to 1 000 per month in 1986. In addition, with Eskom having now adopted the approach of active electricity marketing, the rural reticulation situation is expected to alter significantly over the next few years.

The full picture as regards this grid expansion is not yet clear. However, it is clear that with the new tariff structure there are now very few areas considered too remote for integration into the national grid. In this regard, contact was also made with Tescor, the Transkei Department of Works and Energy and the Somerset East Municipality, which supplies a significant number of rural users. The information obtained is synthesised in the map in Appendix A.

2.1.2 Agricultural Groupings

The Department of Agriculture was helpful in making contact with commercial farmers[1]. In order to distribute questionnaires, the well-developed network of study groups was used as the point of contact. The extension officers in the various regions made this possible. In addition appeals for information were also made through the Farmer's Weekly, Landbouweekblad, the SABC and various newspapers. The response from these sources was not that encouraging, resulting in about 20 of the replies received.

Because extra photocopies of the questionnaire were made by extension officers, it is difficult to estimate exactly how many were finally distributed. Based on the number of study groups contacted, and their average size, 1 000 has been taken as the final number of questionnaires. Of these 412 were returned, which, in the Energy Research Institute's (ERI) experience, is a better than normal response.

As can be seen from the sample questionnaire (Appendix B), details asked for included broader aspects of energy utilisation. Some of these additional data have already been used in another ERI report (Eberhard, 1986). Obviously of interest in this report are the data pertaining to power generation. After careful screening, these data were statistically analysed on the UCT Univac mainframe computer.

Because filling out of the questionnaires was unsupervised, the quality of the data received was extremely variable. This meant that they had to be carefully screened prior to processing, and even then the results obtained must be treated critically. The variability in the quality of data itself is significant, in that it reveals the somewhat varying degree of concern shown by power users towards the costs they face. This is of particular interest with respect to those respondents involved in self-generation of power.

Despite the poor data quality, valuable information was received on the actual costs being incurred through diesel generation of electricity.

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[1]It was assumed in this study that for all practical purposes, black farmers do not have access to electricity

2.1.3 Parks Boards

Information was obtained from the National and Natal Parks Boards. The National Parks Board has already begun moving away from the use of diesel gensets, and has three photovoltaic systems installed in the Kruger National Park. The larger camps have been connected to the Eskom grid, Shingwedzi being the largest diesel installation remaining. The installation of photovoltaic systems is also being considered at the Kalahari Gemsbok National Park camps. The electro-mechanical division of the National Parks Board is very aware of the costs of diesel power generation, and has entered into a project with the Energy Research Institute to now investigate alternatives for Shingwedzi and some of the other camps.

The Natal Parks Board on the other hand is apparently not contemplating any changes and is still a significant user of diesel generating sets. Many of these are small sets used to provide power for remote rangers' homes. Details of the plant installed is diffuse, and it was difficult to obtain detailed information. However, the total installed capacity is estimated to be in the region of 1 200 kVA. It was impossible to extract diesel consumption figures from the Board's accounting system, as all diesel i.e. transport, pumping and electricity generation is included in one system.

2.1.4 South African Transport Services

The SATS make use of diesel generator sets at unmanned lighthouses. Detailed information regarding the installed capacity is restricted for security reasons. Total installed capacity is not however very large, being in the region of 80 kVA, consuming about 8 500 litres per month of diesel.

2.1.5 SADF and SAP

Little information could be obtained as regards the number of diesel gensets used by the SADF and SAP. However, there are quite a number of remote police stations and border posts, especially along the Lesotho and Mozambiquan borders which make use of gensets. It was also learnt that a significant proportion of the Anderson generator production capacity is bought up by the SADF.

2.2 SURVEY RESULTS

The map in Appendix A was compiled primarily from information obtained from Eskom and Tescor. The principal areas still reliant on diesel for the generation of electricity are concentrated in the Eastern Cape, Karoo, Northern Cape, the TBVC areas and the other so-called "homelands". The areas identified on the map are those considered by Eskom and Tescor as unlikely to be included in the national grid within the next five years.

2.2.1 Farmer Questionnaire

Of the 412 respondents, 204 replied that they used diesel gensets. However, 225 respondents are connected to Eskom, indicating that there were 14 gensets used in a standby mode. These are particularly important in the case of large-scale dairy farmers who often use electrically-powered milking machines.

In terms of their distribution, the preponderance of these gensets are to be found in the Eastern and Northern Cape and Karoo, totalling 153. These are mainly located on sheep and cattle farms (113), indicating that their main use would be to supply power for domestic use.

Engine sizes range from 2 - 100 kW, with the bigger engines being found on dairy farms, or large irrigated farms making use of central-pivot sprinkler systems. The mean size of engine is around 5 kW, while the average age of the engines is 14 000 hours, with ages ranging from a few hundred hours to over 100 000 hours.

The most popular engine make is Lister, totalling 130 gensets, with Markon alternators representing 45 out of the 60 replies on alternator make. Petter was the next most popular engine make, totalling 21, with Deutz third with 13. The bulk of the Deutz engines were over 50 kW, and used to power milking machines and fruit coolroom refrigeration plant.

An attempt was made to try and determine the number of farmers still reliant on diesel gensets throughout the country. This proved to be a difficult task, for two reasons. Firstly, figures obtained from Eskom for numbers of rural connected supplies include multiple supply to individual farms, and in the Rand & OFS Region this can be up to as many as five supply points per farm. Secondly, it is difficult to obtain an accurate figure of the number of farms in the country, or more specifically the number of inhabited homesteads.

According to the Department of Agriculture (pers. comm.) there are an estimated 60 000 commercial farming units in South Africa. At the end of 1985 Eskom had connected up 76 937 rural points of supply. Eskom estimates that the average number of connections per farm is two. From these figures it can be deduced that there must be around 21 500 farms still not connected to the grid.

In addition to the above, there are another 9 600 potential points of supply in new schemes that have already been identified, but on which construction has not yet started. It is probable that these will probably each represent one homestead, but to err on the conservative side it is assumed that these represent another 6 500 homesteads, leaving 15 000 farms unconnected. It was impossible to obtain a confirmation of this figure from either Eskom, or the Department of Agriculture.

In addition to the above, there are an estimated 12 million people living in the so-called "homelands" (SAIRR, 1983). Of these it can safely be said that 66% of these are in rural areas, and have no access to a reliable power supply.

2.2.2 Transkei Survey

This involved interviews with both Tescor and the Department of Works and Energy (DoWE), and extraction of data from a consultants report dating back to 1979 (Hill Kaplan Scott, 1979). A fair degree of confusion seems to exist in the Transkei as to who is resposible for maintaining and operating diesel generators in the public domain. It would appear that the majority fall under DoWE, although some are operated by Tescor or the Transkei Development Corporation. In addition, however, Tescor is making every effort to connect all the major load centres to its grid.

Hill Kaplan Scott determined an installed diesel-powered generating capacity of 21,1 MVA, excluding standby gensets in 1979. However, the aggregate actual demand was estimated not to exceed 10 MVA, indicating a more than 100% overcapacity. The diesel consumption was estimated to be of the order of 10 million l/yr.

Since that report was written, Tescor has extended its grid quite significantly to pick up many of the larger loads. In addition, many smaller loads have been supplied in the process. Plans for the next five years are such that there will be virtually no significant load centres in the form of towns, hospitals, sawmills, tea factories and other remotely sited industries remaining to be connected. There will be a few schools and remote clinics still unconnected. Appendix D contains a list of the significant loads still served by diesel gensets in 1986.

2.2.3 Other "homelands"

Through discussions with administrative personnnel and consulting engineers involved in these areas, and Eskom personnel, it was established that very little in terms of rural electrification was being done in these areas. The major load centres, i.e. towns and industrial areas are all either already supplied from the grid, or are planned to be connected in the next five years.

2.3 CONCLUSION

It is apparent that there are still fairly significant areas of the country reliant on self-generation of power, or without any power generation facilities. Current off-grid power users can be categorised as follows:

- Commercial farmers
- "Homeland" areas
    - Clinics
    - Schools
    - Industries
    - Hotels
    - Small businesses
- Small demands
    - Telecommunications
    - Navigational aids

CHAPTER THREE

GRID ELECTRIFICATION

In the past, many small towns and villages generated their own power, making use of diesel generators. Subsequent to the petroleum price increase of 1973 and because of continued escalating fuel costs, pressure was placed on Eskom to connect them to the national grid. This has resulted in significant extensions of the grid over the last decade, to the extent that there are now virtually no towns or villages outside the "homelands" which do not have Eskom power. This extension of the grid to these settlements has made it possible to now supply many remote rural consumers located along the route of the power lines.

The South African Agricultural Union has also been instrumental in applying pressure on both the State and Eskom to have the grid extended into the developed rural areas. This extension has, however, been very limited in the less developed, mainly black areas.

The following two tables give an indication of the tempo of rural electrification for the period 1978 to 1985 (Evkom, 1985). These figures include supplies to smallholdings which are used primarily for farming purposes, but they exclude large power user supplies to farms, which totalled 2026 at the end of 1985.

Table 3.1 ESKOM RURAL SUPPLIES 1978 - 1985

	TOTAL	RURAL SUPPLIES CONNECTED DURING:							TOTAL
REGION	12/78	1979	1980	1981	1982	1983	1984	1985	12/85
W CAPE	9246	227	544	586	556	536	701	832	13228
NATAL	8077	334	712	1036	1365	1373	1411	1826	16134
RAND & OFS	12656	564	1028	1461	1248	1866	2001	3205	24029
N CAPE	2831	318	652	521	165	587	186	235	5495
E CAPE	1746	77	201	215	354	554	934	771	4852
E TRANSVAAL	5608	298	589	508	1092	1287	956	835	11173
TOTAL	40164	1818	3726	4327	4780	6203	6189	7704	74911
CUMULATIVE TOTAL		41982	45708	50035	54815	61018	67207	74911	

Table 3.2 PROGRESS WITH SUPPLY BY ESKOM TO RURAL CONSUMERS - 1985

	W CAPE	NATAL	R&OFS	N CAPE	E CAPE	E TVL	Eskom TOTAL
Supplies connected	832	1826	3205	235	771	835	7704
Under construction	305	112	1437	5	100	60	2019
Approved not begun	401	285	4135	47	678	0	5546
Supplies applied for:							
Being investigated	50	0	157	91	64	0	362
To be investigated	0	0	250	815	423	0	1488
Total to be supplied	756	397	5979	958	1265	60	9415
POWER LINE LENGTH (km)							
Erected	956	3210	6171	390	1371	1005	13103
Length per supply	1,15	1,76	1,93	1,66	1,78	1,20	1,76
Planned length	905	3000	5050	341	1100	1550	11946

According to the 1986 Eskom annual report, a further 16 000 km of 22kV and lower transmission lines were erected in 1986, bringing the total number of farm supply points to 78 809.

3.1 ESKOM'S STRUCTURAL CHANGES: THEIR IMPACT ON RURAL ELECTRIFICATION

The Electricity Amendment Act No 50 of 1985, was introduced as a result of the the recommendations of the De Villiers Commission of Inquiry into Electricity Supply in South Africa. The most important impact of the Act insofar as it affects rural consumers is that it dispenses with the need to identify the costs of supplying individual groups of consumers in distinct geographical areas. This has enabled Eskom to accelerate the gradual equalisation of electricity supply costs, a process which has been ongoing for several years.

3.1.1 The concept of undertakings

Undertakings were the areas (six initially, later seven) of South Africa in which Eskom was licensed by the Electricity Control Board to supply electricity. Before 1960 the undertakings were not only legally but physically separate entities. The following excerpt from the De Villiers Commission report is of interest in this regard:

> "Over the years the boundaries of Escom's undertakings were extended in consonance with the growth of the Escom system. These

> boundaries were originally defined as strips along railway lines and circles where towns were situated. The present system whereby areas are defined by farm boundaries was adopted later. The boundary of different undertakings were consequently defined subjectively, mainly for historical reasons.
>
> As the factors used in determining tariffs may differ from one undertaking to another, it may well happen that different tariffs apply on opposite sides of a boundary between two undertakings." (De Villiers et al, 1984, p37)

The national grid is now sufficiently extended to allow the merging of these undertakings, enabling tariffs to be equalised nationally, regardless of the geographical location of the consumer. The Commission therefore recommended that "the present seven distribution undertaking(s) should be reduced to not more than three in order to reduce administration costs and eliminate differences between undertakings." (De Villiers et al, 1984, p237)

<u>3.1.2 Pooling of capital costs</u>

By way of introduction, the following are the Eskom tariff groupings:

- Tariff A - Large power users (Demand in excess of 100 kVA)
- Tariff B - Small power users
- Tariff C - Urban domestic users
- Tariff D - Rural small power users
- Tariff E - Off-peak large power users

<u>Differentiating between demand costs and energy charges</u>

Based on recommendations by the De Villiers Commission (De Villiers et al, 1984, p210), demand-related charges have been introduced for Tariff B and D consumers. Eskom feels that these charges should encourage a more economic and efficient use of electricity. However, the charge is fixed and is not related to maximum demand i.e. the consumer is not able to reduce the amount through judicious load management. As far as rural consumers are concerned it is a fixed charge that has always effectively been there in the form of the extension charge.

Extension charges

With regard to extension charges, the following excerpts from De Villiers Commission report are of interest:

A. "As far as farmers are concerned it is Escom's practice to provide the necessary capital to erect the power line to the farm and to equip it up to the connection point. If distribution and transmission costs to supply a group of consumers exceed the amount provided for these in the general tariff, extension charges are levied.

Extension charges cannot be recovered by the undertaking through the standard tariffs, as there is only one tariff structure for an undertaking. Because capital expenditure normally covered by the standard tariff is low compared with that for individual farmers while the quantity of electricity used by them is limited and relatively little in relation to the capital costs of the connection, extension charges are levied." (De Villiers et al, 1984, p203)

B. "The broad constraints imposed by the Electricity Act in respect of separate accounts, no surpluses or deficits in the various undertakings and the requirement that one group of consumers should not be subsidised by another have a marked effect on tariffs." (De Villiers et al, 1984, p203)

According to Eskom officials, and indeed the De Villiers Commission (De Villiers et al, 1984, p203), implicit in Section 16, prior to its amendment in 1985, was the concept that a group of consumers subject to one tariff should not be subsidized by another group. This meant that all capital costs incurred in supplying power to Tariff D farmers, for example, had to be recouped through the correct structuring of Tariff D. In this way some consumers in the same consumer group do, in effect, subsidize others in that group. Given the above, the Commission made the following recommendation:

"Unit cost of transmission to a reference point and unit cost of distribution from the reference point to the consumer, calculated on the bases of cost per kilometre for different voltages and loads, should be pooled so that the tariffs for individual groups of consumers can be deduced from average pooled costs, and administration costs as well as loan charges associated with rural supply divided into groups according to consumption density." (De Villiers et al, 1984, p237)

This has resulted in what is undoubtedly the most significant change as regards rural power users, i.e. the removal of monthly extension charges for the great majority of users. These extension charges varied considerably throughout the country, and indeed from one scheme to the next, depending on the age of the scheme, the number of supply points in the scheme and the undertaking in which the scheme was situated. Thus, because the charges were fixed at the time of erection of schemes, old users had very low extension charges, whereas new consumers were paying much higher rates. As a result a great deal of confusion and resentment existed amongst rural consumers (Bester et al, 1978 and Pringle, 1981).

Capital costs for all Tariff D rural power users throughout the country have now been pooled. These costs are now being met by all Tariff D consumers collectively, through the introduction of a monthly demand charge as outlined above, and an increase in the energy cost. The first block, to be charged at the high rate of 8,65 c/kWh, has been increased from 800 to 1 000 kWh. The balance of energy consumed will be charged at 5,00 c/kWh. (These cost figures are based on July 1985 equivalent tariffs).

The abovementioned measures cover the cost of an average scheme power line extension of 2 kms. In schemes where the <u>average</u> distance exceeds this, the consumers will pay monthly capital charges. These will thus be determined on the basis of the capital cost of the reticulation over and above 2 kms. According to the Hansard (1986), only 6% of rural consumers of Eskom power will be paying any form of capital charges.

According to figures released by Eskom, the revenue accruing from the monthly extension charges levied from Tariff D, rural small power users, in 1984, represented 16,7% of the total revenue from these users. The revenue generated by monthly extension charges from all categories of power users represented only 1,8% of the total Eskom income revenue. The contention is, therefore, that this measure has not increased the burden on any power consumers, and has in fact helped to relieve the burden on a significant number. In addition it has made it attractive for a greater number of rural consumers to be connected to the grid.

3.2 COMPARISON OF PRE-1986 AND EXISTING TARIFF STRUCTURES

Of interest in this report are the changes to the tariff structure for rural small power consumers with a notified demand of less than 100 kVA, Tariff D.

Table 3.3 Eskom Tariff Structure Comparison

Old Tariff	New Tariff
Differ by undertaking	Uniform throughout the country
No demand diferentiation, but a basic charge of R12,00 - R18,00 per month	Basic charges differentiating by demand as follows: i) 25 kVA R22,00 per month ii) 50 kVA R30,00 per month iii) 100 kVA - R45,00 per month
800 kWh high rate	1 000 kWh high rate
Monthly extension charges charges for majority of consumers	Existing monthly extension abolished. Small minority to pay monthly capital charges (where average length of distribution line per point of supply exceeds 2 kms)
Quarterly energy charge adjustment for price of coal	No quarterly price adjustment
General discount/surcharge by undertaking	Provision for general surcharge only

Eskom feels that these changes introduce a more equitable structure and greater flexibility.

In order to obtain some idea of the effect of these changes on the revenue earned by Eskom from Tariff D consumers, the following analysis was carried out. A sample group of 66 typical consumers was drawn from the respondents to the questionnaire. Based on these consumer profiles, the monthly revenue accruing to Eskom from this group was calculated according to the tariffs prevailing in January and December 1985 and January of 1986 and 1987. The results are contained in the following tables.

Table 3.4 MONTHLY ESKOM COSTS FOR VARIOUS RURAL CONSUMERS

		EXT CHARGE R	FIRST BLOCK R	SECOND BLOCK R	BASIC CHARGE R	SUR-CHARGE R	TOTAL COST R
JAN 85	W CAPE	2925,60	5414,33	8272,42	1056,00	-2506,27	15162,09
	E CAPE	2925,60	6056,37	9873,94	1056,00	-3567,13	16344,79
	N CAPE	2925,60	5414,33	8272,42	1056,00	-2506,27	15162,09
	NATAL	2925,60	4019,04	5863,84	792,00	106,75	13707,23
	E TVL	2925,60	4888,57	6960,94	1320,00	-1712,04	14383,08
	R&OFS	2925,60	4893,63	6973,55	1320,00	-1582,46	14530,32
	TOTAL	17553,60	30686,27	46217,11	6600,00	-11767,40	89289,58
	% TOTAL	19,66	34,37	51,76	7,39	-13,18	

		EXT CHARGE R	FIRST BLOCK R	SECOND BLOCK R	BASIC CHARGE R	SUR-CHARGE R	TOTAL COST R
DEC 85	W CAPE	2925,60	5429,50	8310,25	1056,00	-1287,23	16434,12
	E CAPE	2925,60	6071,54	9911,77	1056,00	-2232,15	17732,76
	N CAPE	2925,60	5429,50	8310,25	1056,00	-1287,23	16434,12
	NATAL	2925,60	4019,04	5863,84	792,00	1184,91	14785,39
	E TVL	2925,60	4903,74	6998,77	1320,00	-568,57	15579,54
	R&OFS	2925,60	4908,79	7011,38	1320,00	-423,69	15742,09
	TOTAL	17553,60	30762,10	46406,27	6600,00	-4613,95	96708,02
	% TOTAL	18,15	31,81	47,99	6,82	-4,77	

		BASIC CHARGE R	FIRST BLOCK R	SECOND BLOCK R	SUR-CHARGE R	TOTAL COST R
JAN 86	W CAPE	2148,30	5820,79	6349,81	1431,89	15750,78
	E CAPE	2148,30	5820,79	6349,81	1431,89	15750,78
	N CAPE	2148,30	5820,79	6349,81	1431,89	15750,78
	NATAL	2148,30	5820,79	6349,81	1431,89	15750,78
	E TVL	2148,30	5820,79	6349,81	1431,89	15750,78
	R&OFS	2148,30	5820,79	6349,81	1431,89	15750,78
	TOTAL	12889,80	34924,71	38098,83	8591,33	94504,67
	% TOTAL	13,64	36,96	40,31	9,09	

		BASIC CHARGE	FIRST BLOCK	SECOND BLOCK	SUR- CHARGE	TOTAL COST
JAN 87	W CAPE	2148,30	5820,79	6349,81	5083,21	24405,46
	E CAPE	2148,30	5820,79	6349,81	5083,21	24405,46
	N CAPE	2148,30	5820,79	6349,81	5083,21	24405,46
	NATAL	2148,30	5820,79	6349,81	5083,21	24405,46
	E TVL	2148,30	5820,79	6349,81	5083,21	24405,46
	R&OFS	2148,30	5820,79	6349,81	5083,21	24405,46
	TOTAL	12889,80	34924,71	38098,83	30499,23	146432,70
	% TOTAL	13,64	36,96	40,31	32,27	

From the above it can be seen that the revenue from this particular group was lower for January 1986 than it had been in December 1985. However, it can not be inferred from this that the total revenue from Tariff D consumers would have dropped in this way. Although they would not divulge the actual figures, Eskom gives the assurance that this was not the case, and that there was no cross-subsidisation of rural consumers by consumers other than those in the same tariff band. In this respect it should be noted that the total number of Tariff D consumers or, more accurately, supply points is currently 90 329. Of these some 11 500 are non-farming consumers, and would include remotely sited industries etc (pers. comm. Eskom).

The following table shows the average cost/kWh for the group of 66 consumers, depending on region. These costs can only be regarded as typical and are by no means an indication of the actual average cost to rural consumers. Such a figure could only be calculated if access to the full accounts of all Eskom's Tariff D consumers were possible.

Table 3.5 AVERAGE COST PER kWh (1985 c/kWh)

	JAN 85	JAN 86	JAN 87
W CAPE	10,94	11,25	13,25
E CAPE	11,54	11,25	13,25
N CAPE	10,94	11,25	13,25
NATAL	10,04	11,25	13,25
E TVL	10,71	11,25	13,25
R&OFS	10,81	11,25	13,25
AVERAGE	10,83	11,25	13,25

The previous table shows an average real increase in unit cost of 4% from January 1985 to 1986, with a significant increase to January 1987 of nearly 18%.

3.3 GRID EXTENSION COSTS

The cost per kilometre of power line varies significantly depending on its power rating, the terrain over which it passes, the specifications to which it is constructed, and the contractors who undertake the work. Figures quoted by engineers from Eskom, Tescor and consultants vary as widely as from R8 000 to R20 000 per km of 11 kV line. In addition to this there is the cost of switchgear and transformers, which will of course be dependent on the requirements of the consumer.

From the above it is apparent that site specificity, amongst other factors, will affect the cost of supplying grid based power to a remote rural power consumer.

3.4 CONCLUSION

The most significant effect of this restructuring of Eskom's rural supply tariffs has been to make connection to the grid much more attractive for a large number of presently unconnected users. A secondary effect has been to increase the cost of power for those rural consumers who had long been connected to the grid, and were thus paying low or no extension costs. These users are now effectively subsidising the capital costs of the more recently connected consumers, and those in the process of being connected to the grid.

CHAPTER FOUR

METHODOLOGY FOR THE COMPARATIVE COSTING OF POWER GENERATION

Many consumers of self-generated power are unaware of the true cost of the electricity they are generating. Expenses seen by the operator of a diesel genset, for example, are usually limited to the capital cost of the installation, the monthly fuel bills and infrequent repair bills, usually at breakdown. Little, if any connection is made between these cash payments and the electricity consumption. If costs per kWh are calculated in such situations, it is usually on the often erroneous assumption that the capacity factor for the genset is close to unity. In most instances, the capacity factor is far less and unit costs of generation are high. For the above reasons it is important to calculate the cost of electricity over the life of the installation.

In formulating typical systems for comparison in the report, it is assumed that a fixed common peak power and annual demand are to be met. Power generated above the amount considered necessary is not granted financial credit. Likewise systems not capable of meeting the demand criteria are not considered. The principle of working to a fixed demand requirement differs from the practice of calculating electricity costs on the basis of net power generated. For remote area users, the method of working to a fixed demand most closely matches the real situation, and eliminates the use of low-cost make-shift systems. It also does not favour, for example, wind generators located in windy areas where excess power may be available.

In the report some adjustments will be made to this basic approach for particular systems, to bring the annual costing as close as possible to actual practice. These modifications will be detailed under the relevant section. The principal assumptions and any minor adjustments are discussed below. Particular note must be taken of the methodology used and assumptions made in the costing technique, as the resultant cost of electricity is very dependent upon them.

4.1 COSTING METHODOLOGY

Essential to the consideration of power generation alternatives is their cost competitiveness relative to one another. Before a fair comparison can be made, the true unit cost of power delivered by each system must be established, as well as the expected cashflows. Included in the cost of typical systems are such items as:

Capital costs of equipment, which should include any civil works and power transmission equipment.

Transport of equipment to site and installation.

Financing charges.

Fuel costs.

Maintenance costs.

Operating costs.

This report uses life-cycle costing on a common project life basis to compare power generation alternatives. This approach is taken in order to take account of the different times in the project life at which costs occur for the alternatives. An attempt is thus made to take account of the time value of money. Costs to be incurred in the future are brought to a common basis of comparison with initial capital costs. The methods applied lead to two forms of comparison, present worth of the installation and the annualised cost of electricity. The latter can be used to give an indication of the real cost of an unit of power generated by the system being considered.

4.1.1 Project Life

The project life is the total period over which the costs of power generation are to be determined. This parameter is of significance when comparing one form of power generation with another e.g. diesel vs wind. Obviously the longer the project life, the greater the number of times certain pieces of equipment may have to be replaced. However, the longer the project life, the less the impact of future purchases on the present worth.

Based on discussions with users and suppliers, a diesel genset may be expected to run trouble free for 10 000 hours and achieve a service life of around 15 000 hours. A petrol powered genset on the other hand set may only achieve a life of 1 000 hours, a wind generator may last

20 years running continuously, and photovoltaic panels can reasonably be expected to have a life in excess of 20 years.

Taking the above into consideration, a project life of 20 years has been chosen for this report. This gives a common basis of comparison between the long lasting equipment and the diesel-based gensets. The latter will of course have to be replaced a number of times during the 20-year period.

4.1.2 Discount rate

Complications arise in considering long life cycles. A cost escalation rate may need to be considered for items such as fuel or replacement equipment, as well as a discount rate for capital items. Thus it is difficult to select a suitable general discount rate. The current bank discount rate is a significant pointer for selection of a value. However lost opportunity costs for alternative investments and personal attitudes of the system buyer regarding expected rates of return also need to be considered.

All prices and costs used in the calculations are in base year (1987) Rands. By using a real discount rate, inflation is effectively taken into account. On the advice of the UCT Graduate School of Business, the real discount rate for this investigation was taken as 5%. In reality, the real discount rate in South Africa, based on bank interest rates and inflation, has been negative for a few years, and it is not foreseen that this will improve in the short term.

In calculating a present worth of items, a common rate of inflation has been assumed for all items. The discount rate of 5% is thus the amount by which the cost of money exceeds the inflation rate. To simplify the comparison, the escalation of the cost of manufactured items such as generators and batteries has been assumed to be equal to inflation. The same assumption has been made with fuel costs. The latter may be a generous assumption, as the cost and price of diesel fuel has escalated at a rate greater than that of general inflation. However, sensitivity analyses will be done in the relevant sections to determine the effect of a price escalation above the rate of inflation.

4.1.3 Capital cost

The capital cost of various technologies considered are current retail prices. No discounting, taxation or other factors have been allowed for. Capital cost write-offs or discounts will assist capital intensive technologies. Thus the costs per kWh calculated are in some ways "worst case" examples. The need for assistance to reduce the capital cost of systems is discussed later. Such assistance is primarily needed to help with cash flow rather than to reduce the cost per kWh. However it could play a significant role in the adoption of alternative technologies.

4.1.4 Operation and maintenance

In this report operation is assumed to be provided free by the operator. The cost of maintenance will vary from one power generation method to another. These costs are therefore detailed in the relevant sections.

4.1.5 Annual payments

Several payments will have to be made over the life of each system. For example, regular payments will have to be made for fuel in the case of diesel gensets. For simplicity fuel is assumed to be paid for in an annual lump sum. Operation and maintenance charges are also taken as annual lump sum payments. Irregular payments are incurred for equipment replacement.

4.1.6 Present worth analysis

This method of life cycle costing involves the discounting of all future costs or benefits of a system back to their present worth in base year Rands. The compound interest formula shown below moves an amount forward in time:

$$S = P(1+r)^n$$

where S is the value of the amount at the end of year n
P is the principal amount, and
r is the rate of interest or discount rate.

The compound factor $(1+r)^n$ moves the amount P forward in time, the reciprocal of this factor will therefore have the opposite effect, and is known as the present worth factor. Thus the present worth of an energy system can be determined as follows:

$$PW = \sum_{S=1}^{n} ((\text{Costs for year } S) - (\text{Credits for year } S))/(1+r)^{m}$$

where n is the chosen life cycle of the system.
S is the specific year under consideration.
r is the real interest or discount rate (i.e. taking inflation into account).
m number of years from base year to year S.

The factor r determines the rate at which costs will shrink or swell with time. By using a real discount rate, inflation is taken into account, and the need for escalating future costs is obviated. Sensitivity of the unit power cost to the discount rate will be determined in each relevant section.

It may be assumed in the context of this analysis that the most economical system is the one with the least present worth i.e. least overall cost. These are not necessarily the systems with the lowest initial cost. On-going fuel costs and diesel engine replacement are clearly significant cost factors when the long term view is taken.

4.1.7 Annualised cost of electricity

Calculation of present worth allows for selection of the alternative with the least present cost. However, if alternative systems in which some payments are to be made over time are to be compared, it is more representative of the true cost to respread the total present worth of each alternative over the system life i.e. to annualise it. It should be noted however that the annualised cost must not be compared directly with real charges levied by Eskom for example. It is merely a derivation of future energy costs and is calculated specifically in order to compare the yearly costs of each alternative system in Rands of current value. This is achieved by using the following formula:

$$AC = PW * r^{*}$$

$$\text{where } r^{*} = \frac{r(1+r)^{n}}{(1+r)^{n}-1}$$

This annualised cost can be further interpreted by dividing it by the expected annual useful energy consumed. Here care must be taken to only include the kWh actually used and not the kWh generated. For example, because of oversizing, diesel plant may generate significant unused power in low load periods, and this should not be given credit in the analysis.

4.2 CONCLUSION

The aforementioned methodology will be applied to the various available systems for remote area power supply. Where necessary, further parameters will be specified in the relevant sections. In addition, sensitivity of the unit power cost for the various alternatives to relevant parameters will be given in relevant sections.

CHAPTER FIVE

CURRENT DIESEL POWER GENERATING PRACTICES AND COSTS

Electricity used in remote areas of South Africa was for many years provided by a variety of rudimentary systems. Storage batteries played a large part in these installations, which were usually low voltage 12, 24 or 32V DC. Small diesel or petrol generators, often supplemented by small wind chargers were used to charge the batteries. Power use was limited to lights and the few DC appliances that may have been available.

The late 1940s and 1950s saw the advent of reliable diesel generators and relatively low fuel costs, while at the same time the demand for 220V AC supply was growing. With these generators, the owner was able to purchase and run normal appliances and, most importantly, to run refrigeration equipment. As a result the wind driven plant and 32V battery banks rapidly faded into insignificance, and today can only be found in use in very few places, usually providing lighting power only.

Until the 1970s, the diesel generator appeared to be the satisfactory solution for remote area power supply. However, fuel cost and availability, and mounting service costs are placing operators of such plant under increasing pressure. Most installations are now operated on a restricted time basis, typically 5-10 hours per day. Even with these restrictions many installations are grossly underutilised, wasting up to 80% of the fuel used, through poor load matching. Maintenance costs are also increased as a result of this, and complete engine overhaul or replacement is often required after only 3500 - 5500 hours operation.

In the period discussed above, there were also a significant number of towns and villages which were dependent on diesel for their electricity supply. Gradually, as the electrification of the railways took Eskom further out into the rural areas, so the number of these large gensets decreased. The petroleum price increases of the 1970s was the next stimulus for the extension of the national grid. There are now no settlements of substantial proportions dependent on large scale diesel power generation.

5.1 REMOTE AREA POWER SUPPLY REQUIREMENTS

The necessary or desired (as opposed to currently achieved) electricity requirements for domestic and commercial agricultural power supply may be summarised by specifying the two basic parameters; load profile and power supply quality.

5.1.1 Load profile

This basically consists of a curve of instantaneous power demand plotted against the time of day, but includes peak load, power availability, average load, and the load factor relationship (ratio of average power to peak demand). As an historical feature this curve can be used to analyse patterns of usage. Unfortunately little work has been done on typical load profiles for consumers in remote areas either in South Africa or internationally. If an alternative power source is to be considered by a consumer, current demand patterns need to be analysed. In the case of grid power being supplied, this analysis needs to be extrapolated to take into account the changes that take place when conventional power supply is made available.

Currently, where power is supplied by diesel generator alone, the measured load profile could be confused by false load added to the system to ensure adequate or optimum engine loading. An additional confusion occurs because the consumer may have an atypical lifestyle, based on activities centred around times when the diesel generator is running, e.g. such activities as washing and ironing are crammed into evening periods. It is obvious that these patterns may differ from household to household, thus necessitating a very comprehensive survey of load patterns and the factors affecting them.

In considering the required power supply rather than the historical patterns, it is not practical to speculate on the shape of the load profile. It is, however possible to discuss the main features to be expected. These include the peak (or maximum) load, hours per day power is made available, average load, load and capcity factor.

Peak load is reached when a significant number of appliances are turned on together, and is particularly noticeable if motor starting loads are included. Peak load, measured in kW, is the largest sum of expected appliance loads operating at any one time. With the main domestic loads being say, a refrigerator, air conditioner, freezer, coolroom, washing machine and other normal household appliances, plus some workshop tools, a peak load of 10 kW might be expected. Clearly this will vary somewhat from one consumer to another, depending on other loads which may be supplied from the same source, e.g. welding or shearing equipment. It has been found through discussion with various equipment suppliers, consumers and engineers of the Department of Agricultural Engineering that at as a general rule 10 kW peak system capacity is required by most farmers. How often this is achieved in practice is the subject of a later section.

Peak load requirements are high if refrigeration, coolroom and air conditioning loads are in use. As the main advantage of conventional power is its 24-hour availability, thus making cooling load possible where currently it may not be, the peak load requirements are not likely to fall with changing supply conditions.

For effective cooling load, power is required 24 hours per day, unless specially designed heavy insulation freezers are used. Currently durations of 10-16 hours/day are common. Continuous supply is however the ideal for all consumers. This makes the use of electric cooling possible, eases lifestyle by reducing the degree to which activities using power have to be managed, and allows for the use of a wider range of useful appliances.

Difficulty with the timetabling of activities to coincide with diesel genset operating times is a constant frustration. Conversely a great deal of fuel is wasted by the mismatch of activities and diesel running times. Thus 24-hour availability is a requirement if reasonable alternate electricity supply is to be contemplated. Lack of a constant power supply has resulted in a variety of alternative power sources being used - LPG, wood, direct diesel engine power etc. Current quantities of power generated vary widely depending upon the methods and modes of generation used by individuals.

<u>Consumptions</u> varying as widely as from 5 to 48 kWh/day were noted in the farm questionnaire replies, with 8 to 10 kWh/day being the most common.

An installation that has a very high peak demand but a <u>low average demand</u> will require a different generation system to an installation with a more closely matched peak and average demand. The relationship between peak and average demand (averaged over a 24-hour period), expressed as a ratio is termed the <u>load factor</u>. This ratio is usually expressed as the average divided by the peak. Thus the homestead with a peak demand of 10 kW and an average demand of 417 W would have a load factor of 0,04. By way of comparison the load factors for Lady Frere and Cala in the Transkei were 0,69 and 0,46 respectively, in 1979 (Hill Kaplan Scott and Partners, 1979). Both these towns had diesel generator systems at the time, but with fairly well distributed loads. These larger, more sustained loads are provided by consumers such as hospitals and small industries.

In the case of smaller installations, the addition of battery storage and the use of correct charge characteristics results in a load factor during charging, of typically 0,95 (recovery rate) to 0,68 (finished rate). More will be said about such systems in the section dealing with hybrid installations.

Another parameter to be considered here is <u>capacity factor</u>. The capacity factor of a system is defined as the ratio of the nett amount of power delivered by the system to that potentially able to be supplied, during the period for which it is running. Thus an installation that runs a diesel generator set at high load, for a few hours each day, may have a low load factor but a high capacity factor, which would result in optimal diesel use. However, if the generator running time were extended to give a 24-hour supply, it would be underutilised, and thus have a low capacity factor as well.

Often a high capacity factor is achieved by adding unnecessary load, sometimes known as a "load dump". This is not to be confused with load shedding, which is in fact the exact opposite. Load dumping is often of no financial benefit to the operator of the generator set, thus when calculating a capacity factor all such loads should generally be ignored. A sensible method of load dumping is to use the excess power for water heating.

A comparison of the load and capacity factors gives an indication of whether some form of storage would be of benefit to the overall operating efficiency of the system. If, for example, the capacity and load factors are both above 0,8 then nothing would be gained by the addition of some storage system. If, however, the capacity factor is below 0,5, there could well be a case for some storage medium. It is general sound practice for diesel engine protection and optimum performance to ensure that the capacity factor is better than 0,8. Contrary to popular belief, fuel savings are not achieved by low loading of a diesel engine. Peak fuel efficiency occurs close to peak engine performance, and low loading could lead to engine damage.

Finally, power factor is a measure of the power actually available for use from a generating source. By virtue of the fact that the voltage and current may be out of phase, the full power kilowatts delivered will be lower than the kVA rating of the generator.

5.1.2 Power supply quality

This concept embraces voltage fluctuations, frequency stability, and the waveform of a particular system. In general 220V AC, 50Hz electricity supply is required in rural areas, with 380V AC, three-phase being required where heavier machinery is to be used. To give some indication, the all-electric urban home, annual consumption typically exceeds 5 000 kWh, with a peak capacity of 5 kVA, voltage regulation of $\pm$6% and frequency stability of $\pm$5%.

Modern diesel gensets can usually maintain an accurate sinusoidal waveform. However, many alternative sources generate some other waveform. In the case of most inverters it is a modified square wave. Pure square waves may cause motor heating problems as well as producing unacceptable levels of radio frequency interference.

5.2 CURRENT GENERATING PRACTICES

Current practice for generating power in remote off-grid areas of the country can only be described as the sum of many individuals' attempts to meet their needs for electrical power. Systems range from 32V DC wind-powered generators with ancient single-cylinder slow-running Lister engine backup, through to modern 25 kVA, and larger, turbocharged diesel gensets which run for 16 hours or more per day. Maintenance is also just as varied, and generally sub-standard.

Based on information received from the various surveys conducted, both by questionnaire and interview, a somewhat sketchy picture of diesel generator usage was obtained. Nonetheless, it was possible to establish an idea of the areas still reliant on self-generation of power and, in addition, the costs being incurred by users.

The following table shows the response to the ± 1 000 questionnaires distributed to farmers. The regions, in the Cape in particular, are based roughly on those used by the Department of Agriculture.

Table 5.1 Questionnaire Respondents

Region	Total	Escom	Gensets
Winter Rainfall	87	77	13
Eastern Cape	88	34	55
Natal	40	38	6
Karoo	129	22	95
Orange Free State	4	0	4
Highveld	50	45	10
Transvaal	14	9	7
	412	225	190

The range of type, size and quality of diesel installation is wide. Some users claim satisfactory performance from 4 kVA plant while others have installed 25 kVA units. By far the most common is the 8 kVA two cylinder plant, although most consumers would agree that this is a compromise between meeting peak loads of 10-12 kVA and keeping down fuel usage. As a comparison, similar homesteads in areas now serviced by Escom now have 15-25 kVA power supplies.

The generators are usually run either 4-5 hours per day or 10-16 hours per day. The choice is usually based on the method of providing refrigeration. If LPG refrigerators are used, then the diesel usage may be confined to the night. In either case, rarely is the demand well matched to the diesel generator capacity. The diesel size must be such as to allow for peak loads, meaning that for much of the time it is run at very low loads or at best, artificially loaded with unnecessary lighting or heating to avoid engine damage.

Such use of 'artificial' loads is a good principle to pursue. One possibility is to use control switching together with a form of storage, such as a water heating load. This would be switched on and off as other loads varied, and would mean that a better match of genset output to load is achieved, thus reducing chances of engine damage. This practice is on the increase in Australia, however it is doubted whether such management is practised at all in South Africa. Certainly no mention of it was made by any respondents to the questionnaire.

Short duration diesel systems do not usually provide refrigeration load and would typically be run at night to provide lighting and some appliance loads, typically a washing machine and TV. The average load over 24 hours for such systems may be 400-600W, however their load profile for the running time usually shows a continuous high load for the set (2-4 kW). This applies especially when the consumers are well-organised and undertake those tasks requiring electricity in the few hours of operating time. If the diesel set is small (4-6 kVA), then the capacity factor may be as high as 0,75. If it is of larger capacity or if the consumers are not well-organised, the capacity factor may be as low as 0,03. This means that not only is the diesel engine wasting fuel but it may also suffer from underloading resulting in carbonation, cylinder glazing and shorter life.

In systems where the diesel set is used for semi-permanent power supply including refrigeration load, the average load might be 500-700W. The load profile in this case may again show a high peak and low capacity factor with the same engine damage as a result. It is usual in these installations to have some dummy load connected to ensure adequate engine loading at all times. This false load leads to unnecessary fuel usage and poor economics but does preserve the engine.

The justification for longer run times is either to give refrigeration plant time to maintain coolth and/or to provide convenient power supply. Whatever the reason the practice usually results in very low load and capacity factors, meaning the system is quite unsatisfactory.

5.3 DIESEL GENERATING COSTS

Considering that there are about as many operating modes of diesel gensets as there are gensets themselves, it would be impossible to determine a typical load profile for a self generation power supply. Thus in order to determine the real costs to the consumer of diesel power generation, two approaches were taken. Firstly, a simple micro-computer based diesel genset model was developed, and secondly field monitoring of a limited number of diesel genset systems was carried out to determine real operating fuel and power consumption.

5.3.1 Simulation of Diesel Genset Operation

A micro-computer based mathematical model was developed to simulate the running of a diesel genset under various conditions. The model was written in BASIC, and a listing of it can be found in Appendix C. Briefly, the model allows the user to input a particular load curve and to stipulate the degree to which the genset can be oversized for the application e.g. 50%. The gensets capable of meeting the load requirements are then selected from a database. The selected gensets are then 'run' against the synthesised load curve to determine the fuel consumption for the given cycle.

These consumption figures are then fed into a life cycle costing routine set up in a spreadsheet, and the cost of running the genset over a time period is then determined, taking into account all capital and running costs.

Load Curves

As said earlier, with the variety of different genset installations there is as wide a range of load profiles. For this reason load curves for various typical applications were synthesised, based on the typical power consumptions for various household appliances, workshop equipment and agricultural machinery e.g. milking machines, pumps, welding equipment etc.

Diesel Engine Fuel Consumptions

This is a further area of uncertainty, as the consumption figures usually given by manufacturers are for an engine at full load. If an engine is run at less than this load, there is a fuel saving in proportion to the reduction in load. This is however only true up to a point beyond which the engine will use fuel regardless of the load. For example this occurs at 30% load on at least one popular make of engine. Peak engine performance and long engine life is achieved when the unit is run near full load, or full fuel flow.

Diesel consumption data was supplied by manufacturers, either in the form of engine maps, or consumption tables based on British, SAE or DIN standard tests. From these data mathematical correlations for specific fuel consumption vs percentage of full load were determined.

A factor was built into the model to enable the derating of the engine due to altitude to be taken into account. Rated capacity is reduced by ±4% for each 300m increase in elevation above sea-level (Calloway, 1985).

5.3.2 Determination of Diesel Generation Costs

The diesel consumption results obtained from the mathematical model were used to calculate the unit power costs of diesel power generation. This was done by first calculating the present worth of the power plant, its operation and maintenance over a fixed period. A levelized annual cost was determined from this value, and then divided by the power consumed per year to obtain the cost per kilowatthour. For these calculations, assumptions had to be made regarding certain parameters. Careful note should be taken of these assumptions when comparing these costs with those incurred using other forms of remote area power supply.

Before undertaking the detailed cost analysis, the effects of some of these parameters are examined by means of parametric sensitivity analyses on data obtained from simulation of a diesel genset used to supply power for domestic use. The maximum demand of this base case system is 4,0 kVA with a daily consumption of 14,75 kWh, consumed over a period of 5,75 hours. The replacement engine age is taken as 15 000 hours, the real discount rate as 5% and the price of diesel as 55c/l.

The diesel price chosen falls in the middle of the price range paid by farmers for agricultural diesel. There is a wide variation of prices, dependent on location and whether a particular farmer is eligible for rebates from the Department of Customs and Excise. 55 c/l is therefore chosen as the price to be used in all the analyses in this report.

5.3.3 Parametric Sensitivity Analyses

Discount Rate

Figure 5.1 shows the sensitivity of unit power cost to the discount rate.

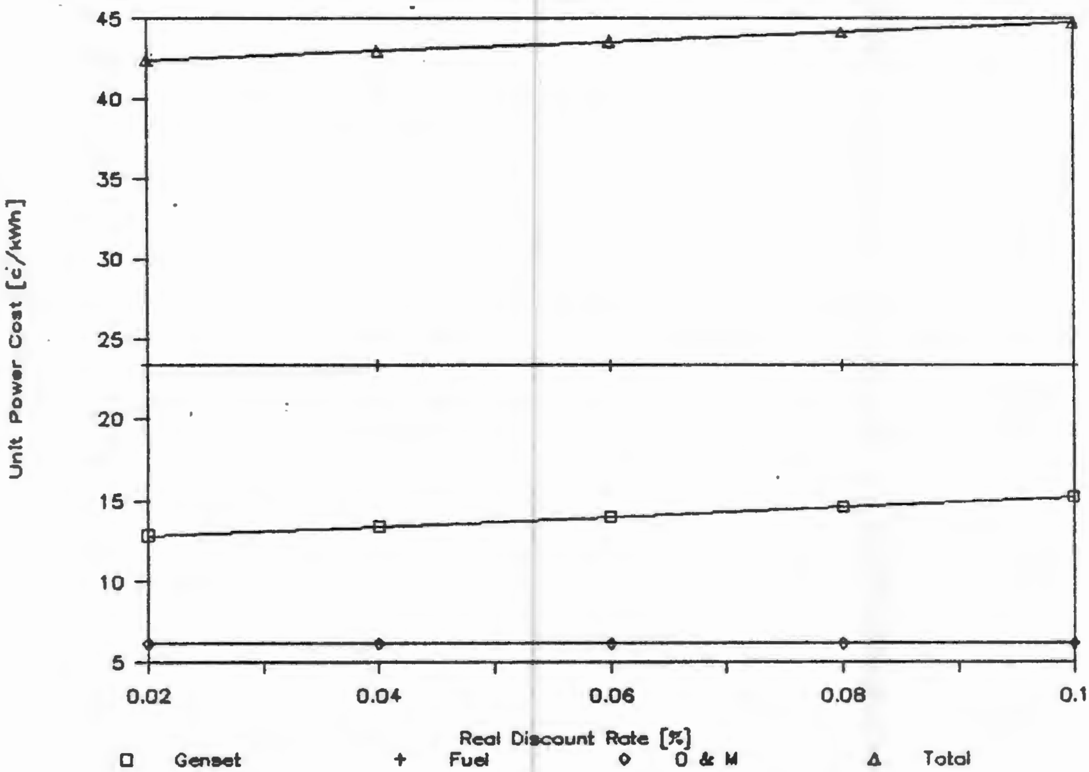
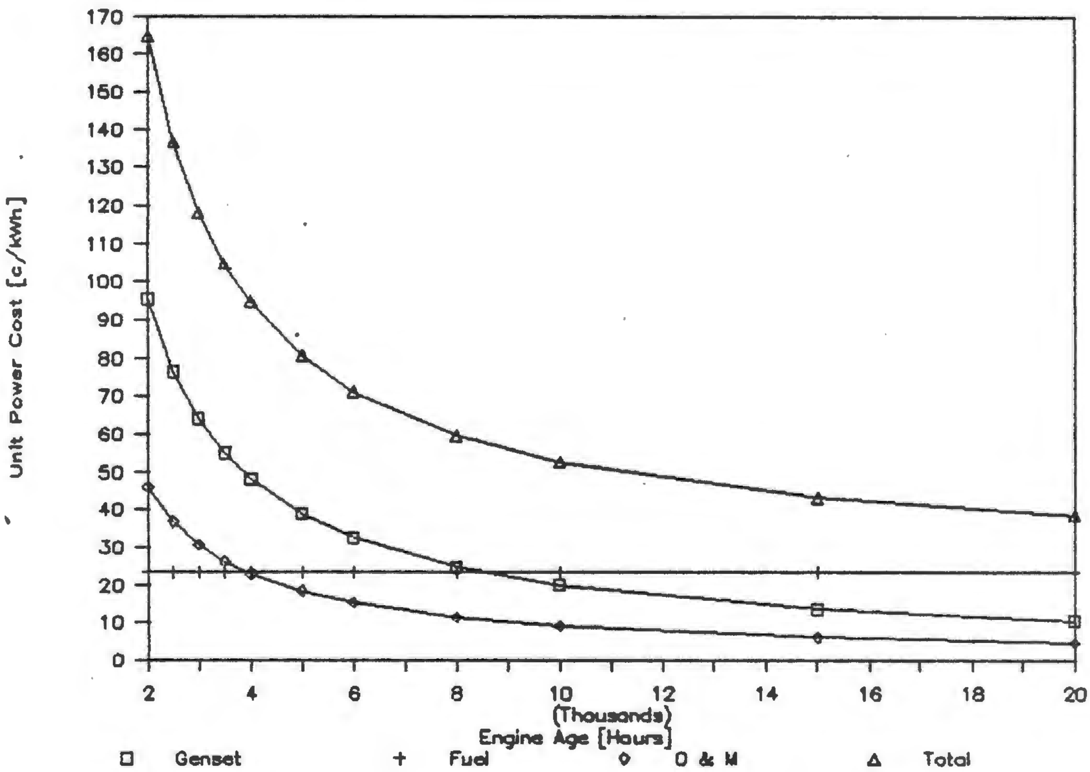


Figure 5.1

From this it is evident that as long as the real discount rate is not set above 5%, its effect on the unit power cost will be insignificant. As mentioned in Chapter Four, a real discount rate of 5% is a realistic figure considering the current economic situation in the country.

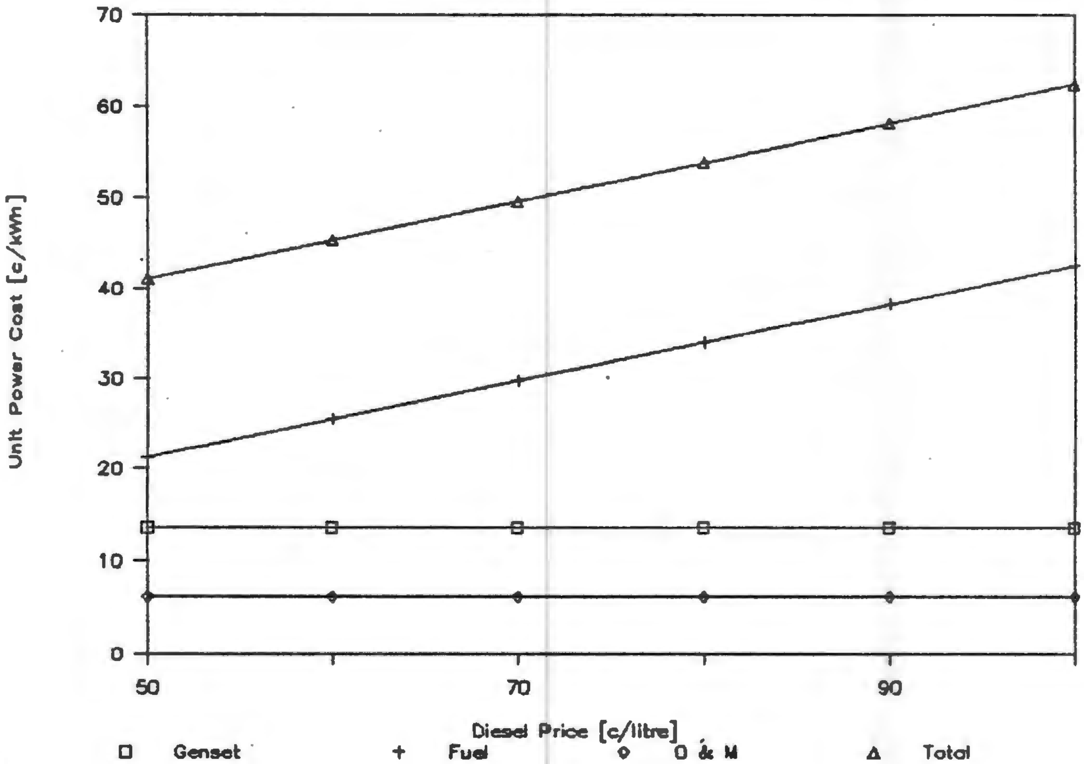
<u>Engine Replacement Age</u>

According to suppliers, diesel gensets may be expected to run trouble free for 10 000 hours, and can achieve a service life of 15 000 hours. Data from the questionnaire survey have shown that engine ages of well over 20 000 hours are not uncommon in South Africa. For this investigation a service life of 15 000 hours has been selected. Figure 5.2 shows the sensitivity of the unit power cost to the engine service life. It is evident from this that the effect of the engine replacement age is of increasingly less importance the greater it becomes, as would be expected.

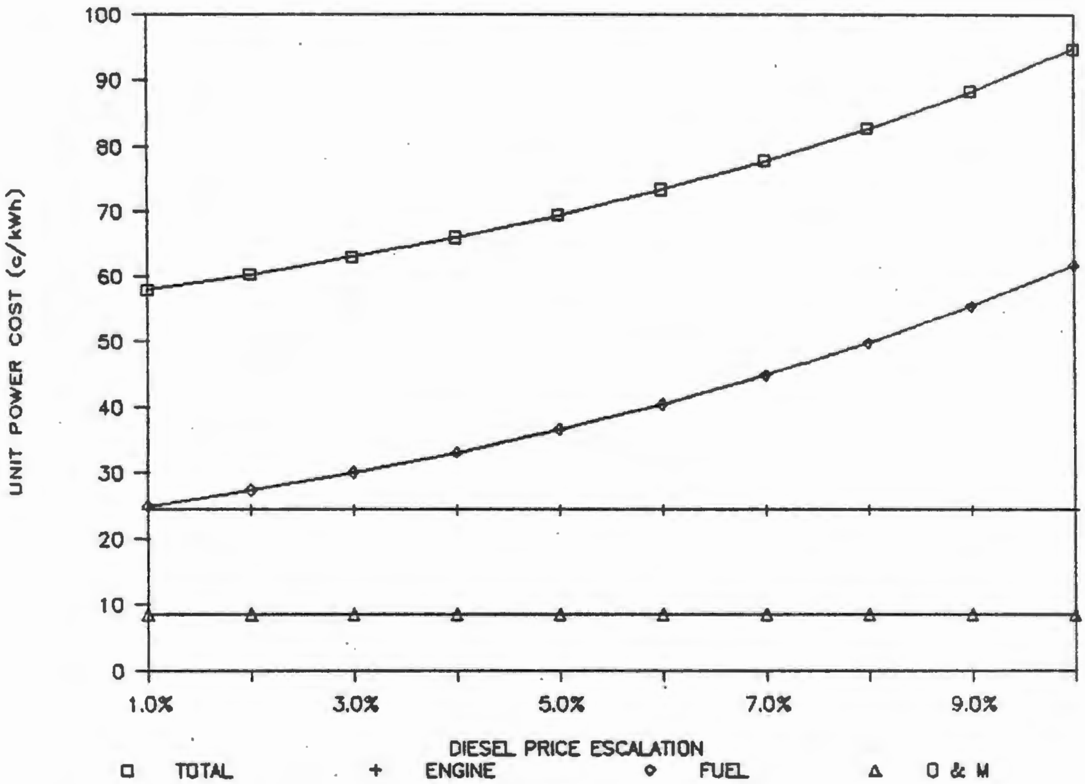


Price of Diesel Fuel

Current agricultural diesel prices are used as the baseline. It is assumed that diesel is paid for in an annual lump sum. From Figure 5.3 it can be seen that the diesel price can have a significant effect on the unit power cost.



Over the past decade the price of agricultural diesel escalated at a rate above that of inflation. Figure 5.4 shows the effect of diesel price escalation on the unit power cost.



<u>Operation and Maintenance</u>

The assumption is made here that labour for the operation of the genset is free. Maintenance costs are determined as 50% of the initial capital cost of the genset spread evenly over its life.

This factor was determined on the basis of discussions with diesel mechanics working in rural areas, and users and suppliers of diesel generating equipment. Such high maintenance costs are justified given the typically low load operation of diesel gensets, resulting in low thermal efficiency, cylinder bore glazing and high oil consumption. It also agrees with the assumption that has been made in similar studies in Australia (Crawford, 1984). It must of course be borne in mind that this is the level of maintenance required to ensure efficient and reliable operation of the genset.

In terms of routine maintenance, a diesel engine operating at 1500 rpm corresponds to a vehicle travelling at 55 kph (pers. comm. Salister Diesels). For example, where a car operating under dusty conditions would require maintenance at intervals of 5 000 kms, a diesel genset would need maintenance every 90 hours i.e. oil replacement and primary fuel filter change. It is doubtful whether there are many diesel gensets in this country which are treated with such respect.

5.3.4 Predicted Power Generation Costs

As was stated earlier, most diesel gensets are used in remote areas to supply power to farm homesteads and workshops. These are usually run for short periods mainly in the evening hours, and are in general not well loaded.

After performing the parametric sensitivity analyses detailed above, the following diesel power generation costs were calculated, using the parameters as listed.

DIESEL COST	0.55 RAND/l
MAINTENANCE	50.00% OF CAPITAL COST SPREAD OVER ENGINE LIFE
DISCOUNT RATE	5.00%
ESCALATION	0.00 % PER ANNUM
ENGINE LIFE	15000 HOURS

Table 5.2 POWER FOR DOMESTIC USE ONLY (DOMSTC-1)

MAX DEMAND	2.50 kVA
RUNNING TIME	5.75 hrs/day
POWER/DAY	11.5 kWh/day
ENGINE LIFE	7.15 yrs

GENSET MAKE & MODEL	kW	l/DAY	l/kWh	GENSET COST	ANNUAL COSTS ENGINE	FUEL O & M	COST/ kWh	CAPACITY FACTOR
				R	R/yr	R/yr	c/kWh	
KUBOTA Z500	4.48	3.32	0.289	6656.80	1130.56	1132.19	53.91	0.44
LISTER SR1	3.70	5.03	0.437	5765.75	979.232	1413.13	57.00	0.54
KUBOTA Z600	5.97	3.60	0.313	8221.86	1396.36	1297.89	64.19	0.33
LISTER ST1	4.50	5.24	0.456	6678.93	1134.32	1519.18	63.22	0.44
PETTER PH1	4.70	5.77	0.502	6898.40	1171.59	1640.93	67.00	0.42
LISTER 6/1	4.48	6.12	0.532	6656.80	1130.56	1694.29	67.30	0.44
LISTER LR2	4.90	6.21	0.540	7114.65	1208.32	1744.39	70.34	0.40
LISTER VA	5.60	6.03	0.524	7847.94	1332.86	1759.55	73.67	0.35
PETTER PJ1	6.30	5.66	0.492	8548.01	1451.76	1734.25	75.90	0.31
LISTER 8/1	5.97	6.79	0.590	8221.86	1396.36	1938.28	79.44	0.33
ONAN DJE	4.50	10.12	0.880	6678.93	1134.32	2498.84	86.56	0.44

Table 5.3 POWER FOR DOMESTIC USE ONLY (DOMSTC-2)

MAX DEMAND 3.50 kVA
RUNNING TIME 5.75 hrs/day
POWER/DAY 14.75 kWh/day
ENGINE LIFE 7.15 yrs

GENSET MAKE & MODEL	kW	l/DAY	l/kWh	GENSET COST	ANNUAL COSTS ENGINE	FUEL O & M	COST/ kWh	CAPACITY FACTOR
				R	R/yr	R/yr	c/kWh	
KUBOTA Z600	5.97	4.23	0.287	8221.86	1396.37	1424.36	52.39	0.43
KUBOTA D750	6.71	4.32	0.293	8944.15	1519.04	1492.96	55.95	0.38
LISTER LR2	4.90	7.38	0.500	7114.65	1208.32	1979.26	59.21	0.52
KUBOTA D850	8.21	4.29	0.291	10316.52	1752.12	1582.94	61.95	0.31
LISTER VA	5.60	7.10	0.481	7847.94	1332.86	1974.35	61.43	0.46
PETTER PJ1	6.30	6.65	0.451	8548.01	1451.76	1932.99	62.87	0.41
LISTER 8/1	5.97	7.97	0.540	8221.86	1396.37	2175.17	66.34	0.43
LISTER SR2	7.50	7.43	0.504	9681.17	1644.21	2168.85	70.83	0.34
LISTER ST2	9.00	7.68	0.521	10996.20	1867.55	2311.04	77.61	0.29
LISTER 12/2	8.95	9.34	0.633	10953.99	1860.38	2641.33	83.62	0.29
ONAN 12DJC	9.00	12.07	0.818	10996.20	1867.55	3192.33	93.98	0.29

Table 5.4 POWER FOR DOMESTIC USE ONLY (DOMSTC-3)

MAX DEMAND 4.00 kVA
RUNNING TIME 5.75 hrs/day
POWER/DAY 10.35 kWh/day
ENGINE LIFE 7.15 yrs

GENSET MAKE & MODEL	kW	l/DAY	l/kWh	GENSET COST	ANNUAL COSTS ENGINE	FUEL O & M	COST/ kWh	CAPACITY FACTOR
				R	R/yr	R/yr	c/kWh	
KUBOTA Z600	5.97	4.45	0.430	8221.86	1396.37	1468.53	75.84	0.30
KUBOTA D750	6.71	4.54	0.439	8944.15	1519.04	1537.12	80.90	0.27
KUBOTA D850	8.21	4.48	0.433	10316.52	1752.12	1621.09	89.29	0.22
LISTER VA	5.60	7.47	0.722	7847.94	1332.86	2048.63	89.51	0.32
PETTER PJ1	6.30	6.99	0.675	8548.01	1451.76	2001.25	91.40	0.29
LISTER 8/1	5.97	8.38	0.810	8221.86	1396.37	2257.47	96.72	0.30
LISTER SR2	7.50	7.78	0.752	9681.17	1644.21	2239.11	102.79	0.24
LISTER ST2	9.00	8.03	0.776	10996.20	1867.55	2381.30	112.47	0.20
LISTER 12/2	8.95	9.75	0.942	10953.99	1860.38	2723.64	121.34	0.20
ONAN 12DJC	9.00	12.47	1.205	10996.20	1867.55	3272.63	136.06	0.20

Table 5.5 POWER FOR DOMESTIC AND WORKSHOP USE (WKSHP-1)

MAX DEMAND 10.00 kVA
RUNNING TIME 11.50 hrs/day
POWER/DAY 68.98 kWh/day
ENGINE LIFE 3.57 yrs

GENSET					ANNUAL COSTS			
				GENSET	ENGINE	FUEL	COST/	CAPACITY
MAKE & MODEL	kW	l/DAY	l/kWh	COST		O & M	kWh	FACTOR
				R	R/yr	R/yr	c/kWh	
KUBOTA V1502	14.62	18.91	0.274	15177.45	4742.93	5919.76	42.35	0.41
KUBOTA V1702	17.31	19.43	0.282	16863.24	5269.74	6260.02	45.79	0.35
PETTER PJ2	12.75	27.68	0.401	13896.74	4342.71	7501.15	47.04	0.47
DEUTZ F2L912	14.50	27.69	0.401	15098.12	4718.14	7671.25	49.21	0.41
LISTER ST3	13.40	29.35	0.425	14352.96	4485.28	7900.23	49.19	0.45
LISTER TL3	16.40	29.83	0.432	16312.01	5097.48	8270.69	53.10	0.37
LISTER SR4	14.90	31.25	0.453	15361.12	4800.32	8422.71	52.52	0.40
LISTER HR2	16.90	31.99	0.464	16617.19	5192.84	8747.01	55.37	0.35
ADE 152	21.00	29.44	0.427	18921.76	5913.02	8557.55	57.47	0.29
DEUTZ F3L912	22.70	32.27	0.468	19784.57	6182.65	9246.39	61.28	0.26
ONAN 17RDJF	14.50	40.58	0.588	15098.12	4718.14	10258.91	59.49	0.41
LISTER HR3	25.30	38.12	0.553	21012.02	6566.22	10592.52	68.15	0.24
ONAN 30DDA	25.00	48.63	0.705	20875.76	6523.64	12683.34	76.29	0.24

Table 5.6 POWER FOR DOMESTIC AND WORKSHOP USE (WKSHP-2)

MAX DEMAND 15.00 kVA
RUNNING TIME 11.50 hrs/day
POWER/DAY 85.23 kWh/day
ENGINE LIFE 3.57 yrs

GENSET					ANNUAL COSTS			
				GENSET	ENGINE	FUEL	COST/	CAPACITY
MAKE & MODEL	kW	l/DAY	l/kWh	COST		O & M	kWh	FACTOR
				R	R/yr	R/yr	c/kWh	
VM 1052 SU	27.60	29.42	0.345	22013.06	6879.04	8986.06	51.00	0.27
ADE 152	21.00	34.87	0.409	18921.76	5913.02	9647.62	50.02	0.35
FORD 2722	33.00	30.55	0.358	24087.58	7527.33	9503.17	54.74	0.22
DEUTZ F4L912	30.50	32.19	0.378	23172.40	7241.34	9704.35	54.47	0.24
DEUTZ F3L912	22.70	38.37	0.450	19784.57	6182.65	10470.97	53.53	0.33
ADE 236	35.00	35.42	0.416	24767.79	7739.90	10575.99	58.88	0.21
LISTER HL3	26.50	41.93	0.492	21543.74	6732.39	11431.78	58.39	0.28
LISTER HR3	25.30	43.33	0.508	21012.02	6566.22	11638.43	58.52	0.29
LISTER HR4	33.70	43.14	0.506	24330.74	7603.32	12064.63	63.22	0.22
ONAN 30DDA	25.00	55.06	0.646	20875.76	6523.64	13974.16	65.89	0.30

Table 5.7 POWER FOR DAIRY AND DOMESTIC USE (DAIRY-1)

MAX DEMAND 16.50 kVA
RUNNING TIME 9.50 hrs/day
POWER/DAY 95.55 kWh/day
ENGINE LIFE 4.33 yrs

GENSET MAKE & MODEL	kW	1/DAY	1/kWh	GENSET COST	ANNUAL COSTS ENGINE	FUEL O & M	COST/ kWh	CAPACITY FACTOR
				R	R/yr	R/yr	c/kWh	
VM 1052 SU	27.60	29.53	0.309	22013.06	5784.54	8472.49	40.88	0.36
DEUTZ F4L912	30.50	33.76	0.353	23172.40	6089.19	9455.66	44.57	0.33
FORD 2722	33.00	33.01	0.345	24087.58	6329.68	9410.88	45.13	0.30
VM 1053 SU	41.40	34.37	0.360	26664.76	7006.90	9981.78	48.71	0.24
LISTER HL3	26.50	42.35	0.443	21543.74	5661.21	10991.86	47.75	0.38
DEUTZ F5L912	38.50	37.45	0.392	25855.42	6794.23	10506.54	49.61	0.26
ADE 236	35.00	38.88	0.407	24767.79	6508.42	10667.90	49.25	0.29
LISTER HR3	25.30	44.16	0.462	21012.02	5521.49	11293.76	48.21	0.40
LISTER HR4	33.70	42.51	0.445	24330.74	6393.57	11346.11	50.87	0.30
LISTER HL4	33.70	45.84	0.480	24330.74	6393.57	12014.61	52.78	0.30
ONAN 30DDA	25.00	55.81	0.584	20875.76	5485.68	13616.75	54.77	0.40

Table 5.8 POWER FOR DAIRY AND DOMESTIC USE (DAIRY-2)

MAX DEMAND 25.50 kVA
RUNNING TIME 5.50 hrs/day
POWER/DAY 137.00 kWh/day
ENGINE LIFE 7.47 yrs

GENSET MAKE & MODEL	kW	1/DAY	1/kWh	GENSET COST	ANNUAL COSTS ENGINE	FUEL O & M	COST/ kWh	CAPACITY FACTOR
				R	R/yr	R/yr	c/kWh	
VM 1053 SU	41.40	35.96	0.262	26664.76	4364.16	9003.29	26.73	0.60
DEUTZ F4L912	30.50	42.31	0.309	23172.40	3792.57	10044.35	27.67	0.82
VM 1054 SU	55.20	38.85	0.284	29541.26	4834.95	9775.94	29.22	0.45
LISTER HR4	33.70	45.67	0.333	24330.74	3982.15	10796.38	29.55	0.74
DEUTZ F5L912	38.50	46.12	0.337	25855.42	4231.69	10988.75	30.44	0.65
DEUTZ F6L912	45.50	45.96	0.335	27678.89	4530.14	11078.65	31.21	0.55
LISTER HL4	33.70	50.49	0.369	24330.74	3982.15	11764.00	31.49	0.74
FORD 2725	50.00	45.32	0.331	28631.19	4686.00	11013.89	31.40	0.50
ADE 236	35.00	53.58	0.391	24767.79	4053.69	12413.56	32.93	0.71
FORD 2726T	64.00	46.95	0.343	30666.83	5019.17	11477.33	32.99	0.39
LISTER HR6	50.60	51.67	0.377	28746.26	4704.83	12296.36	34.00	0.49
ADE 354	51.00	56.92	0.415	28821.48	4717.14	13355.33	36.14	0.49

Table 5.9 POWER FOR PUMPING AND DOMESTIC USE (PUMP-1)

MAX DEMAND 10.00 kVA
RUNNING TIME 13.00 hrs/day
POWER/DAY 100.35 kWh/day
ENGINE LIFE 3.16 yrs

GENSET MAKE & MODEL	kW	l/DAY	l/kWh	GENSET COST	ANNUAL COSTS ENGINE	ANNUAL COSTS FUEL O & M	COST/ kWh	CAPACITY FACTOR
				R	R/yr	R/yr	c/kWh	
KUBOTA V1502	14.62	25.71	0.256	15177.45	5309.37	7561.85	35.14	0.53
KUBOTA V1702	17.31	26.17	0.261	16863.24	5899.10	7920.83	37.73	0.45
PETTER PJ2	12.75	37.78	0.376	13896.74	4861.36	9782.34	39.98	0.61
DEUTZ F2L912	14.50	38.54	0.384	15098.12	5281.62	10124.92	42.06	0.53
LISTER ST3	13.40	40.12	0.400	14352.96	5020.95	10324.25	41.90	0.58
LISTER SR4	14.90	42.52	0.424	15361.12	5373.62	10965.51	44.61	0.52
ADE 152	21.00	40.92	0.408	18921.76	6619.20	11207.48	48.67	0.37
DEUTZ F3L912	22.70	45.04	0.449	19784.57	6921.03	12171.04	52.12	0.34
ONAN 17RDJF	14.50	53.48	0.533	15098.12	5281.62	13124.13	50.25	0.53
LISTER HR3	25.30	50.67	0.505	21012.02	7350.42	13495.40	56.91	0.31
ONAN 30DDA	25.00	64.36	0.641	20875.76	7302.75	16222.12	64.23	0.31

Table 5.10 POWER FOR PUMPING AND DOMESTIC USE (PUMP-2)

MAX DEMAND 20.00 kVA
RUNNING TIME 13.00 hrs/day
POWER/DAY 190.35 kWh/day
ENGINE LIFE 3.16 yrs

GENSET MAKE & MODEL	kW	l/DAY	l/kWh	GENSET COST	ANNUAL COSTS ENGINE	ANNUAL COSTS FUEL O & M	COST/ kWh	CAPACITY FACTOR
				R	R/yr	R/yr	c/kWh	
VM 1052 SU	27.60	52.25	0.274	22013.06	7700.60	13970.92	31.19	0.53
DEUTZ F4L912	30.50	62.81	0.330	23172.40	8106.16	16274.21	35.09	0.48
VM 1053 SU	41.40	58.75	0.309	26664.76	9327.86	16011.54	36.47	0.35
FORD 2722	33.00	63.39	0.333	24087.58	8426.31	16535.39	35.93	0.44
LISTER HL3	26.50	75.49	0.397	21543.74	7536.43	18562.12	37.56	0.55
DEUTZ F5L912	38.50	69.09	0.363	25855.42	9044.74	17959.28	38.87	0.38
LISTER HR4	33.70	73.53	0.386	24330.74	8511.37	18609.46	39.04	0.43
DEUTZ F6L912	45.50	68.50	0.360	27678.89	9682.62	18129.25	40.03	0.32
ADE 236	35.00	75.87	0.399	24767.79	8664.26	19148.34	40.03	0.42
FORD 2725	50.00	70.21	0.369	28631.19	10015.75	18623.16	41.22	0.29
ADE 354	51.00	84.44	0.444	28821.48	10082.32	21509.93	45.47	0.29
LISTER HL6	50.60	91.20	0.479	28746.26	10056.01	22855.10	47.37	0.29

Table 5.11 POWER FOR PUMPING ONLY (PUMP-3)

MAX DEMAND	50.00 kVA
RUNNING TIME	9.00 hrs/day
POWER/DAY	450.00 kWh/day
ENGINE LIFE	4.57 yrs

GENSET MAKE & MODEL	kW	l/DAY	l/kWh	GENSET COST	ANNUAL COSTS ENGINE	FUEL O & M	COST/ kWh	CAPACITY FACTOR
				R	R/yr	R/yr	c/kWh	
VM 1056 SU	82.74	117.18	0.260	31602.05	7911.82	26984.31	21.25	0.60
VM 1306 V	124.90	153.86	0.342	28232.87	7068.32	33978.89	24.99	0.40
DEUTZ F5L413	74.00	152.30	0.338	31391.33	7859.07	34011.58	25.49	0.68
DEUTZ F6L413	89.40	162.90	0.362	31525.64	7892.70	36154.23	26.82	0.56
ADE 354T	64.60	169.84	0.377	30726.12	7692.53	37459.89	27.49	0.77

5.3.5 Power Generation Costs Determined from Field Data

In order to gather some realistic diesel consumption data, ten kilowatt-hour meters were installed on farms situated in the Eastern Cape. These were monitored for three months. During this period one of the diesel engines became unserviceable. This set had not been serviced for the past two years, and was run from breakdown to breakdown, a fairly typical mode of operation in rural areas.

The diesel consumption data obtained from this exercise was used to calculate costs for the power generated in each instance. The parameters selected were the following:

DIESEL COST	0.55 R/l
MAINTENANCE	50.00% of capital cost spread over life
DISCOUNT RATE	5.00%
ESCALATION	0.00%
ENGINE LIFE	15000 hrs

Table 5.12 POWER GENERATION ON A SELECTED SAMPLE OF EASTERN CAPE FARMS

FARM NAME	ENGINE TYPE	kW	DAYS	TOTAL kWh	kWh/ DAY	CAPACITY FACTOR
1 CAREY'S BR 2	PETTER PH2	9.40	138.00	1950.00	14.13	0.24
2 CAREY'S BR 1	LISTER ST2	9.00	152.00	2499.00	16.44	0.34
3 WESTONDALE 2	LISTER LR2	4.90	113.00	573.00	5.07	0.25
4 HARTEBEESLAGTE	LISTER SR2	7.50	143.00	798.00	5.58	0.23
5 VANDEVSKRAAL	LISTER SR2	7.50	91.00	857.00	9.42	0.20
6 DORINGHOEK	LISTER SR1	3.70	152.00	816.00	5.37	0.30
7 WESTONDALE 1	LISTER SR2	7.50	116.00	971.00	8.37	0.17
8 SMITSKRAAL	LISTER SR1	3.70	125.00	540.00	4.32	0.18
9 KAFFERSKLOOF	LISTER SR2	7.50	147.00	915.00	6.22	0.17

FARM NAME	TOTAL LITRES	l/DAY	l/kWh	OP TIME HRS/DAY	GENSET COST (R)	LIFE (YRS)
1 CAREY'S BR 2	1053.00	7.63	0.54	6.00	11330.18	6.85
2 CAREY'S BR 1	1425.00	9.38	0.57	8.00	10996.20	5.14
3 WESTONDALE 2	485.00	4.29	0.85	4.00	7114.65	10.27
4 HARTEBEESLAGTE	540.00	3.78	0.68	4.00	9681.17	10.27
5 VANDEVSKRAAL	514.00	5.65	0.60	8.00	9681.17	5.14
6 DORINGHOEK	1064.00	7.00	1.30	6.00	5765.75	6.85
7 WESTONDALE 1	756.00	6.52	0.78	8.00	9681.17	5.14
8 SMITSKRAAL	396.00	3.17	0.73	8.00	5765.75	5.14
9 KAFFERSKLOOF	1072.00	7.29	1.17	6.00	9681.17	6.85

FARM NAME	ENGINE R/YR	ENGINE c/kWh	FUEL R/YR	FUEL c/kWh	O & M R/YR	O & M c/kWh	UNIT COST c/kWh
1 CAREY'S BR 2	1994.23	38.67	1545.18	29.96	827.10	16.04	84.66
2 CAREY'S BR 1	2480.05	41.33	1898.46	31.64	1070.30	17.84	90.80
3 WESTONDALE 2	902.33	48.75	869.15	46.96	346.25	18.71	114.42
4 HARTEBEESLAGTE	1227.83	60.28	764.69	37.54	471.15	23.13	120.95
5 VANDEVSKRAAL	2183.46	63.52	1143.80	33.28	942.30	27.41	124.21
6 DORINGHOEK	1014.83	51.79	1417.51	72.34	420.90	21.48	145.61
7 WESTONDALE 1	2183.46	71.46	1319.75	43.20	942.30	30.84	145.50
8 SMITSKRAAL	1300.39	82.47	641.53	40.69	561.20	35.59	158.75
9 KAFFERSKLOOF	1703.98	75.00	1476.75	65.00	706.73	31.11	171.11

The figures above are in most cases higher than theoretical costs obtained from the model, although it is difficult to compare them, because of the lack of accurate load curve data for each farm. Engines 1, 2, 4 and 6 exhibit specific consumption figures (l/kWh) close to those given by the computer-based model under what are assumed to be similar conditions. The remaining engines run at consumption rates well over the model predictions, indicating bad maintenance, and poor output to load management by the users.

5.4 CONCLUSION

Table 5.13 SUMMARY OF CALCULATED POWER COST DATA

DIESEL COST	0.55 RAND/l
MAINTENANCE	50.00% OF CAPITAL COST SPREAD OVER ENGINE LIFE
DISCOUNT RATE	5.00%
ESCALATION	0.00 % PER ANNUM
ENGINE LIFE	15000 HOURS

USE OF POWER	MAX DEMAND [kVA]	RUNNING TIME/DAY [hrs]	POWER/ DAY [kWh]	COST/ kWh [c/kWh]	CAPACITY FACTOR
DOMESTIC 1	2,5	5,75	11,50	53,91 - 86,65	0,31 - 0,54
DOMESTIC 2	3,5	5,75	14,75	52,39 - 93,98	0,29 - 0,52
DOMESTIC 3	4,0	5,75	10,35	75,84 - 136,06	0,20 - 0,30
DOM & WKSHP 1	10,0	11,50	68,98	42,35 - 76,29	0,24 - 0,47
DOM & WKSHP 2	15,0	11,50	85,23	51,00 - 65,89	0,21 - 0,35
DOM & DAIRY 1	16,5	9,50	95,55	40,88 - 54,77	0,24 - 0,40
DOM & DAIRY 2	25,5	5,50	137,00	26,73 - 36,14	0,39 - 0,82
DOM & PUMP 1	10,0	13,00	100,35	35,14 - 64,23	0,31 - 0,61
DOM & PUMP 2	20,0	13,00	190,35	31,19 - 47,37	0,29 - 0,55
PUMPING	50,0	9,00	450,00	21,25 - 27,49	0,40 - 0,77

It is evident that the costs of diesel power generation are high. The costs calculated by means of the model, summarised above, are probably the optimum that can be achieved under the given conditions, and can be regarded as the best case. As the field tests have shown, the real costs incurred are always higher, in some cases by as much as 45%. Table 5.14 gives a summary of the costs determined from the field measurements, together with theoretically achievable costs, i.e. if the gensets were well maintained and run at optimum under the same load conditions.

Table 5.14 SUMMARY OF POWER COST DATA FROM FIELD TESTS

	GENSET RATING [kW]	RUNNING TIME/DAY [hrs]	POWER/ DAY [kWh]	COST/ kWh [c/kWh]	CALCULATED COST/ kWh [c/kWh]	CAPACITY FACTOR
1	9,40	6,00	14,13	84,66	83,61	0,24
2	9,00	8,00	16,44	90,80	89,68	0,34
3	4,90	4,00	5,07	114,42	95,20	0,25
4	7,50	4,00	5,58	120,95	113,93	0,23
5	7,50	8,00	9,42	124,21	124,22	0,20
6	3,70	6,00	5,37	145,61	101,01	0,30
7	7;50	8,00	8,37	145,50	135,59	0,17
8	3,70	8,00	4,32	158,75	148,58	0,18
9	7,50	6,00	6,22	171,11	136,62	0,17

Despite the theoretical power generation costs being calculated on a best-case basis, it is apparent from these figures that, even at best, diesel is an expensive source of energy for the remote small power user. When the actual costs incurred are determined, using field data, they are found to be much higher for the reasons outlined elsewhere in this chapter.

The following chapters of this report focus on the determination of the costs of power generation using renewable sources of power, These could in some areas replace diesel gensets, while in others they could be used in a hybrid configuration. Such hybrids could involve the use of any combination of the alternatives, diesel, wind, solar or hydro. An important factor in such systems is the correct sizing of battery storage to achieve optimum savings, while at the same time not incurring too high an initial capital cost.

CHAPTER SIX

SOLAR POWER GENERATION

The amount of solar energy received by the earth in only one hour is about equal to the total world energy consumption in one year. However, only a small fraction of this can be effectively utilised. The most obvious and simplest use of solar energy is to convert it into heat via a thermal solar collector. Thus it is understandable that early developments of solar energy systems concentrated on the use of solar energy to supplement domestic space and water heating.

More recently, the conversion of sunlight to electricity has captured the interest of many scientists and engineers. This has promise as an effective decentralized power generation system, and can basically be achieved through two fundamentally different methods - solar thermal and photovoltaic. Naturally, because of the need for power at times when there is no insolation, all solar power generation systems require some form of storage, usually in the form of chemical or thermal energy.

6.1 SOLAR ELECTRICAL POWER GENERATION TECHNOLOGIES

6.1.1 Solar Thermal

Generation of electrical power from solar thermal energy is achieved by concentrating the sunlight onto an absorber, so as to produce a high-temperature fluid ranging in temperature from 100-1700°C. This fluid is then used to power a Carnot cycle engine, such as a Rankine engine, and thereby generate electricity. The concentration of sunlight is achieved either through central or distributed receivers. In a central receiver system, heliostats, or sun-tracking reflectors direct the sun's rays at a central receiver which absorbs the concentrated sunlight and transfers it as heat to a circulating working fluid.

A distributed receiver system consists of one of two types of collector. Parabolic line-focus or trough reflectors focus sunlight onto a linear receiver tube positioned along the focal line of the trough. A circulating heat transfer fluid in the tube transports the heat energy to the point of use via a network of pipes.

Parabolic dish systems use point-focusing concentrating reflectors up to 11m in diameter that focus the sunlight onto a receiver at the focal point of the concentrator. These dish modules can be used alone or in a multimodule system. The heat generated can then be used by a heat engine coupled directly to the individual dishes, or else a circulating fluid is used to convey the energy to a central point for use.

Solar thermal power generation is being investigated in Israel, the USA, Japan, France, Spain and Australia. The first large scale semi-commercial facility, Solar One, a 10 MWe facility in Southern California, came on line in April 1982, and has achieved a maximum energy delivery in one day of 104 MWh. This central receiver facility has served very well as a proof of concept test. Costs for similar plant have dropped dramatically as a result of the experience gained with this project, in particular as regards the technology for the heliostats. However, the initial capital costs of these systems are higher than those of the distributed collector systems. Thus they are not well suited to small-scale applications. They are, however, being pursued as the commercial option for utility-scale power generation, as they have higher overall efficiencies, and are thus cheaper over a say 30-year life cycle.

Looking now at distributed collector technology, both parabolic trough and parabolic dish reflectors are well demonstrated and proven. Trough reflectors are used to produce the process heat for centrally-located generating facilities, while the dish is the technology best suited to small-scale application, with an individual Stirling engine per dish. This is a technology that has been taken to commercialization by the McDonnell Douglas Corporation who have developed a 25 kW Dish/Stirling in collaboration with United Stirling AB of Sweden. This system has a conversion efficiency of sunlight to electricity of 28%. It also has the advantage of modularity and the system output can be increased with the introduction of additional units.

Luz Industries, an Israeli company, and its Californian operation, Luz International have become leaders in the development of parabolic trough technology. The third and fourth of their solar electric generating systems (SEGS) both came on line in December 1986 in the Mojave Desert, California, and have a combined net output of 60 MWe. Another two 30 MWe plants are currently under construction and dew to come on line towards the end of 1987. SEGS VII will be the last to be constructed under the favourable power purchase contracts made available in California, and will come on line in early 1988. An additional 12 contracts have been sealed for implementation after 1988 (SEIR, 1987). The cost per kilowatt of these plants has dropped steadily with each successive installation, from SEGS I at US$ 4500/kW to SEGS III at US$ 3466/kW and SEGS IV at US$ 3366/kW. (These are 1983, 1986 and 1986 prices respectively. Adjustment of the 1983 price to present day US$ would therefore represent an even greater reduction per kW).

In Australia a number of small systems are being investigated in demonstration experiments. The largest of these is a hybrid solar/ diesel power plant at Meekatharra. The technology being used is that of the German company M.A.N. In the past power was provided by a multi-engine diesel-powered station with a peak output of 800 kW. This is now being supplemented by 100 kW of peak power - 50 kW from the solar plant and 50 kW from diesel exhaust heat recovery. The collector field consists of 960 m^2 of parabolic trough concentrators. The heat from this and the exhaust recovery system is then used to generate steam which drives a two-stage, wet operation screw expansion engine. The level of technical backup has been high thusfar, and the real practical test of the system will come when it is operated solely by the existing diesel plant personnel.

Another small-scale Australian project is the White Cliffs Solar Power Station. This plant produces 25 kW power and comprises 14 modular semi-autonomous parabolic dish collectors. Steam is generated by these collectors and conveyed to a high performance reciprocating uniflow steam engine which converts it to mechanical power at a heat to work conversion efficiency of 22%. This power is then used to drive an AC/DC set, the alternator feeding the load, while any excess output is fed into battery storage. In times of low or zero insolation this DC power is used to drive the DC machine which in turn drives the alternator to supply the load. A backup diesel is also available in the event of total failure. A second stage of this scheme is to provide water to the town through the use of waste low-grade heat for desalination. The total system has proved robust and manageable, and studies have been undertaken on smaller systems suitable for serving single households (Eberhard, 1983).

Since 1981, overall momentum in the development of solar thermal power generation technology has slowed, mainly as a result of lower fossil fuel prices, and the cut in US expenditure on research into energy alternatives (SEIA, 1986). This technology is not yet being used commercially for small remote power applications.

6.1.2 Solar Photovoltaic

Photovoltaic (PV) or solar cells are semiconductor devices that convert photons of incident sunlight directly into DC electricity. These have been used in space programmes since 1958, to provide power for orbiting satellites. These cells are efficient at converting sunlight into electricity, of the order of 20%. However their cost makes them very expensive for use on the earth. In some ways the entire research programme for solar cell development has been directed at taking this proven technology and making it cheaper.

A solar cell typically consists of two different types of semiconductor material, called n-type and p-type. Energy carried by the incident photons frees positive and negative charges within the cell materials. The junction between the n- and p-type materials creates an electric field, causing the freed charges to separate across the junction and thus create a voltage across the cell. Electric contacts placed on the two sides of the cell allow the current generated by this potential to be applied to an external load.

The amount of electric current generated by a cell is primarily dependent on the intensity of solar radiation striking its exposed area. The open-circuit voltage produced, however, is primarily dependent on the temperature of the cell, voltage and cell temperature being inversely related.

Because the power output of a single solar cell is small (1 Watt for a typical cell of 100 cm^2, 10% efficiency), a number of cells are usually connected in series and parallel, and sold as a module. These in turn can be wired together into an array, to generate the amount of power required by the application. Efficiencies being achieved in the laboratory with the latest materials are up at 28%, although many of the new thin-film cells are still close to 10% (Zweibel, 1986).

New technologies are however being pursued, amongst them amorphous silicon (a-Si), copper indium diselenide, cadmium telluride and gallium arsenide. All of these materials are being considered for flat plate applications. Gallium arsenide (GaAs) and thick crystalline silicon are being developed as candidates for concentrator applications, using optical lenses or reflectors. In this way the cost of relatively expensive solar cells is offset by the less expensive enhancing optics. Another strategy for enhancement is based on the so-called cascade or multi-junction cells. These consists of a stack of cells atop one another so that the sun's spectrum is used more effectively (Zweibel, 1986).

The two most important variables determining the economic competitiveness of PV modules are their cost per square metre and efficiency of conversion. The US Dept of Energy has determined that unless module cost can be driven below US\$ 40/m², efficiencies of about 15% will be needed for economical production (Zweibel, 1986). The more expensive but mature technologies, crystalline Si and GaAs have efficiencies of over 20-25%, but high costs, of the order of US\$ 900-1000/m².

This technology provides a potentially cost-effective alternative to conventional power sources in a variety of remote applications, where the operation, maintenance, and fuel costs of the conventional sources are high. PVs can be used to provide either AC or DC power, the former requiring the inclusion of some fairly sophisticated electronic equipment in the system.

PVs have already been used extensively in South Africa and Namibia to provide power for telecommunications, in both radio and telephone repeater stations. Other installations which have been erected in the past year are a large number of audio-visual education facilities in rural areas of Bophutatswana and the Ciskei. Other appropriate applications with near term applicability are refrigeration at remote clinics and water pumping.

<u>The PV System</u>

A practical stand-alone PV power system typically requires several elements in addition to the array in order to satisfy the intended load. This equipment includes what is often referred to as the balance of system (BOS) i.e. support structures, fencing and other infrastructural requirements, and ancillary equipment for power storage and conditioning.

Power storage, most commonly involving a lead-acid battery in present applications, stores electrical energy produced during daylight hours for use during the night or during periods of reduced insolation. To be considered practical for remote applications, a storage battery should have a long life, require low maintenance, and be able to survive a substantial number of deep discharge cycles.

An important component of a power system using storage is a voltage regulator which controls the output voltage from the array when it is charging the battery. The regulator also limits the loss of water from the battery cells. This can occur during periods of gassing if charge rates are kept too high once the battery is fully charged.

6.2 THE POTENTIAL FOR SOLAR POWER GENERATION IN SOUTH AFRICA

Insolation characteristics important for assessing the potential for solar power generation include the following: diurnal variation, regional and seasonal variability, and weather.

6.2.1 Diurnal Variation

The most important characteristic of insolation when considering the use of solar energy is its diurnal pattern, i.e. its variation over the period of a day. The expected solar power available to a solar-powered device, over a 24-hour period, under clear sky conditions, will follow a curve similar to that in the following figure.

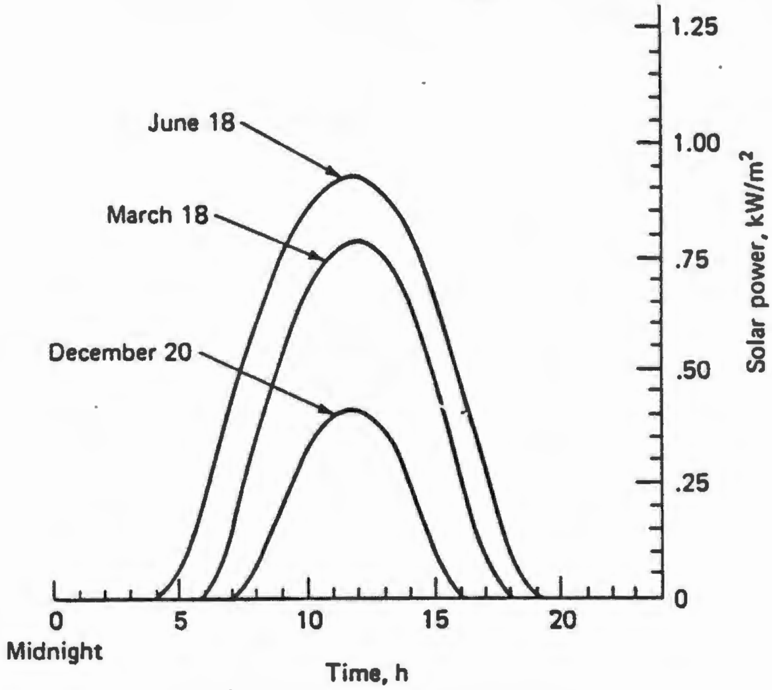


Figure 6.1

Any load that does not closely approximate this power output profile, or accommodate deviations from it, will require the inclusion of battery storage or a backup power supply.

6.2.2 Regional and Seasonal Variability

A second major factor in assessing solar potential is the regional and seasonal variability in insolation. To assess these it is important to have as accurate load and solar radiation data as possible for the site in question. If actual radiation data is not available for a specific site, and estimations have to be made, it is important to bear the spatial variations due to mountainous conditions and proximity to the coast. The transmissivity of the atmosphere has a great influence in this respect.

6.2.3 Weather

Cloudy weather will considerably reduce the output from a photovoltaic system. Since such weather conditions could persist for several days, storage or backup will have to be provided. In sizing a photovoltaic system, the amount of storage is primarily determined by the probable amount of cloudy weather at the site during the worst month of the year. The method for sizing the battery storage makes use of a probability table based on historical weather records. Although previous weather history is not a perfect predictor of future weather patterns, it does serve as a useful guideline for estimating system requirements, and thus solar potential.

6.2.4 The Solar Resource in South Africa

The amount of solar radiation reaching the outside of the earth's atmosphere I_o, is equal to 1367 W/m^2 and is known as the solar constant. However, as it passes through the atmosphere, solar radiation is attenuated. Incoming solar radiation can be divided into direct, diffuse and reflected components. Direct radiation comes right through the atmosphere to the surface of the earth. Diffuse radiation is that which has been scattered by atmospheric particles and comes from all directions before it reaches the ground. Part of the radiation is reflected back into space from atmospheric particles, cloud cover, and land and sea surfaces.

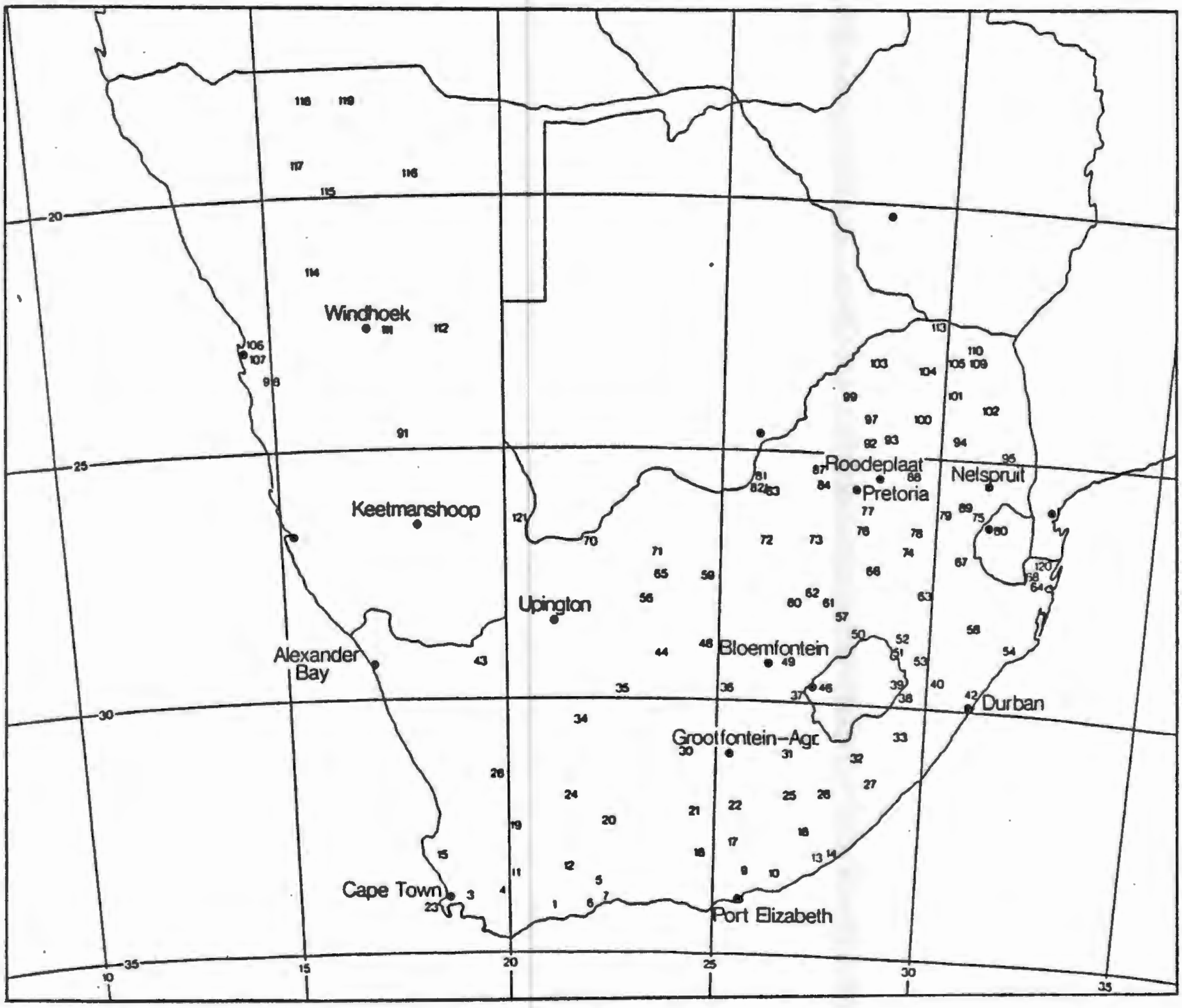


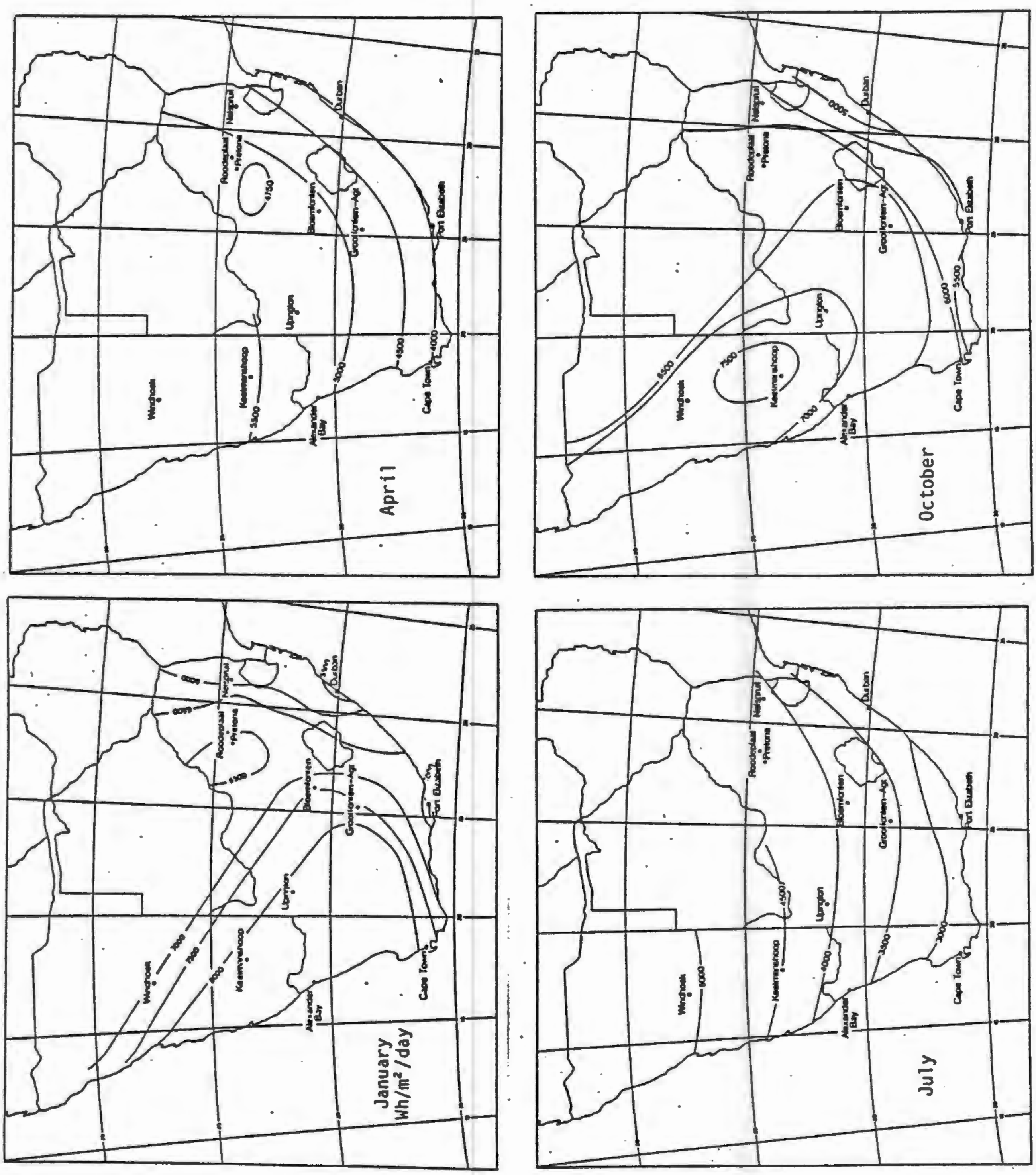
Figure 6.2

Systematic measurement of total and diffuse radiation received at the earth's surface have been made by the SA Weather Bureau since 1951. There are currently fifteen stations recording solar radiation; thirteen are in South Africa and two in Namibia, but only twelve of these are recording useful data (these are named on the map shown in Figure 6.2). As can be seen these stations are located mostly along the coast, where weather conditions vary much more than over the interior plateau. The spatial distribution of sunshine measuring stations (indicated by numbers on the map) is however much better (Tegen et al, 1988).

The ERI has embarked on a project to evaluate all the radiation data available from the South African Weather Bureau and the Department of Agriculture. The aim is to develop a handbook for solar installation designers. One problem already mentioned is that these two sources do not have enough radiation measurement stations to enable the drawing of accurate isopyrs. It is apparent that their spatial distribution is not therefore ideal for the accurate determination of solar radiation in many parts of the country.

However, in addition to solar radiation data, sunshine data is recorded at over 150 locations, with a far better spatial distribution. This data is being used to generate solar radiation data to enable interpolation between the solar radiation stations.

Figures 6.3 to 6.6 show global radiation in January, April, July and October for South Africa (Tegen et al, 1988). These maps give an indication of the seasonal variation that occurs. During the summer the values south of the Tropic of Capricorn are roughly twice those during winter. It is interesting to note that solar radiation levels increase towards the south. This phenomenon can be attributed to the fact that although solar radiation levels are highest around the equator at the atmosphere's outer surface, water vapour, dust and similar aerosols cause higher levels of attentuation in humid tropical and dry dusty regions.


April
October
January
Wh/m²/day
July
Windhoek
Keetmanshoop
Upington
Alexander Bay
Cape Town
Port Elizabeth
Bloemfontein
Grootfontein-Agr
Roodeplaat
Pretoria
Nelspruit
Durban

Cape Town receives one of the highest incomes of solar radiation in the region. In July the average 24-hour radiation is 2 568 Wh/m²/day for Cape Town, while the January figure is 8 472 Wh/m²/day, more than twice as much. But on a sunny day in both cases the radiation can be much higher, e.g. in July with a clear sky up to 6 300 Wh/m²/day and in January, up to 12 000 Wh/m²/day. Such a wide variation presents problems for PV applications, because of the need for large power storage devices to meet demands during the low insolation winter months.

Comparison of radiation figures for South Africa with those of other countries reveals how this country is blessed with high levels of solar radiation. On an annual average basis ±6 000 Wh/m²/day is received over the whole world. This includes the poles as well as tropical and humid regions, where solar radiation is rapidly attenuated. The annual average for South Africa is ±5 280 Wh/m²/day compared to the United Kingdom with an annual average of ±2 400 Wh/m²/day and the USA with ±3 600 Wh/m²/day. Looking at the above figures for the Cape, even the July value is higher than the annual average of the UK.

The tables overleaf show the data used in the economic evaluations of PV systems in this report (Tegen et al, 1988).

Table 6.1 DAILY INSOLATION LEVELS FOR SELECTED SITES IN SOUTH AFRICA

(Levels are given for surface tilt angles of Latitude-10°, Latitude, and Latitude+10° respectively. The units are kWh/m²/day.)

	BLOEMFONTEIN			CAPE TOWN			GROOTFONTEIN (CAPE)		
	-10°	Lat	+10°	-10°	Lat	+10°	-10°	Lat	+10°
JAN	6.87	6.48	6.00	7.29	6.87	6.32	7.16	6.74	6.23
FEB	6.57	6.36	6.04	7.14	6.89	6.50	5.77	5.61	5.32
MAR	6.19	6.23	6.10	5.90	5.90	5.77	6.03	6.03	5.94
APR	5.63	5.90	6.00	5.07	5.30	5.40	5.48	5.74	5.87
MAY	5.35	5.87	6.19	3.87	4.16	4.39	4.74	5.16	5.45
JUN	5.00	5.50	5.87	3.40	3.70	3.93	4.45	4.90	5.23
JUL	5.61	6.23	6.65	3.58	3.87	4.10	5.10	5.61	6.00
AUG	6.13	6.55	6.81	4.32	4.58	4.74	5.52	5.90	6.13
SEP	6.30	6.47	6.47	5.40	5.53	5.53	6.13	6.26	6.26
OCT	6.94	6.84	6.55	6.23	6.10	5.87	6.84	6.74	6.48
NOV	7.27	6.90	6.40	7.10	6.77	6.30	7.10	6.77	6.26
DEC	7.39	6.90	6.29	7.13	6.65	6.10	7.45	6.94	6.32

	NELSPRUIT			PORT ELIZABETH			PRETORIA		
	-10°	Lat	+10°	-10°	Lat	+10°	-10°	Lat	+10°
JAN	5.13	4.94	4.65	6.39	6.06	5.61	6.32	6.03	5.65
FEB	5.71	5.57	5.32	6.14	5.96	5.68	6.00	5.86	5.61
MAR	5.58	5.58	5.48	5.45	5.48	5.39	5.71	5.74	5.65
APR	4.97	5.19	5.50	4.80	5.03	5.13	4.97	5.17	5.27
MAY	5.00	5.45	5.77	4.16	4.48	4.71	5.06	5.52	5.84
JUN	4.71	5.29	5.90	3.83	4.20	4.47	4.97	5.57	6.00
JUL	5.13	5.65	6.03	4.13	4.48	4.74	5.19	5.71	6.10
AUG	5.23	5.55	5.74	4.71	5.00	5.16	5.84	6.23	6.45
SEP	5.29	5.42	5.60	4.93	5.03	5.03	6.30	6.47	6.43
OCT	5.26	5.19	5.03	5.58	5.52	5.32	6.26	6.16	5.94
NOV	4.87	4.71	4.60	6.37	6.10	5.73	6.33	6.10	5.73
DEC	5.35	5.13	4.84	6.42	6.03	5.58	6.45	6.10	6.32

	UPINGTON			WINDHOEK		
	-10°	Lat	+10°	-10°	Lat	+10°
JAN	7.19	6.74	6.16	6.23	5.94	5.52
FEB	6.64	6.43	6.04	6.61	6.43	6.11
MAR	6.19	6.19	6.10	6.16	6.19	6.10
APR	5.80	6.07	6.20	6.30	6.60	6.73
MAY	5.16	5.68	6.00	6.26	6.90	7.32
JUN	4.10	4.53	4.83	6.00	6.77	7.33
JUL	4.90	5.45	5.84	6.16	6.87	7.35
AUG	5.48	5.87	6.10	6.61	7.10	7.35
SEP	6.37	3.87	6.50	7.20	7.37	7.37
OCT	6.87	6.74	6.45	6.90	6.77	6.52
NOV	7.43	7.07	6.50	7.10	6.77	6.30
DEC	7.10	6.58	5.94	7.23	6.77	6.19

6.3 PV SYSTEM SIZING

This involves the sizing of PV array and battery storage requirements to adequately supply power to a given load. These sizes are ultimately depend on the amount and time distribution of insolation at the load site. Since useful insolation is a function of location, season, weather and array orientation, it is essential to account for these factors when sizing the PV system. Furthermore, since the intended load may vary seasonally, sizing will normally require a systematic accounting approach, to ensure that sufficient solar energy will be captured to achieve acceptable system reliability.

Since there are seasonal differences in the daily path of the sun across the sky, the amount of radiation striking a fixed array will vary seasonally according to its orientation, both in the horizontal and vertical planes. These variations are distinct from the seasonal variations mentioned above, which are caused by changing weather conditions.

Under typical weather conditions, the maximum annual energy output from a fixed array usually occurs when the array is tilted at an angle equal to the latitude where it is sited. However, if the load varies seasonally, latitude tilt may not be the most cost-effective angle for the array. The system design should therefore be based on the worst-month insolation and load situation.

The Solar Energy Research Institute (SERI) of the USA has developed a PV system sizing methodology which takes the above into consideration (Borden et al, 1984). In addition it has built into it the concept of Loss of Energy Probability (LOEP). This allows for the sizing of the PV system and its battery storage so as to provide power with a degree of certainty as described by the LOEP. This methodology has been used in the following section, with an LOEP of 0,1 i.e. there is a 10% probability that the system will not be able to supply the required power at any time. This is equivalent to the LOEP of a diesel powered generator, which would in most cases be the alternative to a PV system. The method involves the calculation of two sizing factors, S_a and S_b, which refer to the array and the battery storage bank, and have the units of kWh/m²/day and days, respectively.

6.4 THE ECONOMICS OF PV GENERATED POWER

The economics of photovoltaic generated power is dominated by the high initial capital cost of the equipment. Despite the sustained efforts of cell manufacturers to bring their costs down, they are still not competitive with diesel power generation in many remote applications. This has been further aggravated locally by the decline in the value of the Rand relative to the US Dollar. When photovoltaic cells were first produced in 1959 they cost of the order of US$1 000 per peak Watt (Wp). This price has been steadily decreasing over the past thirty years with 1987 prices now around US$5. However, the South African retail price is still of the order of R20 per Wp. Predictions are that by 1995 cells will be costing around US$2-3,50 per Wp.

Using the system sizing methodology outlined in the previous section, the economics of remote PV power generation has been investigated for a number of sites in South Africa and Namibia. A number of different system specifications have been used, along with the general assumptions and data as follows:

Table 6.2 SYSTEM CHARACTERISTICS AND COST DATA

System life	25.00 years
Discount rate (real)	5.00%
Escalation rate (real)	0.00%

PV MODULES	
Module cost	R20.00 /pW
Module efficiency	12.00%
Module operating temperature	60.00 °C
Module temp coefficient	-0.0050 /°C
Balance of System (% of capital cost)	0.05%
O&M cost (% of capital cost)	1.00%
VOLTAGE REGULATOR	
Voltage regulator efficiency	95.00%
Cost	R1000.00
BATTERIES	
Battery efficiency	90.00%
Depth of discharge	50.00%
Battery type	(Tubular/Traction/Automotive)
Battery life	10.00 years
Cost R/kWh	Dependent on type
O&M cost (% of capital cost)	5.00%
INVERTER	
Inverter efficiency	80.00%
Cost R/Wac	R1.34 /Wac

In all the following tables, the total installed cost referred to includes the capital cost of the solar module array, BOS, all energy storage and power conditioning equipment, and its installation.

The basic specifications of the first system which is evaluated at a number of sites and comprises a small domestic load, are:

Peak load	4.00 kVA
Daily consumption	10.35 kWh/day
AC loads?	YES
Induction loads?	YES

As far as the inductive loads are concerned, they will affect the size of inverter required to provide the necessary starting current. The following are the sites at which it is evaluated: Bloemfontein (BFN), Cape Town (CTA), Grootfontein Agricultural Station in the Cape (GFN), Port Elizabeth (PLZ), Nelspruit (NEL), Pretoria (PTA), Windhoek (WHK), and Upington (UPN). As explained earlier, the design methodology makes use of the worst month solar radiation figures.

Table 6.3 COMPARISON OF PV POWER GENERATION AT VARIOUS SITES

	BFN	CTA	GFN	PLZ
Insolation [kWh/sq m/day]	5.87	3.93	5.23	4.47
Required array power [W]	3047	4825	3549	4250
Required array area [sq m]	30	48	35	42
Required batt. storage [kWh]	37	85	47	66
Total installed cost [R]	87782	141741	101677	122684
Annual O&M cost [R/yr]	1325	2601	1619	2107
O&M present value [R]	18678	36653	22814	29703
Battery type - Tubular cell requiring 1.5 replacements in life cycle				
Battery costs [R/set]	14310	32704	18173	25140
Present value [R]	12227	27943	15527	21480
System life-cycle cost [R]	118687	206338	140019	173867
Annualised cost/kWh [c/kWh]	223	388	263	327

	NEL	PTA	WHK	UPN
Insolation [kWh/sq m/day]	4.71	6.00	6.00	4.83
Required array power [W]	4012	2952	2952	3896
Required array area [sq m]	40	29	29	39
Required batt. storage [kWh]	59	36	36	56
Total installed cost [R]	115302	85231	85231	111802
Annual O&M cost [R/yr]	1929	1274	1274	1847
O&M present value [R]	27192	17953	17953	26036
Battery type - Tubular cell requiring 1.5 replacements in life cycle				
Battery costs [R/set]	22531	13661	13661	21356
Present value [R]	19251	11672	11672	18247
System life-cycle cost [R]	161746	114856	114856	156085
Annualised cost/kWh [c/kWh]	304	216	216	293

It is apparent from the foregoing that the unit cost of PV generated power is very much dependent on the worst insolation level prevailing at a site. Thus it can be seen that Cape Town which over the year receives a substantial amount of solar radiation, in fact one of the highest totals in the region, nonetheless has the most expensive PV generated power. This is of course attributable to the fact that to ensure acceptable power supply during the winter months, both a larger solar module array and battery bank are required. The battery bank is in fact 8,5 times the daily power consumption of the system.

In order to get a better idea of the cost of PV power supply, a number of other systems were evaluated. These evaluations were all based on the solar radiation levels measured at Grootfontein Agricultural Research Station in the Eastern Cape. This site was chosen because of its proximity to a number of areas which could eventually become users of alternative power generation technologies.

The first three systems are all supplying domestic loads of the type currently supplied by diesel gensets. The systems have therefore been sized in order to supply AC loads and the assumption is made that there are induction motors being used for refrigerators and other appliances. Thus allowance is made for the provision of starting current levels of three times the peak.

The batteries specified in these comparisons are all of the tubular cell type. They are therefore the most expensive option, but are claimed by the manufacturers to provide the lowest maintenance and longest service life characteristics.

It is of interest to note that the peak demand has less effect on the system cost than does the daily power consumption. However, the higher consumption has the effect of improving the overall utilisation of the system thus resulting in a lower cost per unit of power. Indeed the system with the highest overall life-cycle cost produces the cheapest power. This highlights the necessity for very careful design of systems comprising such capital intensive equipment.

Table 6.4 GROOTFONTEIN: SMALL DOMESTIC LOADS - ALL AC

Worst-month Insolation 5.23 kWh/m²/day

Peak load	kVA	4.00	2.50	3.50
Daily consumption	kWh/day	10.35	11.50	14.75
AC loads?		YES	YES	YES
Induction loads?		YES	YES	YES
Required array power	W	3549	3943	5057
Required array area	sq m	35	39	50
Required battery storage	kWh	47	53	67
Total installed cost	R	101677	108143	138466
Annual O&M cost	R/year	1619	1798	2306
O&M present value	R	22814	25346	32499
Battery type: Tubular cell requiring 1.5 replacements in life cycle.				
Battery replacement costs	R/set	18173	20187	25879
Replacement present value	R	15527	17248	22111
System life-cycle cost	R	140019	150737	193077
Annualised cost/kWh	**c/kWh**	263	255	254

By way of comparison, the table overleaf, for Windhoek, is presented to show the effects of increased solar radiation on the unit cost of power. The right hand column of the following table is directly comparable with the left hand column of the above table. From this it can be seen that a 15% increase in the daily worst-month insolation at Windhoek has resulted in a close to 18% decrease in the unit cost of power.

Batteries play a central role in PV power generation systems. Because their costs and technical characteristics vary so greatly, their correct selection can have a significant effect on the final performance of the system, both technically and financially speaking. Special tubular cell batteries designed to withstand multiple deep cycled discharges are the most expensive option on a kWh basis. However, their construction is such that they have long life and low maintenance characteristics.

Traction batteries, used in forklift trucks and milk floats, are designed for the same type of service as tubular cell batteries. Consequently they will achieve the same service life, but are currently cheaper than tubular cell batteries. Automotive batteries are totally unsuited to the mode of operation required PV power systems. Thus, although significantly cheaper on a kWh basis, automotive batteries have to be replaced that much more regularly, in this way pushing up their life cycle cost.

The following table gives a good idea of the effect that battery choice can have on the unit cost of power from a PV system. This phenomenon will be dealt with in more detail in the sensitivity analyses.

Table 6.5 WINDHOEK: SMALL DOMESTIC LOAD

Worst-month Insolation	6.00 kWh/m²/day		
Peak load	kVA	4.00	
Daily consumption	kWh/day	10.35	
AC loads?		YES	
Induction loads?		YES	
Required array power	W	2952	2952
Required array area	sq m	29	29
Required battery storage	kWh	36	36
Total installed cost	R	79833	85231
Annual O&M cost	R/year	1004	1274
O&M present value	R	14149	17953
Battery type		Traction	Tubular cell
Battery replacement costs	R/set	8263	13661
Replacement present value	R	7060	11672
System life-cycle cost	R	101042	114856
Annualised cost/kWh	c/kWh	190	216

The next comparison looks at the effect of supplying the same basic system i.e. the first one shown above, but with varying degrees of AC supply required. The first column shows the full AC system costs inclusive of inductive load requirements. The middle column requires Ac supply but no inductive loads i.e. a smaller inverter is required, and the final column shows the costs of a straight DC system.

This comparison raises the interesting debate of whether to continue with the use of AC appliances when considering PV power supply. At present PV users have very limited choice in the matter, given the lack of available DC appliances. Given this state of affairs, another path that could be followed by PV users would be to use smaller dedicated inverters for those appliances that can only be run on AC. This would mean that the inverter would be running at close to its rated capacity, and therefore be operating in its most efficient mode.

Table 6.6 GROOTFONTEIN: SMALL DOMESTIC LOAD - COMPARISON AC/DC

Worst-month Insolation	5.23 kWh/m²/day			
Peak load	kVA	4.00		
Daily consumption	kWh/day	10.35		
AC loads		YES	YES	NO
Induction loads?		YES	NO	NO
Required array power	W	3549	3549	2839
Required array area	sq m	35	35	28
Required battery storage	kWh	47	47	38
Total installed cost	R	101677	94014	72355
Annual O&M cost	R/year	1619	1619	1295
O&M present value	R	22814	22814	18258
Battery type: Tubular cell requiring 1.5 replacements in life cycle.				
Battery replacement costs	R/set	18173	18173	14548
Replacement present value	R	15527	15527	12430
System life-cycle cost	R	140019	132356	103044
Annualised cost/kWh	c/kWh	263	249	194

Some users of power in remote areas are running larger appliances, such as workshop equipment, on diesel generated power. The following two evaluations are of such systems powered by photovoltaics.

Table 6.7 GROOTFONTEIN: DOMESTIC AND WORKSHOP LOADS

Worst-month Insolation	5.23 kWh/m²/day		
Peak load	kVA	10.00	15.00
Daily consumption	kWh/day	68.98	85.23
AC loads?		YES	YES
Induction loads?		YES	YES
Required array power	W	23651	29223
Required array area	sq m	235	290
Required battery storage	kWh	315	390
Total installed cost	R	618087	766276
Annual O&M cost	R/year	10775	13313
O&M present value	R	151863	187630
Battery type: Tubular cell requiring 1.5 replacements in life cycle.			
Battery replacement costs	R/set	120849	149307
Replacement present value	R	103256	127571
System life-cycle cost	R	873206	1081477
Annualised cost/kWh	**c/kWh**	246	247

6.4.1 Sensitivity Analyses

Having evaluated a number of systems, and seen that the unit cost of power does not vary all that significantly with size of system, it would be of value to investigate the sensitivity of the unit cost to other parameters. The following are the basic parameters of the system used for the analyses.

Table 6.8 GROOTFONTEIN: SMALL DOMESTIC LOAD

Insolation	5.23 kWh/sq m/day
Peak load	4.00 kVA
Daily consumption	10.35 kWh/day
AC loads	YES
Induction loads?	YES
Required array power	3549 W
Required array area	35 sq m
Required batt. storage	47 kWh
Battery type	Tubular cell

The independent variable in the sensitivity analysis plots is taken in most cases as the cost per peak Watt of the solar modules. The range is roughly from the present price of R20/Wp down to the targeted level of R2/Wp (US$1/Wp).

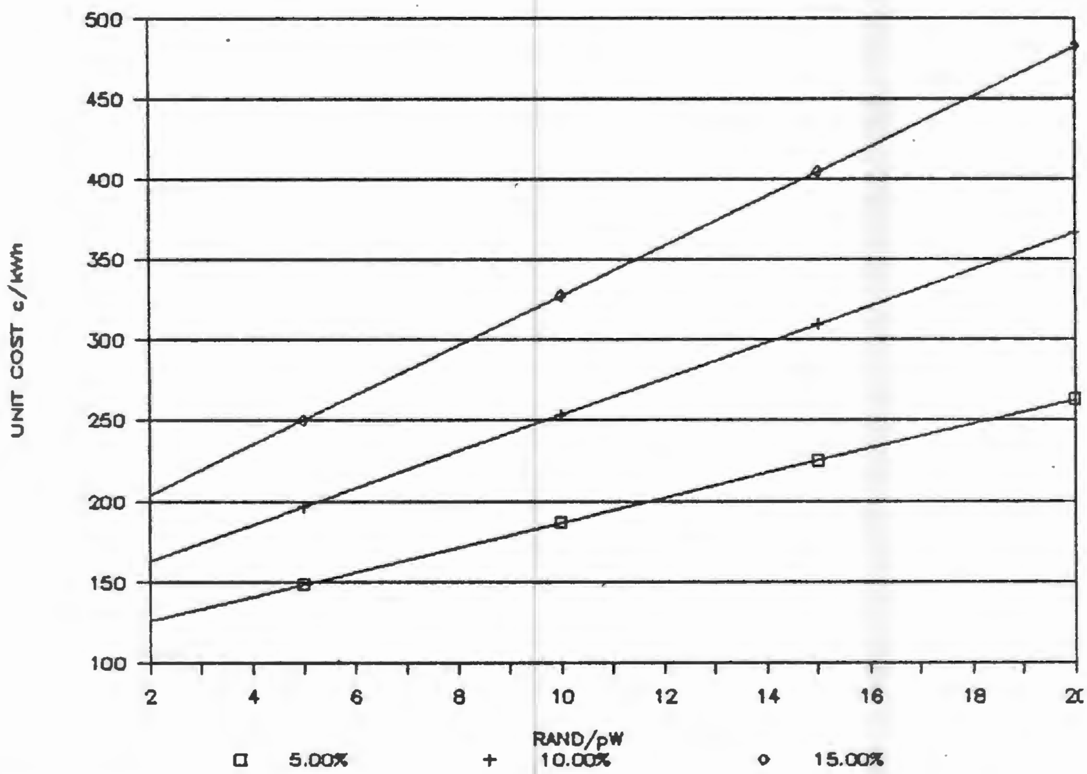


Figure 6.7

The first parameter to be investigated is the discount rate. As would be expected with any project requiring large amounts of capital early in its life, the discount rate has a significant effect on the unit cost of power as is shown in Figure 6.7

Because of the newness of photovoltaic technology, there are no reliable data on the expected life of solar modules. However, manufacturers claim that a life of 25 years will be easily achievable. At present module costs, the selected system life does have an effect on the final unit cost of power, although this will diminish with a reduction in the module cost, as is shown in Figure 6.8.

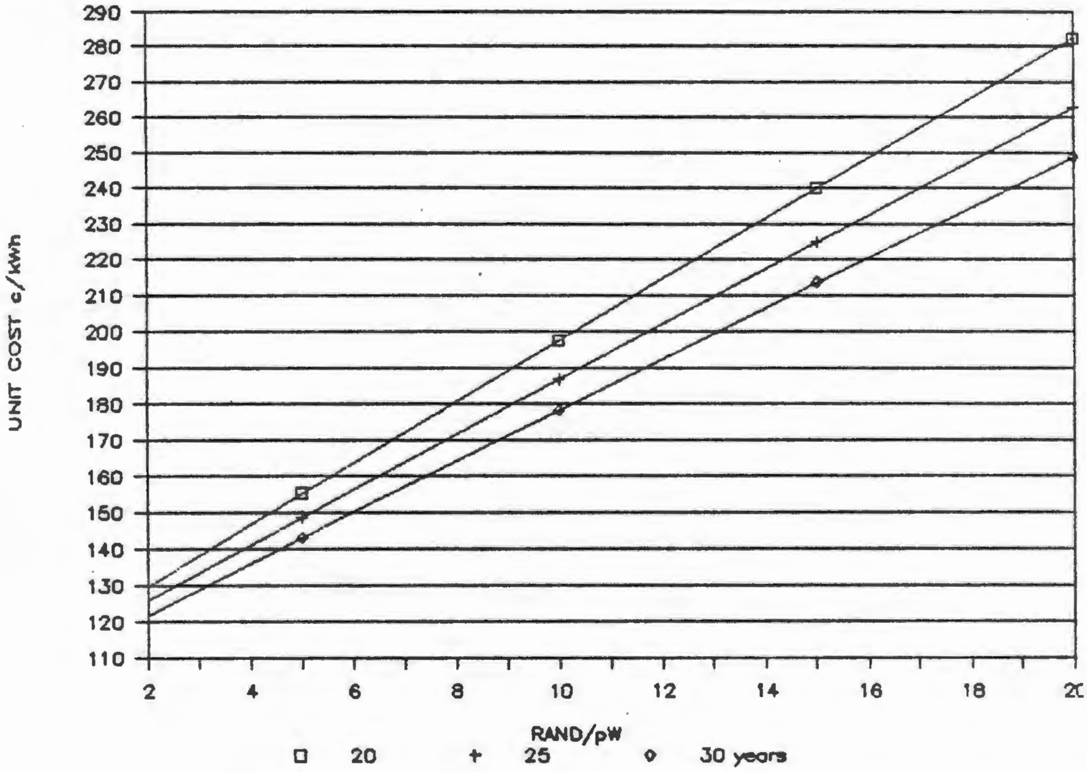


Figure 6.8

As was mentioned earlier batteries are central to the operation of PV power systems, in ensuring a continuously available reliable source of power. Their correct specification is therefore crucial to the efficient running of a system both from the technical and economic points of view. Figure 6.9 overleaf gives an indication of the effect of battery choice on the unit cost of power. The battery lives used in this analyses are as given by the manufacturers and are 10, 10 and 2 years for Tubular cell, Traction and Automotive batteries respectively. More details on batteries can be found in Chapter Ten.

CHAPTER SEVEN

WIND POWER GENERATION

Wind was one of the earliest commercially exploited renewable energy resources, and wind power systems used today are the product of centuries of trial and error experimentation which began with the ancient Persians. The first use of wind to generate electricity is recorded to have taken place in Denmark in the late 1800s (SEIA, 1986). Similar experimentation began in the USA after World War 1. Famous names in early wind electric systems, most of which began producing equipment in the 1930s or 40s, were Jacobs and Winco in the USA and Dunlite in Australia.

Jacobs in particular was able to capture a large portion of the market with their DC machines, and were still being produced right up until 1960. Their turbines were small, ranging from 1,8 - 3 kW, and the company sold a number of DC appliances along with them. A good number of these turbines were sold in South Africa, and there are still a few in operation.

7.1 CURRENT WIND POWER TECHNOLOGY

The 1973 oil crisis revived interest in wind energy as a source of electricity for the commercial market, and a number of developers sprang up, especially in the USA, Denmark and the Netherlands. Some of the basic design choices which have faced these developers will be discussd here.

7.1.1 Blade Configurations and Materials

The first choice faced is that of placing the turbine in the horizontal or vertical axis. Most of the vertical axis designs can be disregarded as being non-competitive for most markets. Remaining for discussion therefore are the "egg-beater" Darrieus vertical axis and the propellor horizontal axis systems. There are advantages to both types of turbine, and they are both being produced commercially, although the horizontal-axis configuration dominates the market.

Another issue which has occupied a great deal of debate in wind energy discussions is the number of blades that should be used. In the horizontal-axis regime, proponents have long argued for the inherent stability of the three-bladed machine. Commercially available machines up to 20 kW in size would seem to bare this out. However as the size increases it would appear that the added penalty in mass of the third blade has resulted in twin-bladed machines being the most popular.

The choice of blade material is another area of diversity in the many machines already available on the international market. The materials found include wood, aluminium, fibregalss and composites. All have their inherent strengths and weaknesses. In the smaller end of the market, wood seems to hold the edge, given its low cost and light weight, and the ease with which it can be shaped. This last point is of particular importance in horizontal-axis machines, where the aerofoil shape is of vital importance.

7.1.2 Blade Pitch Control

The aerodynamic efficiency of a wind system is greatly affected by the pitch of its blades. The optimum angle of attack, for horizontal-axis turbines changes with the speed of the wind and turbine, thus making variable-pitch machines more efficient than fixed pitch systems. In addition to maximising system efficiency, controlling blade pitch can be an important method for avoiding turbine overspeeding.

For the above reasons, designers have often sought to provide some means of varying pitch. Because of the obvious increased complexity of such a system, with its concomitant reduced reliability, a number of ingenious approaches have been devised, especially as regards small wind electric systems. These include the use of flexible blades such that the wind itself makes them pitch, and the use of counterweights mounted along the blade to make them pitch due to centrifugal force. In general however, small systems use fixed pitch blades.

7.1.3 Downwind or Upwind

Although this was the source of much debate in the past, it now appears that both configurations are equally workable. Very small systems are however, uniformly upwind in design, owing to the fact that the tail vane provides a yaw (movement in the horizontal plane) system of unequalled simplicty and cost. As the system size increases, however, the cost of materials reduces this advantage, and downwind designs become more common. Downwind systems must contend with the problem of "tower-shadow", which produces a wind speed variation whenever the blade passes the tower. This can result in stress problems in the blade, and requires careful design.

7.1.4 Generator Options

Converting the wind, a highly variable energy source, into a steady source of power is a fundamental problem which has been faced by all wind turbine manufacturers. This is of particular concern to small machine manufacturers, as the cost of the generator and electrical equipment as a fraction of the overal cost drop rapidly as the machine size increases.

Wind machines can use either AC or DC generators. DC generators are rugged and efficient and can be self-exciting. In addition DC generators are identical to DC machines and can therefore be checked easily by connecting them to a power source and running them as a motor. This is particularly useful when they are being used in remote locations. On the negative side, DC generators are more expensive, because of their higher copper content and being more difficult to manufacture. In addition, they make use of brushes which have to be replaced occasionally, and can be the source of problems. AC generators include alternators and induction generators, and most require some external source of power for starting. In smaller systems using AC generators, the current produced is often rectified for use as a battery charging power source.

In the past, all small wind electric systems had DC generators, and were used to charge batteries and power DC appliances. Today, however, systems connected to the grid or other sources of power are much more popular, thus requiring more sophisticated electronic equipment to convert the wind's variable energy into utility-grade electric power i.e. constant frequency AC. In the case of small wind electric systems the use of pitch control mechanisms to achieve this is prohibitive, and thus other methods are used. One common approach is the use of synchronous inverters, while the development of the field modulated generator has been something of a breakthrough in this field. This generator allows the turbine to operate at varying speeds while producing constant frequency current through the use of electronic compensation.

Direct drive generators are available up to 4,5 kW capacity. Although modern gearboxes are reliable devices, they are best avoided if possible, as they represent an extra source of failure, and are another item requiring maintenance. Where a gearbox is required they are usually pinion and gear assemblies.

7.1.5 Wind Machine Performance

The overall efficiency of a wind turbine depends mainly on its aerodynamic characteristics, the mechanical efficiency of the transmission system, and the matching of the turbine characteristics to those of the generator. Although some differences occur in overall efficiencies, some general assumptions can be made.

The power output of a wind machine increases in proportion to the swept area i.e. diameter of the turbine. The number of blades has no significant effect on the power output, but is relevant to other design characteristics, such as rotational speed and starting characteristics. It should also be borne in mind that a wind machine does not comply strictly with the cubic relationship between wind velocity and power, and furthermore, its efficiency is also a function of wind speed.

The operating wind speeds of a turbine indicate the range over which it will produce useful energy. The turbine starts rotating at the so-called "cut-in" wind speed with its power increasing with the speed of the wind up to the "rated" wind speed, at which point the maximum power output is obtained. The turbine may function at wind speeds above this up to the "cut-out" wind speed, at which point it will be stopped automatically, either by feathering of the blades or a mechanical brake.

7.2 WIND ENERGY POTENTIAL IN SOUTH AFRICA

For a freely moving stream of air with cross-sectional area A, the amount of power associated with it is equal to the product of this times the velocity of the wind stream times its kinetic energy per

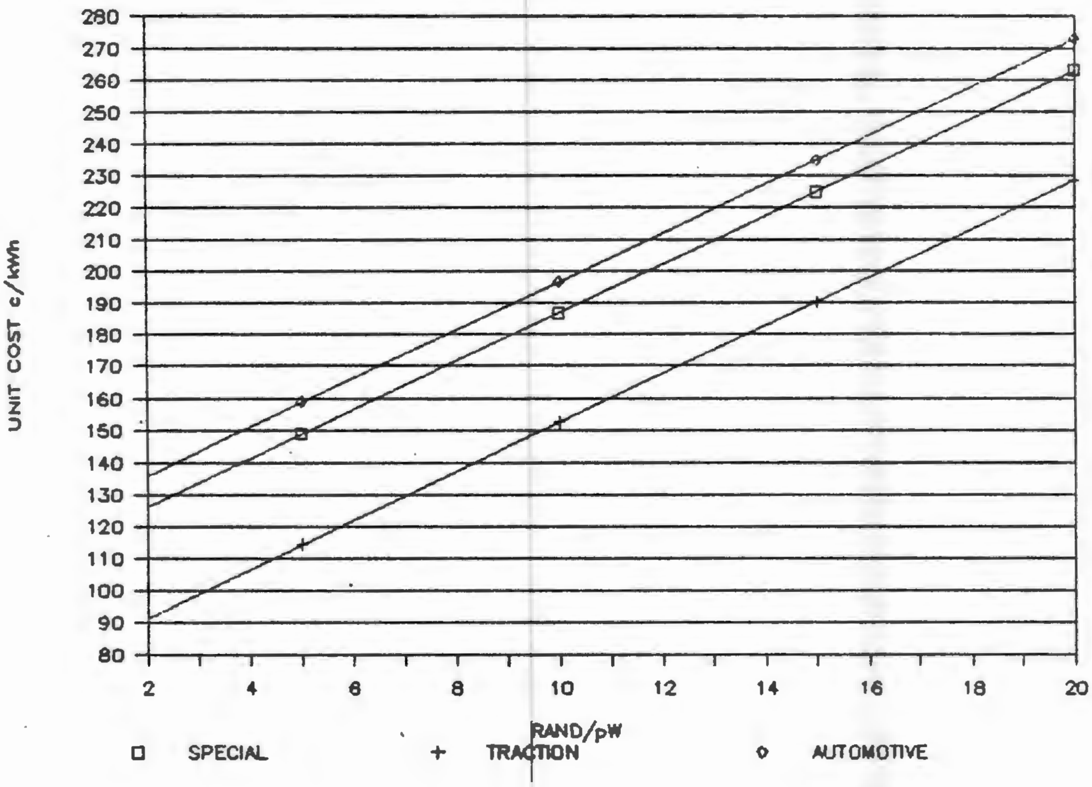


Figure 6.9

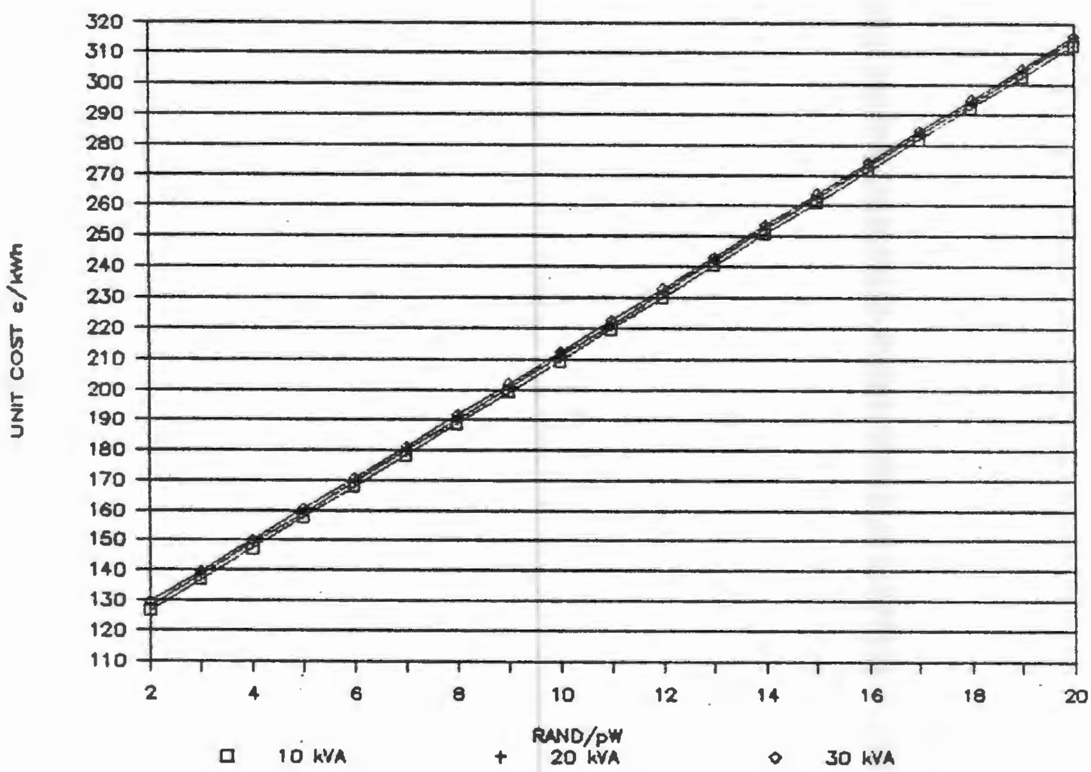


Figure 6.10

As was mentioned earlier, the peak demand has very little effect on the unit cost of power at a specific site. Figure 6.10 bears this out. This can be attributed largely to the fact that PV power systems are modular in nature. Thus as the power demand increases, all that is required is to add as many solar modules to the array, and lead-acid cells to the battery bank as may be required to meet the increase. This is one of the major advantages of using PV power generation in remote areas, where development may result in power demand increasing over the years. The power system is thus easily expanded to meet the new requirements.

6.5 CONCLUSION

The following tables are a summary of the costs reported elsewhere in this chapter. To allow comparison with the diesel systems, these have been named using the same nomenclature as was used in the conclusion to Chapter Five.

Table 6.9 COMPARISON OF VARIOUS SITES - ALL AC, BASED ON DOMESTIC 3

		BFN	CTA	GFN	PLZ
Insolation	[kWh/m²/day]	5.87	3.93	5.23	4.47
Required array power	[W]	3047	4825	3549	4250
Required batt. storage	[kWh]	37	85	47	66
System life-cycle cost	[R]	118687	206338	140019	173867
Annualised cost/kWh	**[c/kWh]**	223	388	263	327

		NEL	PTA	WHK	UPN
Insolation	[kWh/m²/day]	4.71	6.00	6.00	4.83
Required array power	[W]	4012	2952	2952	3896
Required batt. storage	[kWh]	59	36	36	56
System life-cycle cost	[R]	161746	114856	114856	156085
Annualised cost/kWh	**[c/kWh]**	304	216	216	293

The above table gives a good indication of the effects of solar radiation levels on the unit cost of power from photovoltaic systems.

Table 6.10 GROOTFONTEIN: SMALL DOMESTIC LOADS - ALL AC

Worst-month Insolation	5.23 kWh/m²/day			
DOMESTIC		1	2	3
Peak load	kVA	2.50	3.50	4.00
Daily consumption	kWh/day	11.50	14.75	10.35
Required array power	W	3943	5057	3549
Required array area	sq m	39	50	35
Required battery storage	kWh	53	67	47
System life-cycle cost	R	150737	193077	140019
Annualised cost/kWh	**c/kWh**	255	254	263

Table 6.11 WINDHOEK: SMALL DOMESTIC LOAD - AC

Worst-month Insolation	6.00 kWh/m²/day	
DOMESTIC		3
Peak load	kVA	4.00
Daily consumption	kWh/day	10.35
Required array power	W	2952
Required array area	sq m	29
Required battery storage	kWh	36
System life-cycle cost	R	114856
Annualised cost/kWh	**c/kWh**	216

Table 6.12 GROOTFONTEIN: SMALL DOMESTIC LOAD - COMPARISON AC/DC

Worst-month Insolation	5.23 kWh/m²/day			
DOMESTIC		3		
Peak load	kVA	4.00		
Daily consumption	kWh/day	10.35		
AC loads		YES	YES	NO
Induction loads?		YES	NO	NO
Required array power	W	3549	3549	2839
Required array area	sq m	35	35	28
Required battery storage	kWh	47	47	38
System life-cycle cost	R	140019	132356	103044
Annualised cost/kWh	**c/kWh**	263	249	194

Table 6.13 GROOTFONTEIN: DOMESTIC AND WORKSHOP LOADS - ALL AC

Worst-month Insolation	5.23 kWh/m²/day		
DOM & WKSHP		1	2
Peak load	kVA	10.00	15.00
Daily consumption	kWh/day	68.98	85.23
System life-cycle cost	R	873206	1081477
Annualised cost/kWh	**c/kWh**	246	247

Although PV power is still an expensive option when compared to other remote area power supply options, it has already begun to be used in areas which are difficult to access for maintenance or refuelling purposes. A list of the current state users of PV power are given in Appendix E.

The potential for PV use is conceivably substantial in those areas where people currently have no power. In these areas it could be used very effectively to provide the minimum in terms of lighting and possibly communication in the form of audio-visual equipment. These systems would of course be DC and thus eliminate the need for expensive inverters. Table 6.12 gives a good indication of the reduction in unit power cost if this piece of equipment can be excluded.

Even such limited use of the technology can be expensive under present circumstances, and it would be worthwhile investigating the development of lower cost components, especially for power conditioning and energy storage. In Colombia, for example, modified automotive batteries, with consequently longer service lives, and low cost charging equipment have been successfully developed by local entrepeneurs.

unit volume. Wind power density, P, is defined as the power per unit cross-sectional area of the windstream, and is given by:

$$P = 0,5 * p * u^3$$

Where:
p = density of the air
u = velocity of the windstream

From the above it can be seen that given the cube power dependency of extractable wind power on wind speed, it is clearly the variability of wind speed that is of importance in determining available wind power.

7.2.1 Climatological Effects on Wind Power

South Africa is located astride the subtropical high pressure belt which is centred on average at 30°S (Diab, 1986b). The high pressure systems in this belt do not give rise to much kinetic energy in the atmosphere. To the south of 30°S, lies the westerly wind belt within which occur the travelling weather systems. These systems move from west to east mainly along the coast, penetrating further into the interior in the winter than in the summer. Winds in these mid-latitudes can be strong, particularly to the rear of a cyclone or cold front.

7.2.2 Local Effects on Wind Power

In areas with apparently low wind power, certain topographical features can as much as double the wind speed, giving an eightfold increase in wind power. On the other hand, good wind potential can be marred by the interference of topographical and other obstructions, such as buildings and trees. In flat countryside, a fairly good estimate of the wind potential can be obtained by looking at the data from the nearest weather station. However, if the countryside is hilly, it is nearly impossible to estimate the available wind energy.

The large scale motion associated with the high and low pressure systems provides the framework within which the smaller scale circulations occur. Solar heating and topographical features give rise to local circulations which are generally light, but should by no means be discounted as a source of energy. The Energy Research Institute is currently investigating topographical effects in wind enhancement in the Cape Agulhas region.

7.2.2 Wind Resource Surveys in South Africa

Evaluation of the data measured by the S.A. Weather Bureau at various weather stations has been carried out (Diab, 1979). All indications are that the coastal regions of the country generally experience the highest wind speeds, but that there are also isolated pockets of strong wind potential in the interior. This report is somewhat misleading in its findings, as it was reliant on very few recording stations, with a poor spatial distribution over the country.

A more detailed regional study carried out over KwaZulu and Natal (Diab, 1986a), making use of data other than that purely obtainable from recording stations, has revealed greater potential than was first thought. It is also apparent from the widespread use of windpumps throughout the country that there is definitely a greater potential for wind power generation than published surveys would lead one to believe. However, the assessment of the true potential of the wind resource would necessitate more detailed measurement. This monitoring would be guided by the existing baseline data, and a thorough study of the local features which could enhance prevailing wind speeds in a particular region.

To assess the wind energy potential some experts recommend measuring the wind resource at a potential site for five years, while others feel that three years will be sufficient. The degree of accuracy required is a function of the investment being made i.e. a 50% error in estimation will have far greater implications if a 100 kW machine to supply a small town is being installed as compared to a 1 kW machine to supply power for a holiday home.

It should be borne in mind, however, that records taken over short periods e.g. a year can be off ± 30% from long-term averages. For this reason measurements should be compared with data from the nearest weather station. By comparing in this way it is possible to increase the degree of confidence in data collected over a short period. However, the less that is known about the actual wind conditions at a site, the more that is left to chance when installing a system. Nielsen (1978) is a good guide to wind power estimation techniques, while Diab (1986a) has documented some useful biological indicators which can be used to determine local wind resource potential.

To conclude, the following maps show the wind energy potential in South Africa as far as it has been assessed to date. Some areas of high potential have been defined, however, the data should be further refined through the carrying out of more detailed studies. These studies would initially be along the lines of those done on a regional basis covering Natal and KwaZulu (Diab, 1986a). These studies should also focus on the areas identified as likely to remain "off-grid" e.g. the Eastern Cape, Transkei and Karoo.

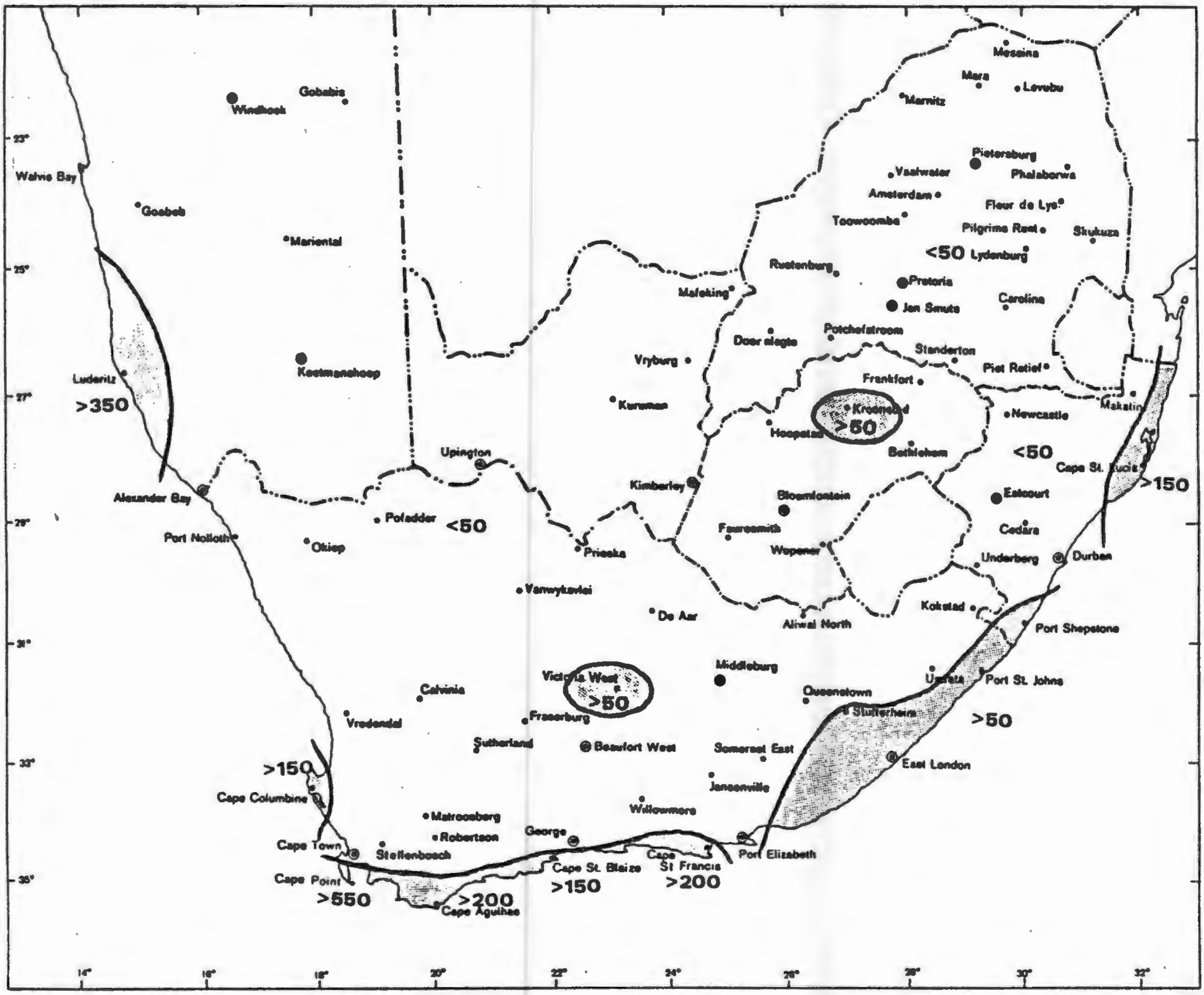


Figure 7.1 Mean Annual Power [W/m²] at 10 m. (Diab, 1979)

7.3 THE COST OF WIND POWER

The cost of wind power is governed by a number of considerations. Firstly, power will only be available inasmuch as the generator is able to extract it from the wind. If the supply of and demand for power are not well matched there will be times of shortfall and others of excess. In times of shortfall the consumer must either do without power, draw from energy stored during times of excess, or make use of some backup system such as a diesel genset. The economics of wind power are obviously dependent on the system chosen. As with all self-generation systems, as a general rule, the cost increases in direct proportion to the increase in reliability of the system.

To carry out an economic analysis of a wind generation system, apart from reliable wind data, the following data are required:

Total installed cost,
Annual operation and maintenance costs,
Expected system life, and
Total power production over the system life.

Some work in this field has already been done for South African conditions, looking at the performance of a number of wind turbines at nine sites for which long-term wind data are available (Roberts, 1984).

7.3.1 Capital and Installation Costs of Equipment

Although one company has locally developed and marketed a small wind turbine known as the Aerogen, it has not proved successful, and is no longer available. Prices for the two sizes available in 1985 were for the 1 kW machine, R2 450 and the 3 kW machine, R5 500 (pers. comm., Semiconductor Services). Thus as there are currently no locally manufactured reliable wind generators available in South Africa, costs will all be based on the price of imported machines. An analysis of the capital cost of wind generators shows that the cost per kW drops fairly rapidly as the capacity of the machine increases, as is shown in the following figure (SEIA, 1985), (Roberts, 1984).

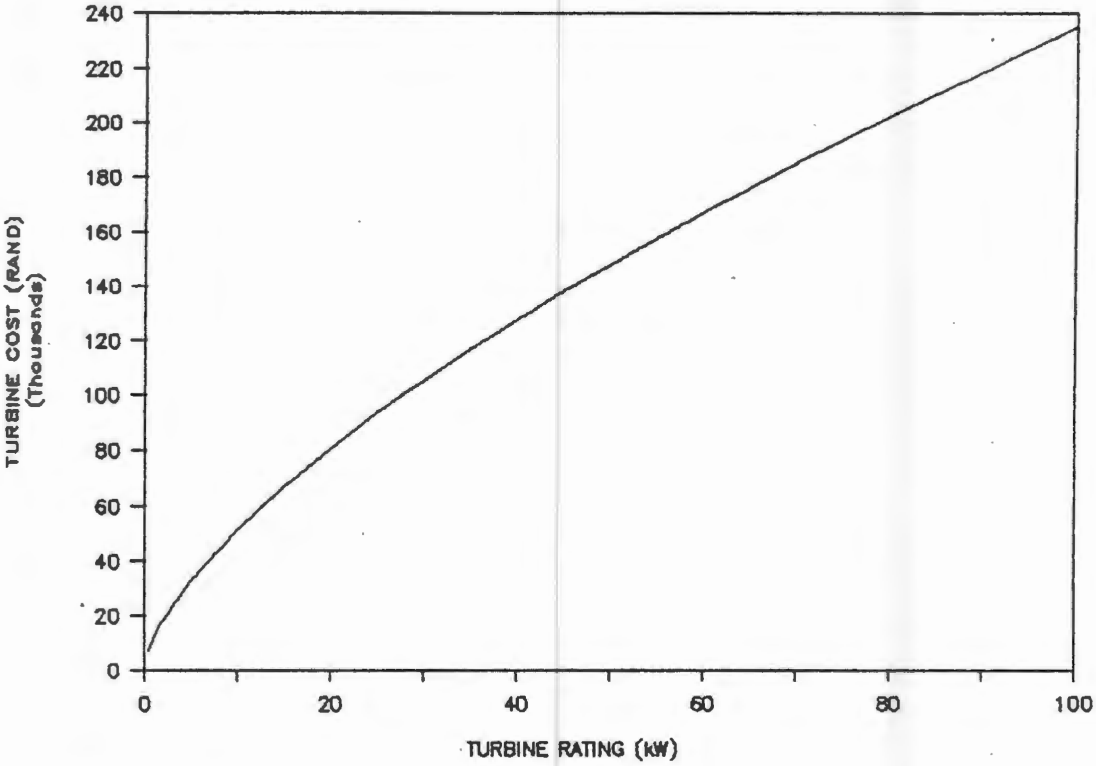


Figure 7.2

Historically, the wind electric power business began with small turbines and estimates are that 16 000 turbines of under one kilowatt rated capacity have been sold worldwide. More recently, however, interest has moved to larger machines. A survey conducted in the USA in 1985 by the American Wind Energy Industry Association (SEIA, 1985) revealed an average 1984 fob price for machines in the 1 - 5 kW range of $2 085/kW, while the installed cost/kW was given as $4 126.

Turning to the next segment of the market, the 6 - 19 kW range, it is apparent that not much demand exists for machines in this range, the 1984 fob price was $1 233/kW and the installed cost/kW, $2 242. Manufacturers predicted that their factory price would drop 20% by 1987 and then remain constant i.e. the price/kW would drop by the rate of inflation from 1985 through to 1990, giving an installed cost in 1987 of $1 664/kW.

The most active area of the wind machine market in terms of equipment development, price trends and sales has been the 20 - 74 kW segment. The average fob cost/kW in 1984 was $965 with the installed cost/kW at $1 622. Finally, in the medium-sized turbine segment i.e. 75 - 100 kW market growth with the development of windfarms in the USA has been explosive. The average fob cost/kW was $830 in 1984 with the installed cost/kW at $1 188. Figure 7.3 gives a summary of all the above data (SEIA, 1985).

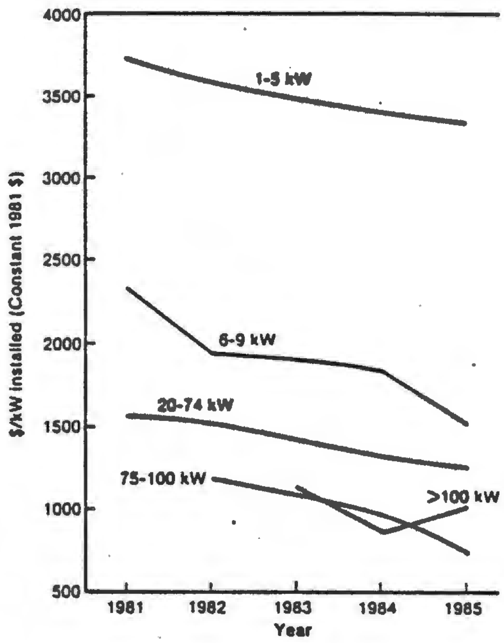


Figure 7.3

The costs in this report will be based on the 1984 prices.

7.3.2 Reliability, Operation and Maintenance

Given the expense of installing wind generating capacity, especially in the lower capacity range, reliability is important, as on-line time has a great effect on the pay back of the system. With this in mind, a study was carried out in the USA to gauge the system reliability and performance of a number of small wind generators in the 1,5 - 20 kW range (SEIA, 1985). Twelve machines were operated over an extended period with an availability of 78,5%. The proven makes such as Jacobs and Bergey had availabilities in the high 90%s. More recent studies have shown that most of the better medium-sized turbines are available for well over 90% of the time, and operation and maintenance costs for these machines are from 1 - 1,5 USc/kWh (SEIA, 1985).

7.3.3 Expected System Life

Wind turbines have been installed in Antarctica and have operated for over 20 years, while others installed elsewhere have been destroyed in a few months. Old windchargers installed in the 1930s have operated for in excess of 40 years provided they have been well maintained. A survey of the literature has revealed that wind system designers have in general planned their equipment for useful lifetimes of longer than 20 years. Admittedly, bearings, belts and some other small parts may have to be replaced during this time, but the basic machinery, if well designed, can be expected to last for at least this period. A lifespan of 25 years will therefore be used in this analysis.

7.3.4 Annual Power Production

The most accurate indication of the power generated by a wind generator in a year would obviously be obtained by using actual wind speed time series data for the site in question. However, as these data are not always easily available, and especially not for the remote areas being considered in this study, the data available from S.A. Weather Bureau (SAWB) stations were used by Roberts (1984). In his analysis of wind-powered generation at the three most favourable SAWB sites he obtained the following results for two turbines rated at 15 and 15,7 kW respectively:

Table 7.1 Wind Power Outputs and Capacity Factors at various sites

	Output (kWh/yr)		Capacity Factor	
	15 kW	15.7 kW	15 kW	15.7 kW
Cape Town	20176.00	24458.00	0.15	0.18
Port Elizabeth	19920.00	25545.00	0.15	0.19
Alexander Bay	19984.00	25137.00	0.18	0.18
Average	20026.67	25046.67	0.16	0.18

Capacity factor is here taken as the following ratio:

$$\frac{\text{Actual kWh Output in one year}}{(\text{Turbine kW Rating})*8760\text{ hours}}$$

The above figures were used as guides as to the capacity factors that could be reasonably expected in wind regimes around South Africa.

As the demand for power may at times exceed the available power, storage of excess power generated at times of low demand has been included in the calculation of unit power costs. The systems examined in this report are based on the principle that all power generated is passed through the power conditioning and storage equipment, i.e. voltage regulator, batteries and inverter.

7.3.5 The Cost of Wind-generated Power in South Africa

Simple system sizing techniques, such as were used in the costing of PV generated power, are not available for wind power systems. This is a consequence of the more complex relationship that exists between the wind resource and the power extracting turbine. The following analyses are therefore more concerned with the sensitivity of wind-generated power costs to various parameters. The following are the basic system parameters and cost data used for these analyses.

Certain factors are present in the parameters, all of which err on the conservative side to ensure that wind-generated power is not given an advantage over other power sources. The two most important factors are firstly the assumption that the required turbine power is twice the peak demand, and secondly, that the turbine cost function yields a figure which accurately reflects the cost of importing, transporting and installing a turbine.

Table 7.2 SYSTEM CHARACTERISTICS AND COST DATA

System life	25 years
Discount rate (real)	5.00%
Escalation rate (real)	0.00%
WIND TURBINE	
Turbine cost installed (Rand)	$e^{(0.88 * \ln(kW) + 8.31)}$[2]
O&M cost	1.00% of cap. cost
VOLTAGE REGULATOR	
Voltage regulator efficiency	95.00%
BATTERIES	
Battery efficiency	90.00%
Depth of discharge	50.00%
Battery type	Tubular Cell
Battery life	10.00 years
O&M cost	1.00% of cap. cost

---

[2]This is based on data from SEIA (1985) and Roberts (1984) as shown in Figure 7.2.

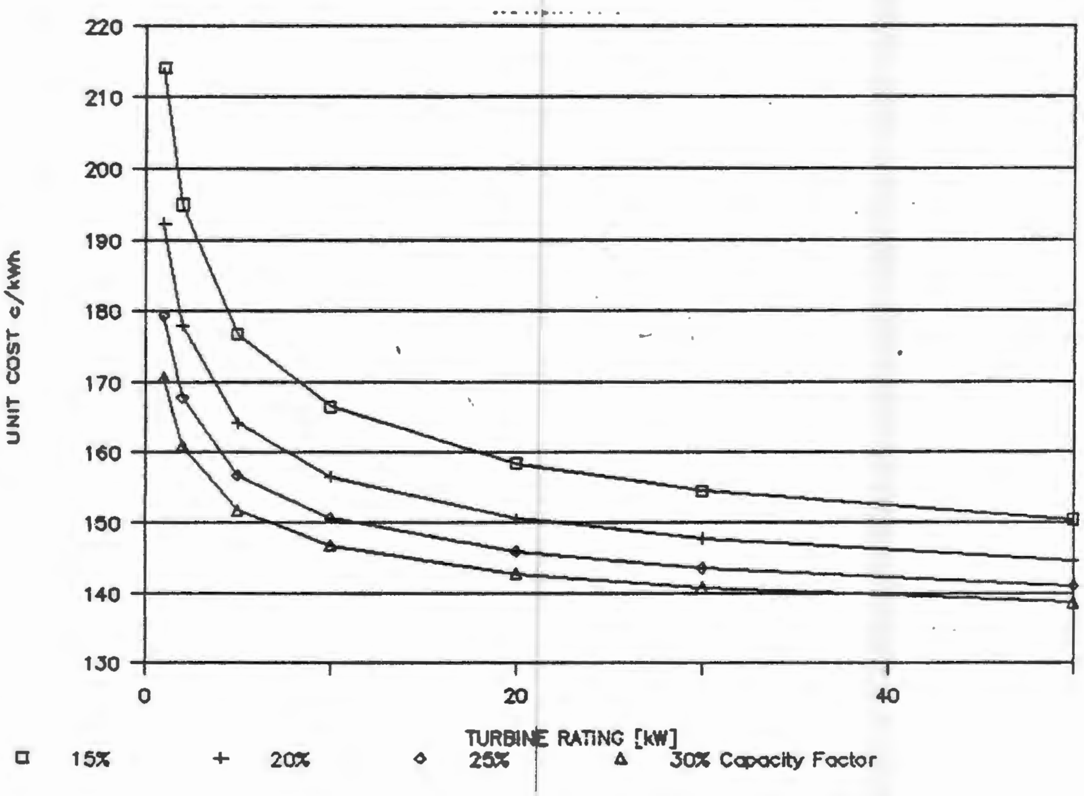
INVERTER

Invertor efficiency	80.00%

SYSTEM DESIGN DATA

Peak load	10.00 kVA
Required turbine power	20.00 kW
Capacity Factor	18.00%
Daily consumption	86.40 kWh/day
Power produced	31536.00 kWh/year
System autonomy i.e. Battery storage	3.00 DAYS
Required battery storage	648 kWh
AC loads?	YES
Induction loads?	YES

The above data were used as the basis for the sensitivity analyses which follow. The first parameter to be investigated is the turbine capacity factor. As explained earlier this is a function of the wind available at a site i.e. the turbine's ability to use the wind to generate power. This will obviously affect the economics of a wind power system, given the high capital input represented by the turbine.



As was the case with PV systems, because of the high initial capital input, the discount rate chosen will also have a significant impact on the unit cost of wind-generated power, as is evidenced by the following figure.

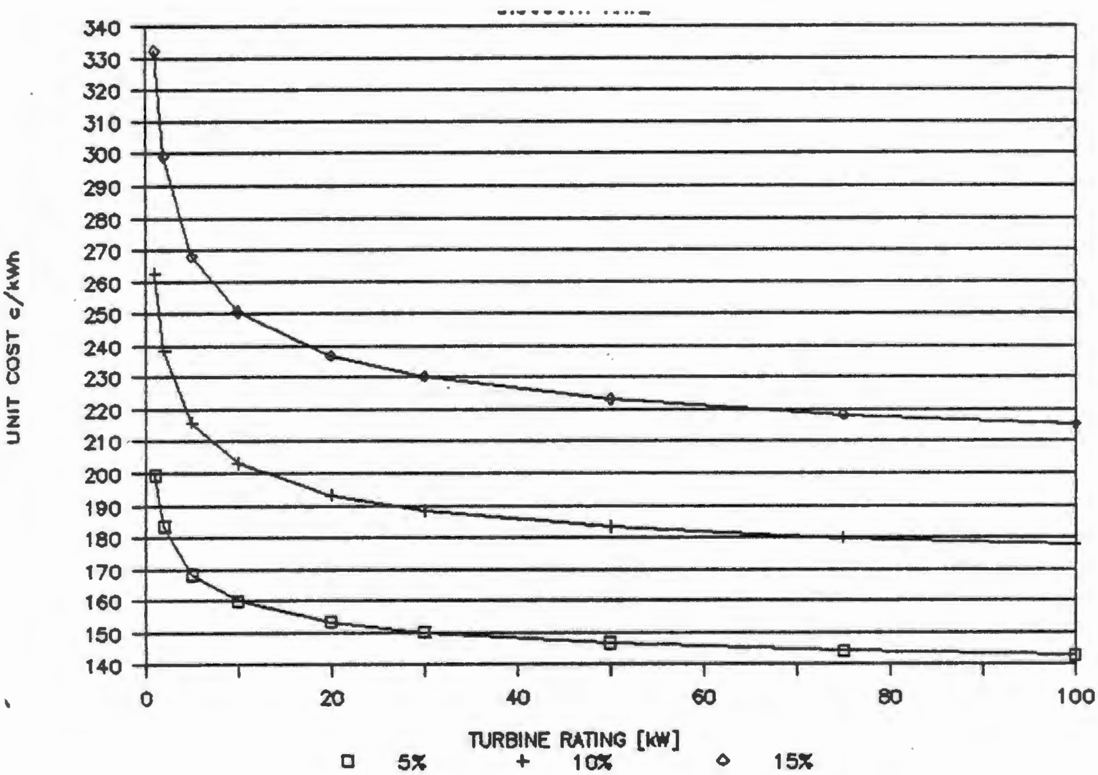
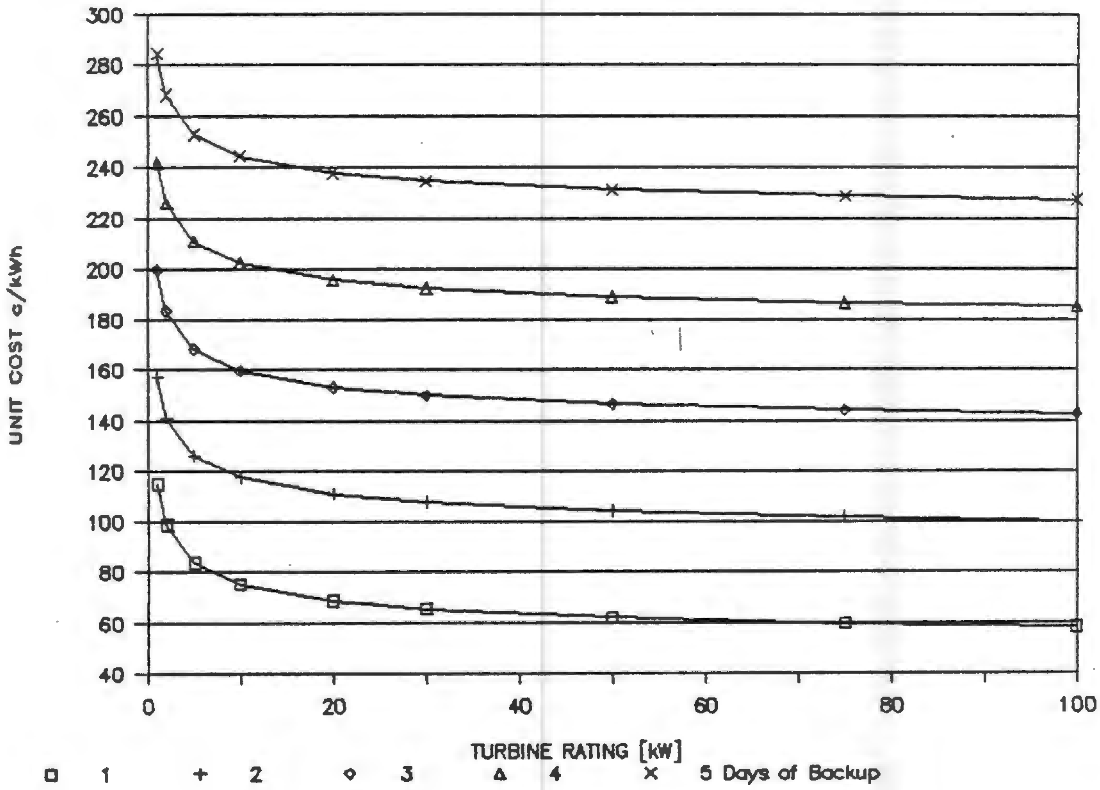


Figure 7.5

With power demand seldom being perfectly matched to available wind-generated power, energy storage plays a significant role in wind power systems. Depending on the projected wind "drought" duration at a particular site, so the number of days of required energy storage will vary. Figure 7.6 gives an indication of how an increase in battery capacity will affect the unit cost of power.


UNIT COST c/kWh
TURBINE RATING [kW]
1
2
3
4
5 Days of Backup

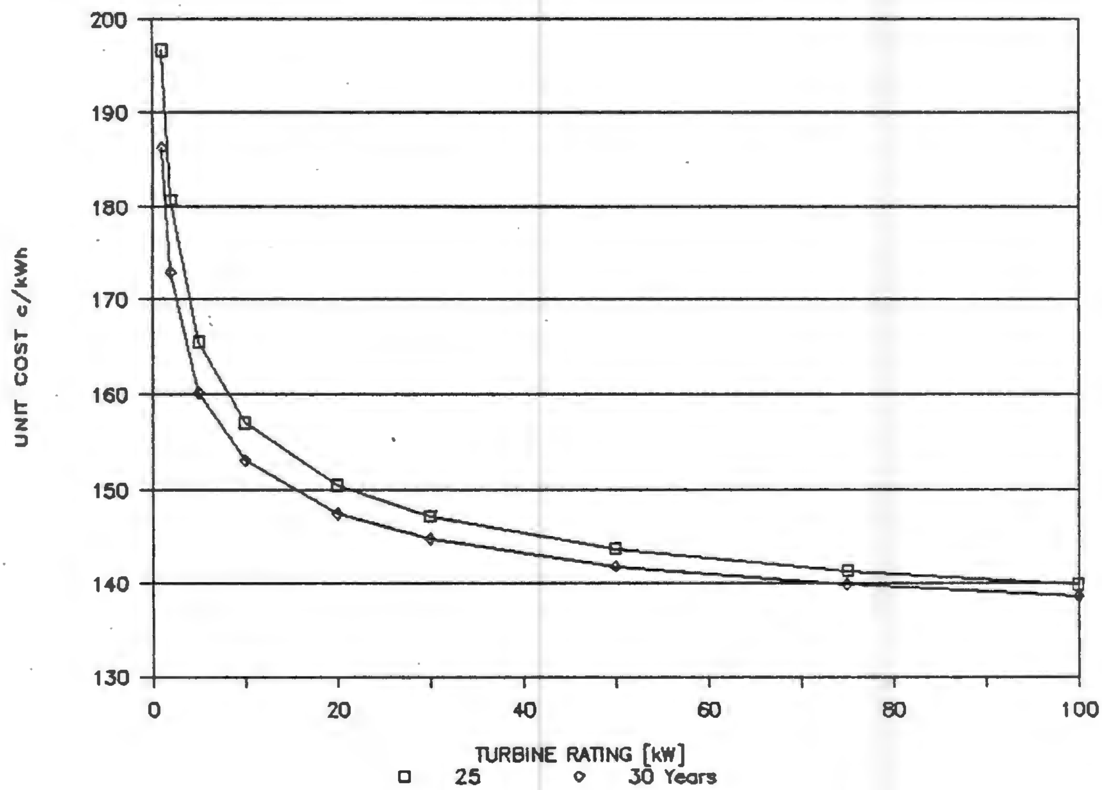

UNIT COST c/kWh
TURBINE RATING [kW]
25
30 Years

Figure 7.7 on the previous page shows the effect of an increase in turbine service life on the unit cost of power. As would be expected there is some reduction, although not all that significant.

Figure 7.8 gives a component breakdown of the unit cost of power.

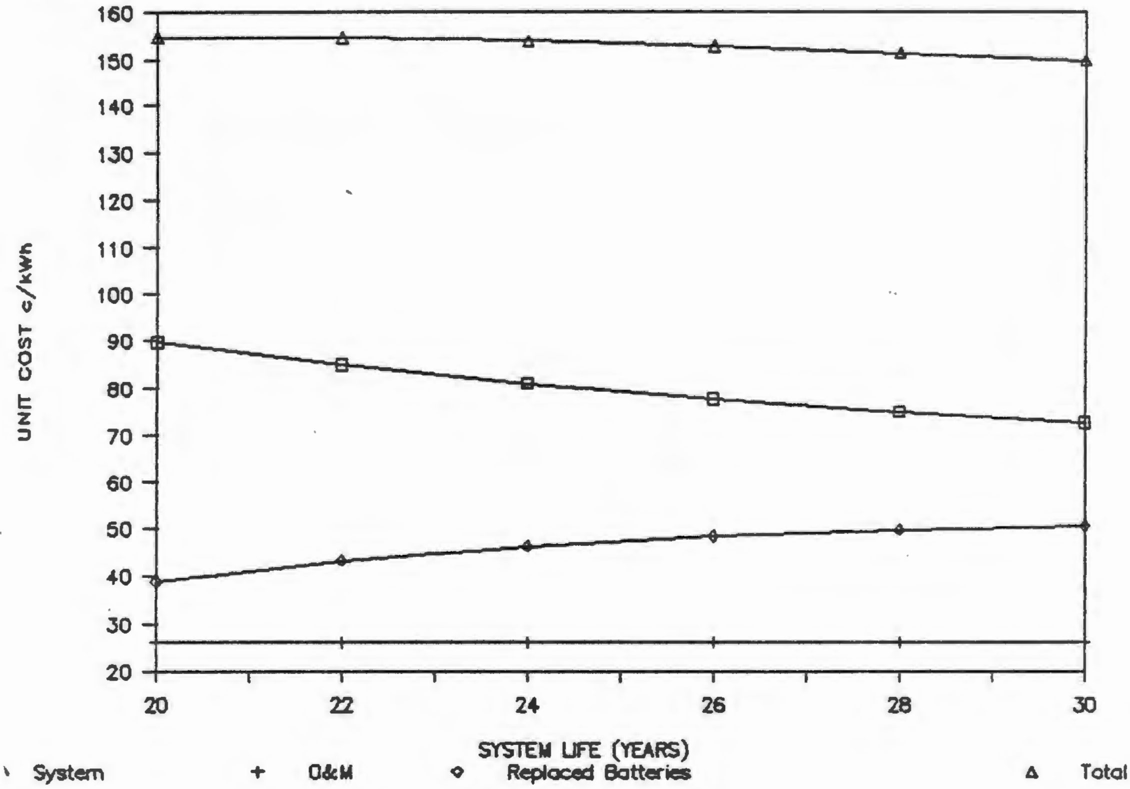


Figure 7.8

Finally, the following table allows comparison with Table 6.7 in the previous chapter. The load characteristics are similar to those described in Table 6.7 while the turbine capacity factors chosen are within the bounds of possibility for a site in South Africa. It is of interest to note that the battery storage capacity is nearly twice that specified in the PV systems. Analysis has shown that each day of battery storage adds ±40c to the unit cost of power.

Table 7.3 Hypothetical Wind-powered Systems

Peak load	kVA	10.00	15.00
Daily consumption	kWh/day	67.20	86.40
AC Induction loads?		YES	YES
Required turbine power	kW	20.00	30.00
Capacity Factor	%	14.00	12.00
System autonomy i.e. Battery storage	days	3.00	3.00
Required battery storage	kWh	504	648

Turbine Installed cost	R	80730	105668
Batteries Installed cost	R	193080	248232
Voltage reg and inverter Installed cost	R	23980	32223
Annual O&M cost	R/yr	6600	8504
O&M present value	R	93016	119850
Battery type		Tubular cell	
Battery replacement costs	R	193080	248232
Number of replacements in system life		1.5	1.5
Replacement present value	R	164971	212094
System life-cycle cost		555776	718066
Annualised cost/kWh	c/kWh	161	162

7.4 CONCLUSION

The following table gives a summary of the unit cost in c/kWh of 24-hour power. The effect of turbine capacity factor is evident.

Rating	Capacity Factor		Diesel
kW	15%	30%	
1.00	214.09	170.63	
2.00	195.95	161.05	36.00
5.00	176.68	151.92	30.50
10.00	166.50	146.83	28.20
20.00	158.53	142.84	
30.00	154.68	140.92	22.70
50.00	150.52	138.84	21.11
75.00	147.68	137.42	
100.00	145.89	136.52	17.97

It would appear that wind power may have some potential to supply power in remote areas of South Africa. However, more detailed assessments of the wind regimes prevailing in the remote areas needing power are required before exploitation of this resource can take place. Historical evidence, as shown by the number of windchargers used in the past would indicate that this should be possible for the provision of power for lighting and other low demand appliances. The development of lower cost, locally-produced turbines would also greatly facilitate the use of this resource.

CHAPTER EIGHT

SMALL SCALE HYDROELECTRIC POWER

The climate of Southern Africa is characterised by a steep climatic gradient from the generally wetter eastern coast to the semi-arid and desert regions of the west. The variability of annual rainfall in both time and space increases with increasing aridity. Surface runoff per unit area also falls with increase in aridity due to the combined effects of lowered volume and raised rainfall variability, plus increases in evaporation from land surfaces and vegetation. Typically, river flows vary over a wide range from year to year.

Evaporation losses from stored water are high. The water levels and corresponding surface areas and shorelines of storage reservoirs fluctuate over a wide range, in response to variations in inflow, while the flow regimes of rivers downstream are radically altered, and become dependent on the operating criteria of the impoundments.

In the light of the above, the potential for widespread large-scale use of hydropower in South Africa is obviously limited. However, there are a number of areas and ways in which it could be put to use, to meet the needs of small consumers.

8.1 HYDROPOWER SCHEME CONFIGURATIONS AND TECHNOLOGY

This section gives a brief overview of the various ways in which hydropower schemes can be implemented, especially on a small scale.

8.1.1 Run of River Schemes

Run of river (ROR) schemes make use of the river's flow to drive a water wheel or turbine as it passes, and do not have any significant reservoir, at the most a small head pond providing daily storage. They are of particular interest in the provision of power in remote areas, and have been used extensively in remote areas of China, Nepal, the Phillipines, Papua New Guinea, Indonesia, Colombia and Peru.

If used to drive a generator to provide electrical power to a varying load throughout the day, a true ROR scheme is impractical on all South African rivers, with the exception possibly of irrigation schemes such as the Fish River below the outlet of the Orange-Fish tunnel. In all other cases some form of dam or diversion weir is required to impound the water which can be drawn down during the day, and replenished during the night. Of course it would be preferrable to size such a dam to provide seasonal storage, based on mean river flows and water requirements for power generation.

Even with seasonal storage, when rainfall falls below the mean average, the power plant will obviously be unable to meet the demands made upon it. Thus, unless the scheme is interconnected electrically with another supply with excess generating capacity, it will be necessary to provide some source of "firming" generation capacity from another source, i.e. a hybrid configuration would be needed. This firming capacity would typically be provided by a diesel genset, or possibly some other reliable renewable power source. Provision of this firming power could represent a significant expense. It is therefore important that the sizing of the dam be based on as accurate river flow data as possible.

ROR schemes with impoundments often lend themselves to extension, as and when the demand requires it. This is achieved by cascading the tailwater from one turbine to the inlet of the next. The original storage dam then serves a number of stations and the amortisation of the capital cost of the civil works is spread over them. This is naturally subject to there being sufficient gradient in the river's course. One feature of a cascading scheme is its inherent capacity to meet peak loads. At times excess water will be trapped between the stations, either in the stream bed or canals, thus allowing lower stations to generate more electricity than under constant flow conditions through all stations. This capability can be enhanced through the addition of intermediate small volume reservoirs.

The above installations would typically be in the kilowatt range i.e. from 2 kW upwards. Another demand range however exists in remote areas of this country, where power consumptions in the watt range exist. Power at this level is required for lighting and the operation of a number of small appliances such as clinic refrigerators, audio-visual equipment for education and recreation. This power could easily be supplied in many areas with the harnessing of a small stream, or the flow through a domestic water reticulation system. Such small systems have been designed and produced in Colombia. These make use of a Pelton wheel, a modified automotive alternator and batteries. The batteries are based on standard automotive battery components with a few modifications to ensure longer life and deeper cycle charge and discharge characteristics.

8.1.2 Multi-purpose Schemes

In these schemes, the generation of electricity may not be the prime consideration, and is sometimes more in the nature of a by-product. Their prime purpose is usually to provide some form of equalisation of the flow in a basin, by storing water during the times of high rainfall to allow for its use during the dry periods. Storage capacity is often sufficient to provide for needs in statistically anticipated low rainfall years.

The Orange River scheme is an example of a large-scale multi-purpose scheme, although the amount of electrical energy being produced by the scheme is relatively small. However, because the release of the water to lower riparian users does not have to take place at specific times of the day, it can be released at times to coincide with peak demands on the grid, and thus provide low-cost peak power. The Kouga river irrigation scheme also makes use of some of the water flow for generation of power for use in the Gamtoos valley (Langford and Webb, 1970). The Ox-bow scheme in Lesotho will similarly make use of HEP generation to dissipate the potential energy in the water being released to lower levels.

Extensive irrigation development of South African rivers has already taken place, but little effort has been made to combine these developments with the generation of power. This has resulted from the apparent lack of coordination between Eskom and the Department of Water Affairs. In addition, the Electricity Act requires that Eskom should generate and transmit power at the lowest possible cost. In the case of straight hydro-electric power (HEP) generation, the cost of power generation is higher than that from the eqivalent thermal power station, primarily because of the high civil works cost component. However, if a multi-purpose scheme were to be developed, very little, if any of the civil costs would be borne by the electricity generation component of the scheme. There is also great potential for the use of small ROR schemes which could be installed in the many kilometres of irrigation canals that cross parts of South Africa.

In a study carried out in Australia, a total of 1 248 GWh/yr was identified as being potentially available at existing irrigation and water supply dams (Water Power and Dam Construction, 1987). This study only looked at plant betwen 100 kW and 20 MW, and revealed an estimated cost/kW installed of $620 and $2 860, and the cost/kWh from 0,7 to 5,6 cents. There is no doubt a great deal of potential for installations of smaller capacity.

Related to multi-purpose development of water storage facilities is a development by a US company of the PowerBarge (Broome, 1986). This prefabricated unit is aimed at use on medium-sized rivers with an annual flow of from 28-280 m^3/sec that can be controlled by dams as low as 3,2 m. The unit consists of a fully floating hydroelectric station supported by two barges, one above and the other below the dam. The estimated total capital cost of an installation is estimated to be 20 - 30% lower than that for a conventional system at the same site.

8.1.3 HEP Equipment Selection Criteria

The purpose of this section is to present some criteria for the installer to select equipment for micro hydro plants of up to about 150 kVA. The context is the application of micro scale hydropower for remote rural communities for productive activities (grain milling, workshops, food processing, sawmills, and so on). A brief survey of the criteria used in selecting equipment for micro hydro plants for developing country applications has shown, as would be intuitively expected, that cost and simplicity of operation are critical factors.

In the rural, developing scenario capital cost is generally a severe constraint, and reliability, maintainability and simplicity of operation are paramount. Plant efficiency is important, but within the constraints of what is achievable with the resources available. For example, locally made turbines used in many countries achieve efficiencies in the range of 70 to 80 %. Improving the efficiency through higher cost manufacturing techniques or more elaborate designs is subject to the law of limiting returns.

The capital cost of the installation has to be kept to a level such that the final energy costs are comparable with (and preferably lower than) the immediate alternatives. These will normally be extension of the grid or provision of a diesel generator.

The Intermediate Technology Development Group (ITDG) has been running a series of demonstration micro hydro projects in Nepal, Sri Lanka, Colombia and Peru. These schemes have involved the use of locally made turbines (in some cases after initially using British ones). The objective is to provide power for small processing industries, with a probable additional benefit of providing some domestic electric power. These plants generally aim for load factors of 25 - 40%. Even with these high (for small plants) load factors, there is a severe constraint on the capital cost that can be justified. A typical target cost breakdown would be:

Penstock	30 % of total
Other civil work	20 %
Mechanical and electrical equipment	40 %
Engineering supervision	10 %

Of the target total system cost of US$1000 - US$2000/kVA, $400 - $800 would be for the mechanical and electrical components (not including electrical transmission/distribution). These costs, it should be emphasised, are not unrealistic. There are plenty of examples of reliable and well built micro hydro plants constructed to these cost targets using locally made turbines of acceptable reliability.

Penstock Pipes

There is a wide choice of pipes available, the relative prices of which vary considerably. As mentioned before, pipe costs can made up a third of the total installation cost so it is certainly worth comparing all available possibilities. Handling costs should also be considered. For example, GRP pipe may well be preferable to cheaper ductile iron when the costs of transport to a remote site with difficult access are taken into consideration. In other instances, PVC pipe may be suitable, or steel pipe welded on site.

Turbines

In spite of the wide variation in site conditions, there are possibilities for standardisation of turbine designs. Most micro HEP programmes based on locally made machines specialise in one or two types. Often cross-flow turbines and/or multi-jet Pelton wheels are used, depending on the heads and flow rates normally encountered. These machines offer the possibility of being suitable for a wide range of site conditions and power outputs, particularly as they normally use belt or gearbox drive as speed increasers to extend the useful working head and power range.

Figure 8.1 provides an indication of the ranges of turbines (Hothershall, 1984). The diagonal lines represent the water power available. Lines a-a and b-b represent the limitation in the performance of crossflow turbines with widths of 1 and 0,05m respectively. It is apparent that crossflow turbines will meet a wide range of applications. The turbines plotted are either actual applications or reflect data from manufacturers' brochures. Selecting the most appropriate type for the job will involve considerations of cost, part-flow efficiency, resistance to silt abrasion and the type of control system to be used.

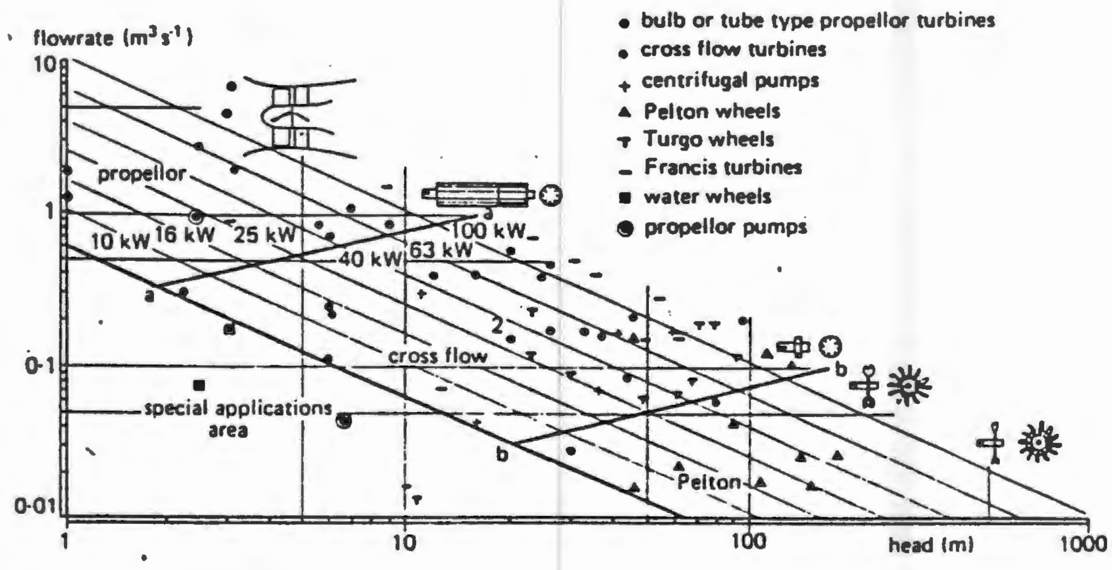


Figure 8.1

When the extra expense of controllable geometry turbines may not be justifiable, as in most ROR installations, load control governors are used. In some applications, such as an installation with water storage, where economising in the use of water is very important, flow control governing may be preferable. In most installations, however, it is not necessary except perhaps for a manual change in guide vane position or blade angel, to cope with day to day flow variations. The part-flow efficiency can be important when the available flow at a site is predicted to fall below the rated flow for a significant portion of the year. Mixed flow pumps operating as turbines have low cost but poor part-flow characteristics. Nonetheless they certainly merit consideration in cases where full flow conditions can be guaranteed, although that is not common.

Materials and construction techniques for turbine manufacture have changed in recent years. New materials, such as plastic for runners, are being used by some manufacturers for very small turbines. Oil-lubricated journal and Michel thrust bearings used on larger machines are not generally used for micro hydro, and spherical roller bearing are common for impulse turbines. Water lubricated cutlass type bearings are used for some very small propeller turbines. Regular e.g. annual bearing changes are simple and inexpensive.

Finally, it should be borne in mind that many micro scale applications can be adequately supplied using a centrifugal pump run in reverse. These have been used with great success in Colombia, South America, to charge batteries for lighting and television. Locally, engineers at the Dept of Agricultural Engineering in Pretoria have investigated their potential, as have students at the Universities of Natal and Cape Town.

<u>HEP Generators and their control</u>

On isolated micro hydro plants, synchronous generators have to be used, normally of the type mass-produced for diesel generator sets (generally four pole, 1500 or 1800 rev/min). Lower speed multi-pole machines of this size are generally very expensive (at least twice the price for 100 rev/min). Induction generators used for paralleling with the grid have the disadvantage in most developing country applications of not allowing isolated operation. Also the capacitors that normally have to be fitted to compensate for the reactive current drawn from the grid can be expensive. It is possible to run induction generators independently, but voltage control is required so that the excitation provided by capacitance across the terminals can be varied with load and phase angle. Such a controller is at present under development in the UK, co-sponsored by ITDG and the Science and Engineering Research Council.

Voltage control of synchronous generators can be by electronic or static automatic voltage regulators (AVR). Electronic AVRs have been found to be the most unreliable part of micro hydro systems, and it is recommended that static voltage regulators be used wherever possible, although it does seem that electronic AVRs are at last becoming more reliable. Overspeed rating of generators is an important constraint. The mass-produced synchronous generators are not normally rated for the overspeed they may experience when used for micro hydro and manufacturers must normally strengthen the rotors to meet the overspeed specification.

The protection equipment normally required includes an over-current device to trip the circuit breaker, over-voltage trip to cut the field in the event of overspeed and under- and over- frequency trips are generally used to operate the circuit breaker. It is also normally necessary to fit a means of shutting down the turbine automatically in the event of overspeed, since prolonged running at overspeed is likely to cause damage.

If electronic load controllers are fitted, the ballast load should be connected directly to the alternator, protected only by fuses. The main load should be fed by circuit breaker with auxiliary contacts for tripping from the protection devices mentioned above.

<u>HEP System Control</u>

Automatic and remote control techniques can be put to good use on micro hydro plants. Examples are: remote monitoring and control of the plant; automatic start up and shut down governed by storage water level; and, load management by automatic switching on or off of load according to predetermined priorities. Automatic control of sluice gates, penstock valves, trashracks, and so on, may also be worth consideration.

It is important to remember that micro hydro plants remain exposed to all sorts of potential natural calamities, and automation is no substitute for personal monitoring. Control equipment can also be difficult for semi-skilled artisans to repair. Care also has to be taken not to decrease the system reliability by building in too many extra failure modes. Electronic load control governors for speed regulation are now widely used and generally considered the most appropriate form of speed control for micro hydro plant. Their main advantages are:

1. Price

2. Reliability

3. Speed of response

4. No fly wheel required, and

5. Simplification of the turbine design.

Phase angle control electronic load governors, which use a single resistive load able to absorb the full output of the generator have been used by ITDG and have been found to be very satisfactory. Potential disadvantages of wave form distortion and radio interference do not, in practice, prove to be real problems. The basic principle of operation is to sense the frequency, and the power fed to the ballast load is then varied to adjust the total load, thus keeping the speed constant. Use of multiple ballast loads and zero voltage switching of increments of ballast is an alternative approach, but is generally more complex.

The use of mechanical/hydraulic or electro-mechanical governors is more appropriate on larger systems and on plants where water economizing is important. A combination of slow response flow governing with electronic load control can also be used for water economising.

8.2 HYDROPOWER POTENTIAL OF SOUTH AFRICA'S RIVERS

Because of the climatic characteristics of the country, large basin schemes for the generation of HEP have been discounted as a source of power in South Africa, except for the limited peak power generation capacity installed on the Orange River. In addition, in this country, with its abundant, low cost coal, power engineers have not been forced to be resourceful in their search for power generation sources, and have thus not even considered smaller scale schemes. Nonetheless, in a 400 km wide strip along the east coast, extending northwards from East London, and in parts of the Escarpment, the mean annual runoff (MAR) is sufficient to warrant investigation of small, mini and micro[3] scale

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[3]Small hydro is defined as less than 10 MW, mini as less than

HEP potential. Although extensive hydrological studies have been carried out by various researchers, these have focussed mainly on the quantification of surface water resources for agricultural, industrial and domestic purposes.

The principal engineering argument against HEP is the high cost of the civil works necessary for impoundment. However, this argument falls away when the water <u>has</u> to be impounded for domestic and agricultural purposes.

It is apparent, however, that sites do exist for limited development of HEP, especially on a small scale. All existing studies on HEP potential have concentrated mainly on large-scale exploitation, and in general have disregarded small hydropower. Unfortunately it is beyond the scope of this project to make more than a general estimate of the micro hydropower potential in South Africa. More detailed assessment would require a survey of the specific areas for which the power is required. There is already one small commercial hydro scheme in existence in Natal run by the Albert Falls Power Company, which supplies power to a number of surrounding farms.

Planning of HEP schemes should realise the maximum potential of this limited resource. It should begin with a thorough basic study of hydrology and water resources. Many schemes have been and are being proposed with inadequate data. An integrated data collection system to develop Transkei's water resources is at present being developed (Taylor and Stephenson, 1986). For satisfactory analysis, a data series of 10 - 15 years is desirable. Records of the following are required:

1. Precipitation in the various catchment areas in this 400 km coastal strip with both totals and rates.

2. River flow data including variations from season to season and peak flood flows.

3. Silt loads in rivers.

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2 MW and micro as less than 500 kVA - UNIPEDE standard (Dutkiewicz, 1984).

In parallel with the above, an in-depth analysis of local and regional needs is required. This includes:

1. Power and energy.

2. Water to meet existing and proposed agricultural, industrial, commercial and domestic needs

3. Environmental protection.

Once resources are identified and needs determined, both local and regional, then potential developments should be classified within a regional or local context. Development of HEP facilities should then take place within this framework.

8.2.2 Eastern Cape and Transkei

Transkei has a relatively high runoff in comparison with the rest of South Africa. The total runoff from its rivers averages 7 000 million cubic meters per annum, or one sixth of the total runoff for South Africa. Owing to the high variability from year to year however, less than half of this could probably be efficiently utilised, even with reasonable storage. There are limited reservoir storage sites and also a number of smaller streams which could not be exploited economically.

HEP development also requires fall in elevation either created by means of a dam wall, or by means of tunnels to lower levels. It is estimated that the maximum theoretical hydro potential of Transkei is some 14 000 GWh/yr (Stephenson, 1986). Owing to losses by spillage during floods, lack of suitable dam sites and uneconomic scale of some sites, a conservative estimate of the net useable energy is 1 000 GWh/yr which at a 100% load factor would only justify 120MW of power. More optimistic and intensive studies have however indicated that over 5 000MW could be installed at load factors between 5 and 10%. South Africa's current electricity consumption is 100 000 Gwh/yr and the peak demand 18 000 MW.

Studies are in progress by the Transkei Department of Works and Energy on the large-scale exploitation of the Mzimvubu river, the main catchment in Transkei. Installations with over 2 000 MW of generating capacity are envisaged but these would only be viable feeding a regional grid, as the scale is out of context in Transkei.

The conducting of studies such as the above reveal flaws in the approach to energy supply in a region which has a great need for a cheap, dispersed source of energy. This would initially be required for cooking, lighting and space heating purposes, but as development progressed in the region, the need for light industry power supply would increase. As regards HEP potential what is needed therefore is a study of the small-scale potential, and how feasible it would be for small hydro-based local grids to be developed, providing power for domestic consumption. As the demand increased beyond the capabilities of the plant, they could be upgraded in a modular fashion, or else the grid could be connected to the larger grid. This approach has been used with great success in the People's Republic of China.

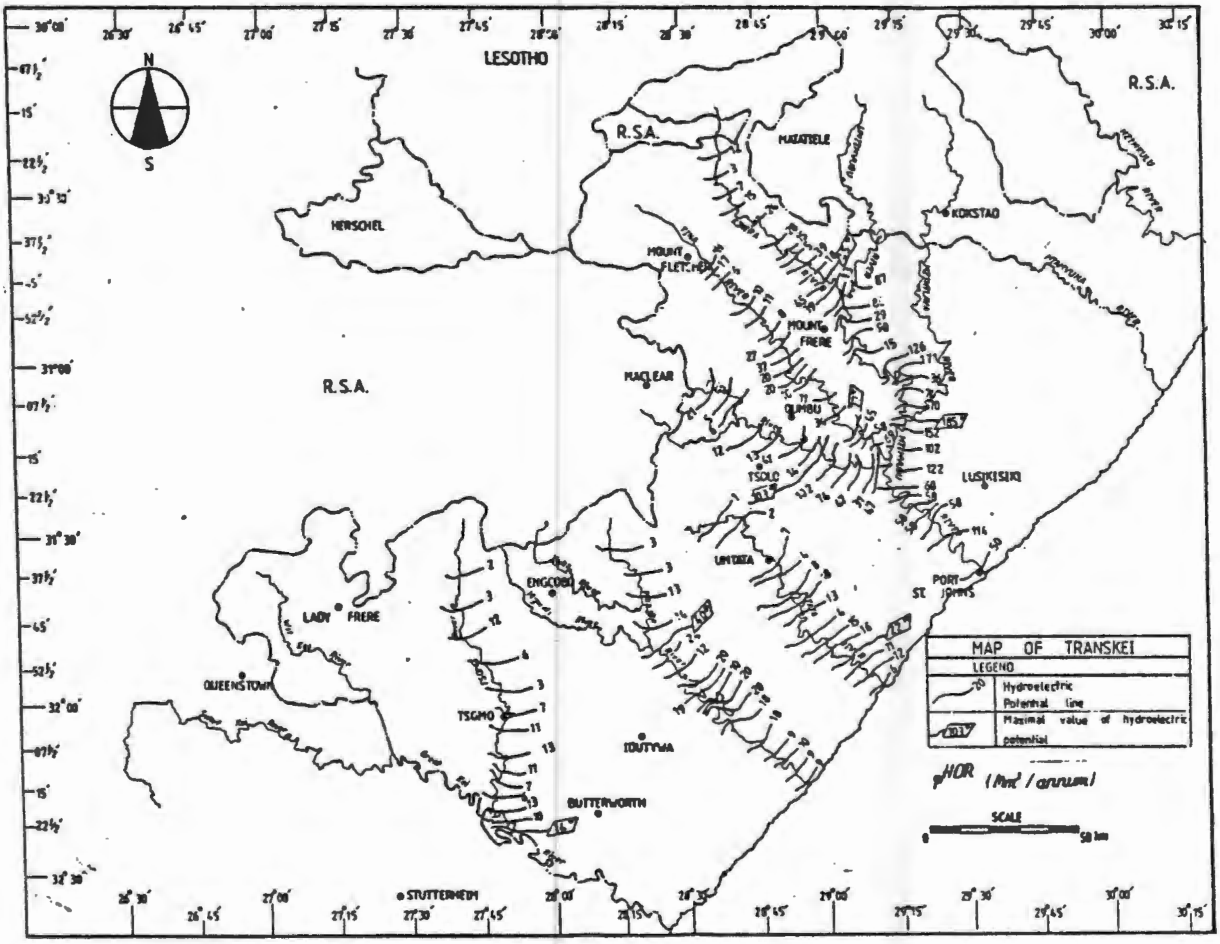


Figure 8.2 Hydro-electric Potential of Transkei Rivers (Mdoda, 1986)

Another factor to consider is the reliability of the river flow. The estimates of this should be conservative and the variability of inflow from year to year should be closely studied. If for instance the flows were over-estimated then it may be impossible to meet the power demands even if the hydro station were designed for peak loads only. During droughts the load factor of a hydro system should be decreased and in this way the total power demand can still be met. During periods of high flow the hydro power plants could even be operated on base load.

A number of micro hydro schemes are in use by farmers in the Eastern Cape. These have all been built either by the farmers themselves or by local contractors and are either ROR, or make use of minimal impoundment. Appendix F lists details of some of those schemes about which information was able to be found, and is not by any means exhaustive.

8.2.3 Natal

Various studies of hydropower potential have been done in Natal, mainly looking at the larger scale potential (Langford et al, 1963; Matthews, 1969; van Robbroeck et al, 1970; Chew and Bowen, 1971). As mentioned earlier, the only private power company in South Africa operates near Howick, making use of Francis turbines. There are also a number of private installations on farms in the Drakensberg. These, however, represent but a fraction of the hydropower potential.

8.2.4 Eastern Transvaal

No literature on the potential in this region was found, although it is known that a number of small installations do exist along the escarpment. Eskom is also involved in the development of a pumped storage scheme in this area.

8.3 THE ECONOMICS OF SMALL HYDROPOWER IN SOUTH AFRICA

It is in remote underdeveloped areas that the use of mini and micro hydro power generation would be most appropriate. Many of these areas along the previously mentioned 400 km wide strip are still too remote and sparsely populated to be serviced by the grid. However, the potential exists for small multi-purpose hydro schemes to be developed to serve the needs of communities. These would include the supply of water for domestic and agricultural use and sufficient power for lights, water pumping, and possibly some cottage industries. When the demand for power at such a location increases sufficiently to warrant extension of the grid, the hydro station would provide voltage stabilisation at the end of the line.

As was mentioned earlier, the above concept has been used with great success in remote areas of the Peoples' Republic of China, to the extent that nearly two-thirds of rural Chinese households use electricity, one-third of which is derived from hydropower (Zhu et al, 1985). Prior to 1949, the total installed small hydropower (SHP) capacity was 3 634 kW, which has now risen to close to 10 000 MW, 5 910 MW of which is connected to the grid (Bai, 1985). Of great assistance in the development of this potential has been the coordinated effort on the part of the water and power supply authorities. Whenever dams are constructed for irrigation purposes, space is left in the civil engineering works for the installation of hydropower equipment. There has also been a concerted effort to standardise on the equipment itself, thus greatly facilitating its design, construction and maintenance.

Generally speaking, the smaller the hydropower scheme under consideration, the higher the specific costs, i.e. per kW installed, are likely to become. However, the costs will, especially in the case of small scale HEP projects be very much project specific. This is as a result of the wide range of civil works that may be necessary, and will thus vary from project to project. This was definitely found to be the case with the micro-hydro schemes investigated in South Africa. As site-related i.e. civil costs can be expected to be between 50% and 70% of project costs on many HEP schemes (Gingold, 1981; Gordon and Noel, 1986), it can be seen that this variability will have a significant effect on the overall cost of a project.

The cost of the equipment, including the turbine, generator and transmission equipment can be expected to constitute a further 20% to 40% of project costs with the last 5% to 15% devoted to engineering costs (Gingold, 1981; Gordon and Noel, 1986). An approach often used in the initial costing of HEP equipment for a particular scheme, is that of applying an empirical specific cost correlation, based on the cost of previous projects. A review of costs internationally has shown that the development of a hydropower site requires a certain minimum sum (Gordon and Noel, 1986). This minimum cost can be related to a function of available head, and generating capacity. Gordon and Noel developed such a correlation.

8.3.1 The Economics and Use of Small Hydropower in South Africa

The abovementioned correlation of Gordon and Noel has been adjusted for South African conditions by Hoy (1987). This correlation, which will be used for the calculation of project costs in this report is as follows:

$$C = 18\ 750 * kW^{0,82} * h^{-0,246}$$

where:
C = minimum capital cost in R
kW = installed capacity of turbine in kW
h = net head in meters

This function applies in the case of small i.e. 1 - 100 MW hydropower projects designed to the high standards required for the generation of reliable power. If, on the other hand, a micro hydro project is being considered, and the level of reliability required is not according to normal grid specifications, then lower design standards can be applied. In such cases costs can be cut by a factor of two or more, especially if most of the civil works are undertaken by the owner.

The potential for the use of small scale hydropower by farmers and remote communities in South Africa has been recognised by a number of small entrepreneurs. Two of these were visited during the course of the project, and data on their various installations were collected. The plant ranged in size from 0,25 kVA to 54 kVA, and were all robust in design, and entirely appropriate to the technological skills of their operators.

The largest installation, designed and built by Mr P. Downey of Hofmeyr, is situated not far from the outlet of the Orange-Fish Tunnel. It is thus assured of a steady water flow for all but three weeks of the year, when the tunnel is emptied and inspected. The turbine is of the crossflow type, and utilises a head of 7,3 m and a flow of 1300 l/s. The power generated by it supplies all the domestic needs of two homesteads, lighting and hot water for 14 labourers cottages, and all the power requirements of a workshop and fodder processing. Power is transmitted at 6,6 kV over a distance of 5 km to the various users. The total cost of the system including transmission and switch gear, and wiring of the houses was R30 000 in 1982. The cost of the turbine, alternator and power conditioning equipment was R12 500. Prior to its installation diesel power generation was costing the owners R6 000/yr in diesel fuel alone (pers. comm. P.Downey).

Downey has installed a total of 15 turbines, of both the Pelton and crossflow turbine type, ranging in size from 0,25 kVA to 54 kVA. A second designer and constructor of turbines, Mr M. Cotterrell of the Cathcart district, has installed 37 turbines ranging in size from 0,8 kVA to 40 kVA. He has built Pelton, crossflow and Francis turbines. Some details of these are listed in Appendix F.

It was apparent from both inspection of the equipment, and discussions with customers, that it is of a high standard, and comparable with similar equipment obtainable elsewhere in the world. These two manufacturers have shown that the technology has potential in South Africa, and is in addition well within the capabilities of local industry. Their production facilities are anything but sophisticated, making use of equipment found in most farm workshops.

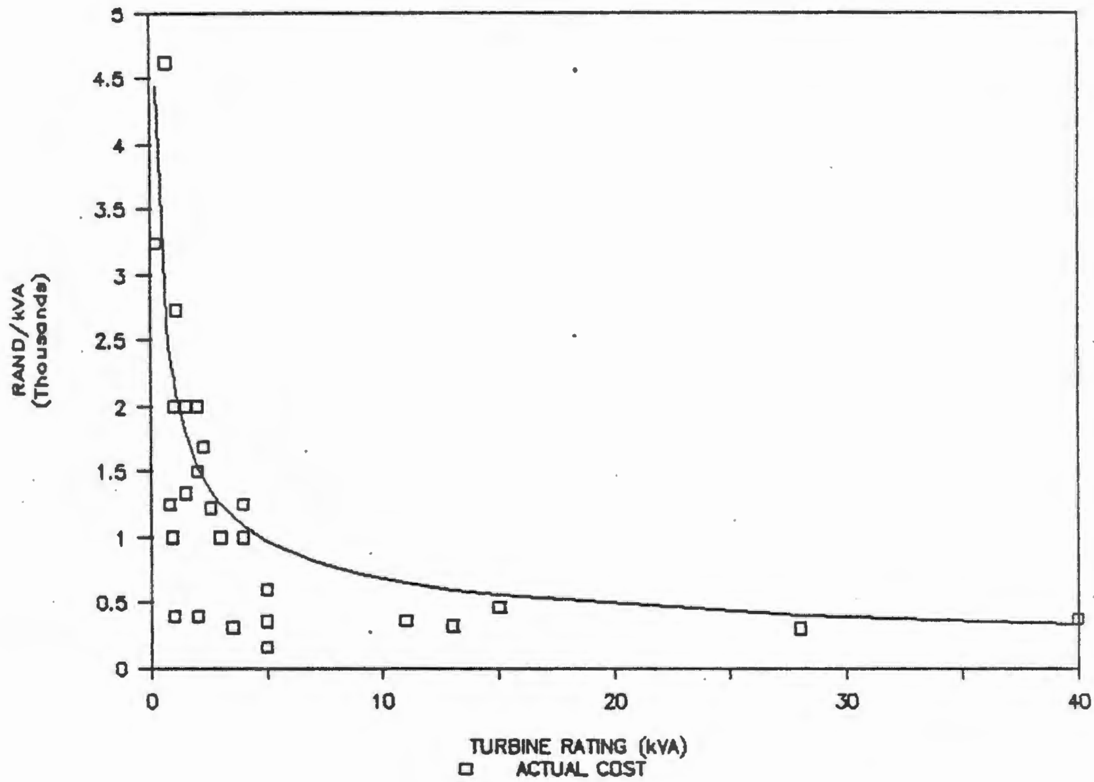
With the data obtained from these two manufacturers, it was possible to gain a good indication of the local cost of small hydropower plant. Based on this data general correlations for the cost of turbines suitable for use in remote areas were determined. It should be noted that the capital cost of these turbines has been found to be relatively insensitive to the available head, and is most dependent on their power rating. The following are the Rand per kVA correlations obtained for Pelton, Francis and crossflow turbines respectively:

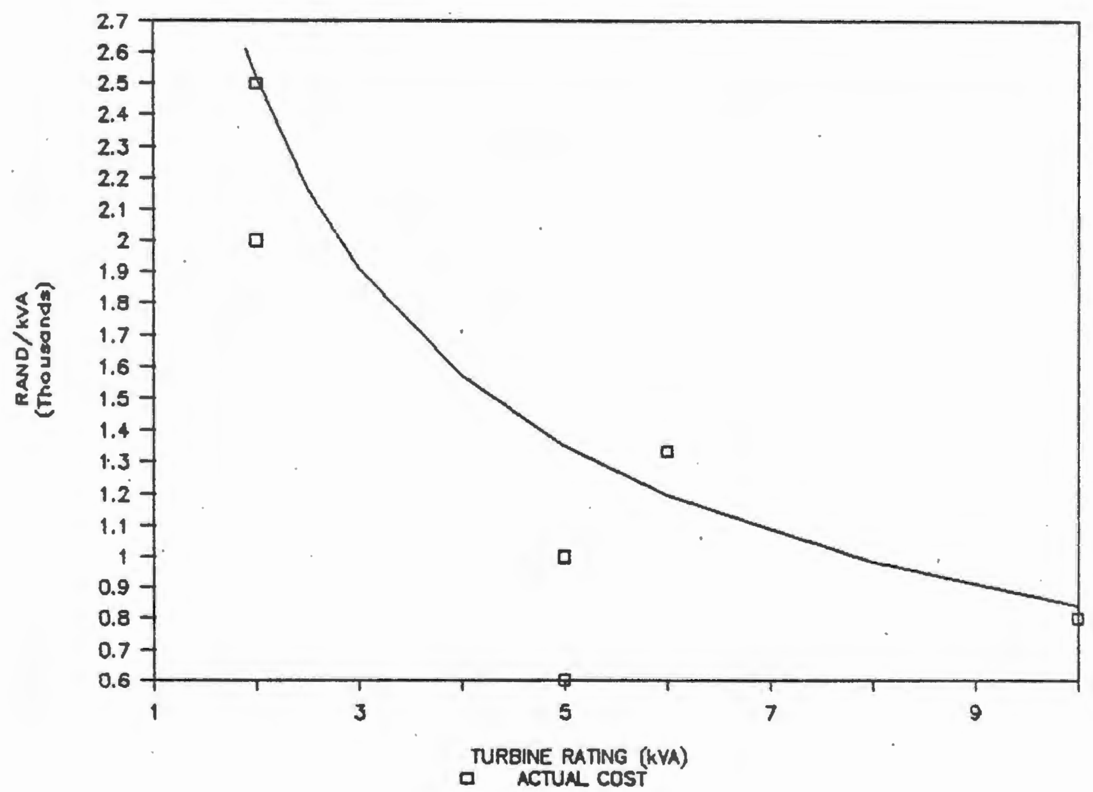
Pelton: $1.5 * e^{-0.51*\ln(kVA)+7.3}$

Francis: $1.5 * e^{-0.88*\ln(kVA)+8.1}$

Crossflow: $1.5 * e^{-0.77*\ln(kVA)+8.6}$

Figures 8.3 - 8.5 overleaf indicate the actual costs of some of the installed turbines in South Africa, relative to their predicted cost as given by the correlation (solid line).


RAND/kVA
(Thousands)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
10
20
30
40
TURBINE RATING (kVA)
ACTUAL COST


RAND/kVA
(Thousands)
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
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7
9
TURBINE RATING (kVA)
ACTUAL COST

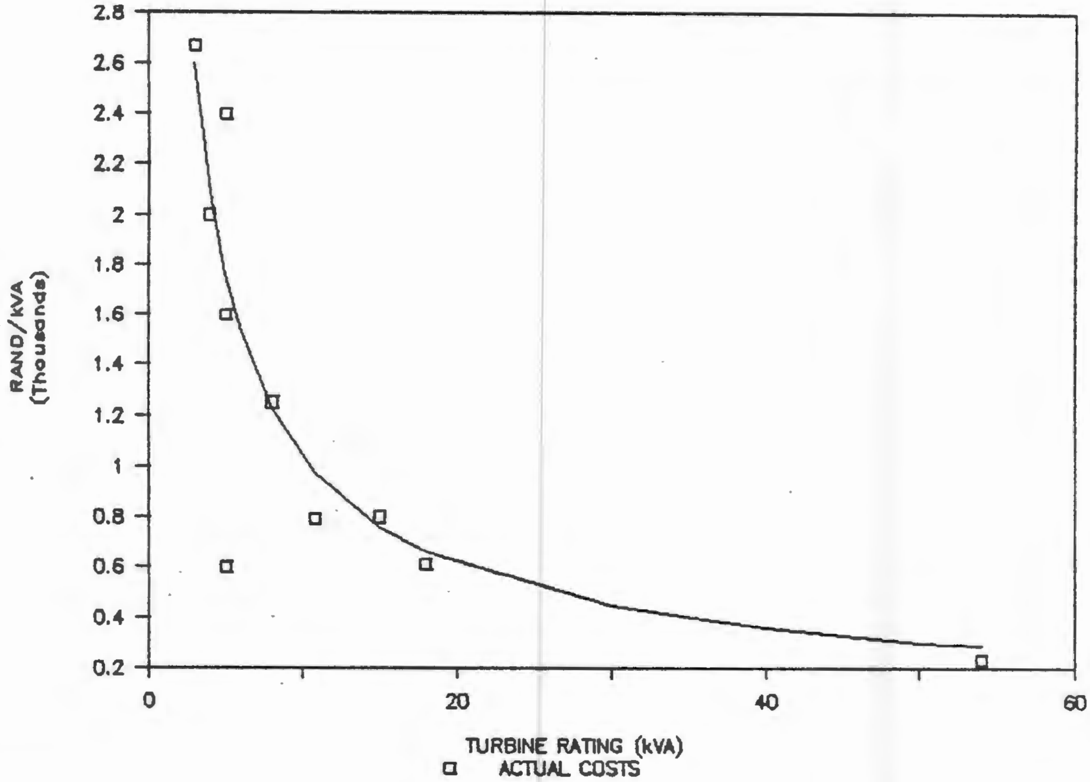

Figure 8.5

Using the correlations, the economics of small scale hydropower generation in South Africa have been investigated. The following shows the basic assumptions made in the economic evaluations.

Table 8.1 SYSTEM CHARACTERISTICS AND COST DATA

System life	25.00 years
Discount rate (real)	5.00%
Escalation rate (real)	0.00%
O & M	1.00% of capital cost per annum
Civil works cost	90.00% of turbine cost
Transmission cost	R5 000 /km

Note the high percentage figure used for the cost of civil works. This is based on the experiences of Messrs Cotterrell and Downey. Using the above assumptions, sensitivity analyses were performed on various parameters as shown in the figures which follow. The following additional data was used to generate these plots:

Turbine type	Crossflow
Turbine rating	10.00 kVA
Load factor	50.00%
Power usefully used/yr	43 800 kWh/yr
Transmission distance	1.00 km

In addition to the above assumptions, it must be constantly borne in mind that hydropower, is particularly site specific, and the following comparisons merely give a relative indication of the technology's capacity to satisfy power requirements. Figure 8.6 shows the unit cost of power from the various turbines. The power conditioning in all these systems is done by means of load control i.e. there is no mechanical governing of the turbines. The curves shown do not require further interpretation, and it is evident that there is little to choose between the various turbines once the power rating is higher than 50 kVA.

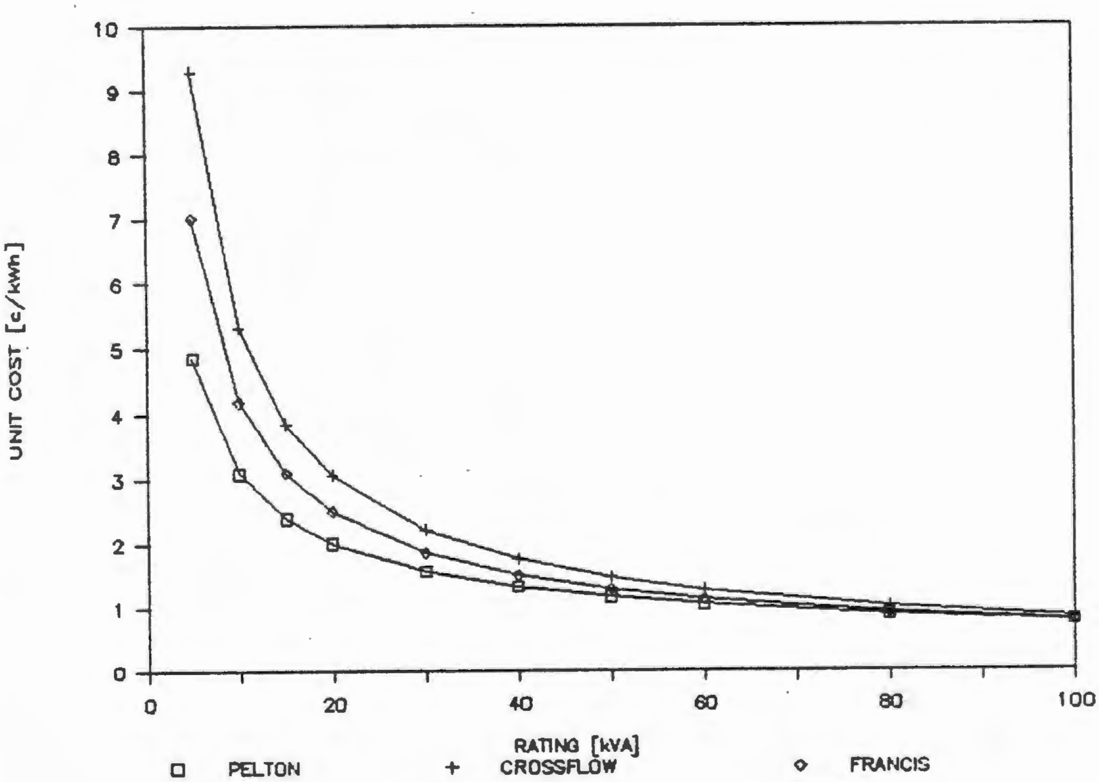

Figure 8.6

Probably the most significant factor affecting the unit cost of power from a small hydro turbine is the load factor under which it operates. As can be seen from Figure 8.7 that the unit cost is particularly sensitive to this parameter when turbines of less than 40 kVA are being considered. This would indicate that a high loading of micro-hydro plant greatly increases its economic viability.

In order to achieve high load factors in run of river hydropower plants, some form of energy storage should be considered. Examples of these are hot water cylinders which are used as the "dump" load when power is not required by other higher priority loads. In Colombia and Nepal excess power is used in slow cookers. These two options can be used as the resistive load necessary for the power conditioning equipment. Finally, excess power could be used to pump water to hill-top villages such as are found in many parts of the Transkei.

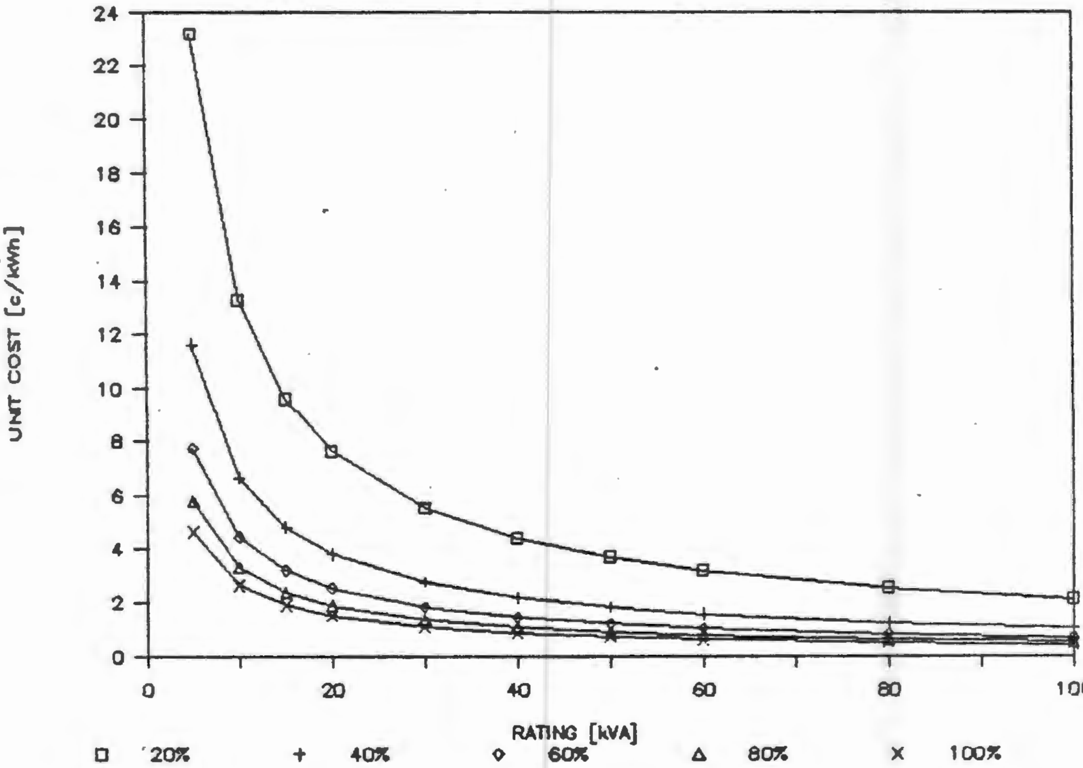

Figure 8.7

The unit cost of power is relatively insensitive to the time period over which the hydropower plant is amortized, as can be seen from Figure 8.8. In general, a life cycle of 25 years is used for the economic evaluation of small hydro plant, although the equipment may have a useful life well in excess of this.

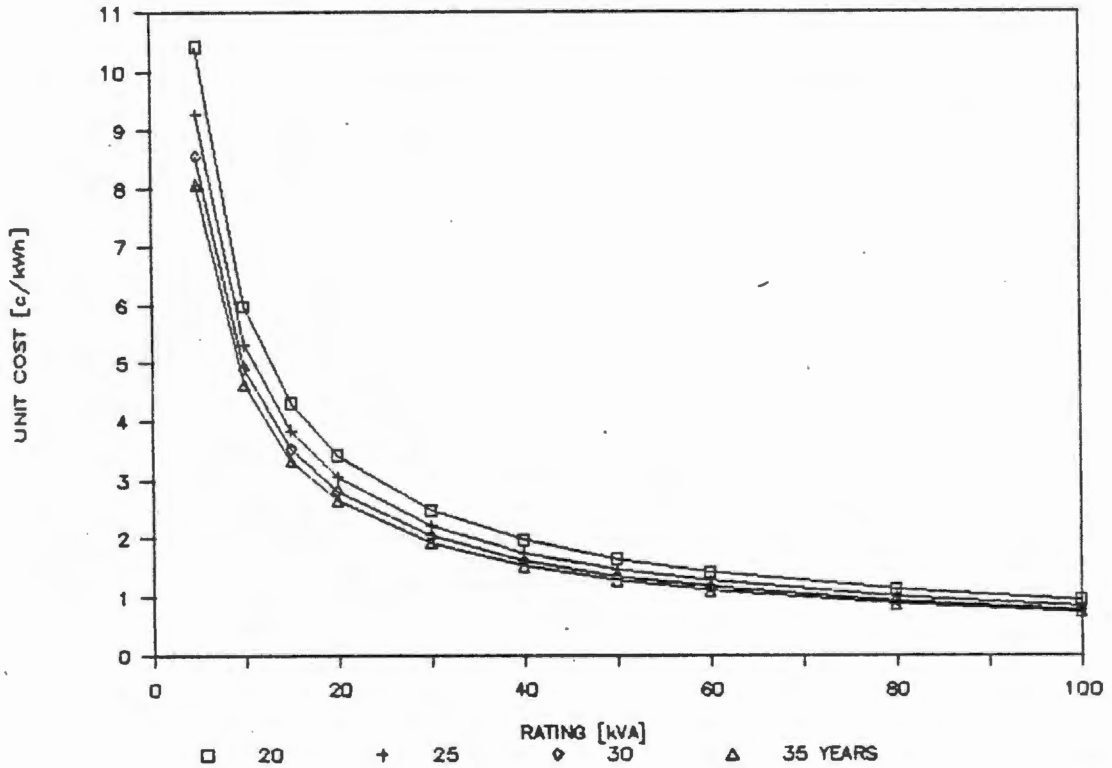

Figure 8.8

Figure 8.9 shows the sensitivity of the unit cost of power to the cost of the civil works required for the hydropower plant. It is expressed as a percentage of the hydro equipment cost. This and the cost of the power transmission are the most widely variable parameters in small hydropower plant. Two main factors affect them firstly, the location and nature of the site, and secondly the construction methods and specifications. From the plot it is apparent that civil costs could play a significant part in determining the final economic viability of a hydropower scheme, particularly in the case of turbines smaller than 50 kVA.

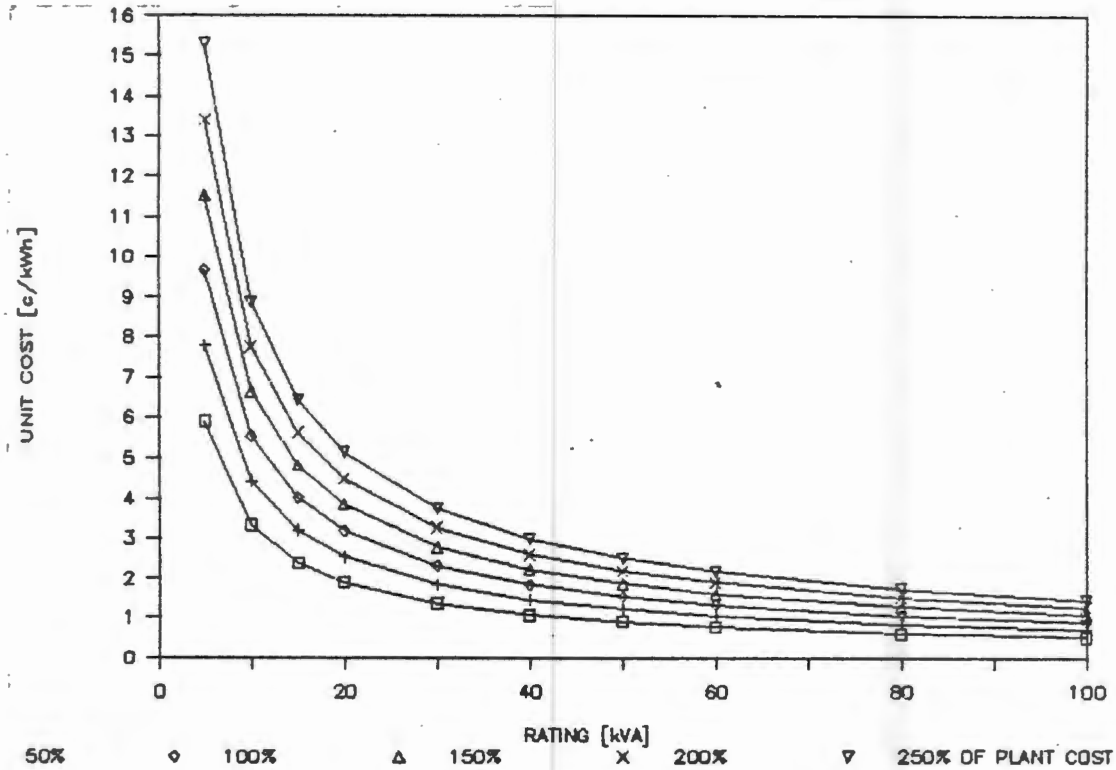

Figure 8.9

8.4 CONCLUSION

Equipment for micro hydro plants can vary widely in price and quality. Many of the potential applications in remote areas of South Africa could be adequately served by the equipment available locally.

It is apparent that small scale hydropower plant could well provide the solution to the supply of power in a number of remote areas of South Africa. This option should therefore be borne in mind when considering the alternatives, particularly in the Escarpment areas. The following table provides a summary of the unit cost of power from microhydro plant. The units are c/kWh.

Rating	Load Factor			Diesel
kW	20%	40%	100%	
1.00	106.23	53.12	21.25	
5.00	23.44	13.63	4.64	30.50
10.00	13.29	7.66	2.66	28.20
30.00	5.53	3.10	1.11	22.70
50.00	3.69	2.05	0.74	21.11
100.00	2.13	1.17	0.43	17.97

CHAPTER NINE

ALTERNATIVELY-FUELLED INTERNAL COMBUSTION ENGINE POWER GENERATION

Various biomass derived feedstocks can be used to fuel conventional or modified internal combustion engines. The fuels that will be discussed in this chapter include gas derived from both the gasification of biomass such as wood, maize cobs and other agricultural residues, and the gas, also known as biogas, derived from anaerobic digestion of manure and other agricultural residues.

9.1 THERMAL GASIFICATION OF BIOMASS FEEDSTOCKS

Producer gas has been used as a fuel since the 1920s and during World War II it was used extensively as a fuel for internal combustion engines. Small producer gas units were used successfully on trucks and tractors in Europe and Japan. Interest in it waned when fossil fuels again became readily available, but was re-awakened with the oil crises of the seventies. Considerable progress has been made in the design of gasifiers, filtration methods and range of fuels able to be used.

Producer gas is a combination of gases formed by the passage of air through a bed of hot coals (wood, charcoal, coal etc), into anaerobic conditions where reduction and cooling then take place. The combustible components are formed during the following reactions:

Carbon monoxide is formed by the partial combustion of carbon:

$$2C + O_2 = 2CO$$

Hydrogen and more carbon monoxide is evolved through the reaction of steam on hot carbon:

$$C + H_2O = CO + H_2$$

Methane is produced by the action of some of the above hydrogen with hot carbon:

$$C + H_2 = CH_4$$

This gives a low calorific value gas with the following typical analysis by volume:

Carbon monoxide	20 - 25%
Hydrogen	15 - 20%
Methane	2 - 4%
Carbon dioxide	10 - 15%
Nitrogen and inerts	42 - 52%

The effective heat value varies from 3.5 to 6 MJ/m³.

9.1.1 Gasification Techniques and Equipment

The best established of all gasifiers are the fixed bed type, also referred to as vertical shaft gasifiers. There are three basic types, counter-current, co-current and cross-current (also referred to as up-draught, down-draught and cross-flow). They are generally used for heating applications, spark and compression ignition, and small spark ignition engines respectively.

Most gasifiers consist of a hopper containing the feedstock which gravitates into a chamber in which the processes of drying, pyrolysis, oxidation and reduction take place. The ash produced during these reactions falls into a lower casing while the resultant gas, at a temperature of 500-600°C, is piped to the cleaning and cooling system.

Some degree of preparation of the feedstock is almost always required, and may take the form of chopping, hogging, drying and/or briquetting. Feedstock with a moisture content in excess of 20% is generally unsuitable since it reduces the high temperatures needed for effective pyrolysis and tar cracking.

Because the fixed bed gasifier technology is well established for coal, scale up factors are well-known. All such gasifiers tend to have certain features in common. They are all able to accept a fairly wide range of feed sizes, ranging from 10mm up to at least 200mm, although the quantity of fines (less than 10mm) they can handle is limited to between 5 and 10% maximum in most cases. Higher levels of fines tend to block the bed, making gas transfer less even, and increasing the pressure drop across the bed. Most gasifiers are, however, able to tolerate fairly high moisture contents, thus allowing the use of undried biomass.

Downdraught Gasifiers

For the generation of electricity, the downdraught is the most commonly used, because of its being particularly suited to most internal combustion engines. Its major advantage over the updraught type is that any tars and volatile pyrolysis products must pass the combustion and reduction zones, and are cracked into fuel gases before leaving the gasifier.

The downdraught gasifier, however, is sensitive to moisture content, and can not accept more than 25% moisture. Several small gasifiers of this design are known, and were mainly developed during World War II for use as gas producers for IC engines. They all operate at atmospheric pressure, using air/steam as the gasifying agent. More recently they have found application in small scale power generation. Locally the National Timber Research Institute (NTRI) has successfully developed a unit with a thermal output of 1MW.

The main disadvantage of the downdraught mode of operation is that the drying and distillation occur by radiation and conduction. This, together with the fact that all the steam produced, must pass through the gasification zone, means that temperatures are reduced, and more carbon has to be burnt to counteract these effects. On the other hand the level of tars and other condensibles are significantly reduced, or possibly even eliminated. This is due to their being cracked while passing through the gasification and combustion zones before leaving the gasifier.

It was generally considered unlikely that downdraught gasification in fixed beds would develop to any great extent for anything but small scale gasifiers. However, the NTRI is confident that their successes will lead to commercialisation of this technology on both the small and large scale. Another successful downdraught gasifier is the System Johansson Wood Gas Producer, developed by Mr K G Johansson of Halfway House, Midrand. More details of these will be given later.

Cross-draught Gasifiers

This type of unit was used quite widely in the UK to power vehicles during World War II. They are not suitable for use with high-tar fuels, but do allow simple, robust construction. For the former reason this type of gasifier has proved to be suitable for fuelling with carbonized biomass such as charcoal. They also have operational advantages with their quick-start characteristics and rapid responses to load changes.

Important development of these gasifiers has been done by the Tropical Development and Research Institute (TDRI), with the specific objective of providing a fuel for motive power in underdeveloped countries. This research has concentrated on small stationary power systems in the 1-20 kW shaft power output range (Hollingdale et al, 1985). This is typically the power required by remote communities for maize grinders, electricity generation and irrigation pumps.

9.1.2 Gasifier Feedstocks

Commonly available biomass gasifier feedstocks include wood wastes, nut shells, plant stalks, maize cobs - the list is almost endless. In most cases the material requires some form of preparation before gasification, such as size reduction or densification. In addition its physical and chemical properties (e.g. ash content, total volatiles, fixed carbon content) must be established, since these factors strongly influence gasifier design, the gas cleaning train, and the quality of gas produced. Certain gasifiers, as mentioned above, are also sensitive to moisture and tar content, so could necessitate the prior carbonisation of the biomass.

Although the carbonisation step may appear to be both an energy and time consuming operation, it has a number of advantages. Tars and pyroligneous acids are largely removed in this process, and as a result the gasifier design is simplified. More consistent gasifier operation can also be achieved, because of the more uniform nature of the feedstock.

9.1.3 Producer Gas-powered Engines

Although in principle, any internal combustion engine can be converted to run on producer gas, in practice, a number of factors which affect engine choice can be identified. In view of the low calorific value of the gas, the maximum amount of gas must be drawn into the engine with each induction stroke. For naturally aspirated engines, therefore, high volumetric efficiencies should be sought - thus implying slow or medium speed operation.

If 100% operation on producer gas is required, then a spark ignition engine is needed, with a compression ratio as high as possible, up to a maximum of 11:1. A gas/air mixer carburettor must ensure a mixture ratio of about 1:1 over the required load/speed range. Suitable spark plugs must be fitted and the ignition timing must take account of the lower flame speed of producer gas/air mixture compared with the petrol/air mixture. If the engine is a converted petrol engine, then a power reduction of 40%, on average, will be experienced when running on producer gas.

When operating a gasifier with a spark ignition engine, arrangements must be made to start up and sustain the gasifier to the point at which good quality gas is available (usually about 15 minutes from ignition). At this point the engine can be started. This start-up phase is usually accomplished through the use of a suction fan, hand or electrically powered, depending on the size of the gasifier.

If a compression ignition engine is to be used, then a substantial reduction in the consumption of diesel fuel can be achieved. For power systems below 25 kW, internal engine modifications are often unnecessary, an adaptor to connect the gasifier outlet to the engine manifold generally being all that is required. If the hydrogen content of the gas is above about 7%, a change in injection pump timing may be needed to avoid detonation in the engine cylinders. A timing change is more likely when using uncarbonised feedstock.

The engine is usually started with 100% diesel fuel and a small proportion (10%) is induced through the gasifier, which is then ignited. The amount of gas/air mixture drawn into the engine is slowly increased over a period of about 15 minutes until about 75 - 80% of the diesel fuel normally consumed is replaced by gas. Engine speed control is via the normal diesel pump rack governor.

9.1.4 Case Study of Producer Gas-powered Genset

Extensive tests have been carried out on a prototype System Johansson gasifier at Halfway House in the Transvaal. This prototype was designed to provide 40 kW shaft brake power at sea level, with the added criteria that the gas be, as far as is possible, tar free and clean. Since commissioning in September 1983 this gasifier has provided fuel for various engines for close on 2 500 hours (Johansson, 1986).

The furnace design is somewhat similar to the basic Imbert hearth, with however, extensive improvements to reduce the loss of heat from the furnace walls. A high degree of gas cooling and cleaning has been achieved by the use of a wet scrubber followed by fibreglass filter media and a finned fan-cooled circulation water cooler. Coarse particles are removed by a cyclone fitted before the gas scrubber.

Two engines have been tested using the gas alone as fuel, a two litre Mazda petrol engine with 14,5 kVA alternator, and a 5 litre Chevrolet V8 with a 37,5 kVA alternator. The Mazda engine had, up to the end of May 1986, done over 2 200 hours of trouble free running, providing power for various small workshop machines and domestic use. It delivers up to 13 kVA at an altitude of 1 500m, with an engine speed of 2 450 rpm. The Chevrolet has run for about 175 hours, delivering 30 kVA, at an engine speed of 2 150 rpm. Engine speed control is achieved through double control governors, consisting of a conventional centrifugal governor, compensated by a commercially available electronic revlimiter.

The operation of the above gasifier has been monitored by the CSIR, and extensive analyses of the gaseous products has been carried out. Based on these analyses the efficiency of the gas producer has been determined as 88 - 94% in converting the wood energy into gas energy (Johansson, 1986). The specific fuel consumption was found to be of the order of 1,20 - 1,33 kg/kWh. At a woodblock production cost of 3 - 4c/kg, this gives a cost per kWh, including some allowances for waste, of around 6 - 7c/kWh on fuel costs alone.

9.2 BIOCHEMICAL GAS PRODUCTION THROUGH ANAEROBIC FERMENTATION

In the process of anaerobic fermentation, organic matter is completely degraded to the gaseous products, CH_4 and CO_2, with about 90% of the energy content of the substrate being retained in the methane. Although a large amount of organic matter is degraded, only a relatively low yield of microbial cells is obtained. This process is very important for the carbon and nitrogen cycles in nature and it has long been used for the stabilisation of sewage and other organic wastes. In addition it has great potential for use in converting biomass sources such as animal manures, agricultural products and residues, and domestic wastes into an energy-rich fuel.

Bacteria are primarily responsible for the fermentation, but anaerobic fermentative protozoa, some anaerobic fungi, and other organisms may also be important in certain environments. The metabolism and growth of one species is often dependent on its interactions with other microbial species. The complete fermentation occurs naturally in a large number of anaerobic environments that have a slow turnover of material and where the main electron acceptor, CO_2, is produced from the degraded substrates eg. swamps, aquatic sediments of lakes. It does not occur in environments where other electron acceptors such as oxygen, nitrate, sulphur or sulphates are readily available.

9.2.1 Biogas Digesters

The above natural process is the subject of ongoing research, but has been used for many years in the processing of domestic and industrial sewage. The conventional sewage sludge digester consists essentially of a completely mixed, one step process operating on a continuous basis without solids recycle. Due to the low specific growth rate of the methanogenic bacteria, effective digestion of the waste in a conventional reactor can only be obtained at long retention times. In practice, liquid retention times of 20 days or longer are considered to be essential for efficient waste stabilisation with the result that conventional digesters tend to be of large size involving high initial capital costs.

On the other hand various developing countries have adopted anaerobic digestion as a means of providing energy in rural areas. The most publicised of these digesters are those used in rural China, of which there are reported to be 8 million in use. These were initially conceived of as a means of stabilising the sewage of rural communities, thereby reducing the incidence of disease caused by parasites and pathogens, but they have subsequently been optimised for the production of biogas. The Indian gobar (cow dung) gas project, on the other hand, was initiated with the express intention of producing gas to try and alleviate rural energy problems.

The Chinese digester has no moving parts, the digester itself acting as the gasometer, with the liquid level providing the gas compression. These digesters were originally designed to be operated on a family basis, or at most with three families and their animals providing the feed for the unit. However, problems with their maintenance, in particular the repair of leaks, has caused many of them to fall into disrepair. Larger digesters serving a community or village are however still much in evidence, and make use of separate gas storage tanks, large polythene balloons being used for this purpose with good results.

In the 1950s and 1960s a South African pig farmer designed and operated two large plugflow digesters on his farm near Rustenburg, obtained a gas yield of $1m^3/m^3$ digester/day at an operating temperature of 35°C, and retention time of 15 days (Fry, 1974). The yield drops well below $1m^3/m^3$/day if the temperature is not maintained, and levels of as low as $0,1m^3$ are not unusual. Indeed temperature is one of the critical parameters determining the performance of a biogas digester. Any sudden changes in temperature can have disastrous effects on the bacteria.

The yields obtained from Fry's digester, based on volatile solids fed to it were as follows. (Volatile solids (VS) is a unit used to measure that part of the digester feed that is consumed by the microorganisms):

Substrate	Yield of biogas
Pig slurry	0,714 m^3 of biogas/kg VS
Silage effluent	1,1 ditto

Typical values from the literature would be in the range of 0,4-0,5 m^3/kg VS added, using primarily animal manures, human waste and crop residues as feed, with retention times of between 10 and 20 days. The methane content of the gas is usually expected to be about 60%, thus giving a CH_4 yield of 0,22-0,3 m^3/kg VS added, over an average retention time of 15 days.

9.2.2 Biogas Composition and Cleaning

The major constituents of biogas generated by stable fermentations are given below:

Constituent	Concentration
Methane	50-65% by vol
Carbon dioxide	35-50%
Moisture	30-160 g/m^3
Hydrogen sulphide	5 g/m^3

As shown in the table, methane comprises about 50% to 65% of the biogas produced during anaerobic fermentation. It is a colourless, odourless, flammable gas which has an energy value of 37,3 MJ/m³. Natural gas contains about 95% methane. The critical temperature and pressure of methane are -82°C and 4,6 MPa, respectively. Thus liquification of methane is not a practical alternative. Methane is flammable when mixed with air at concentrations between 5 to 15%, and because of this caution must be exercised to prevent accidental ignition.

Carbon dioxide is the other major constituent of biogas, and its predominant effect is to dilute the energy value from 37,3 MJ/m³ to between 18 and 24 MJ/m³, and to increase the volume of gas to be handled and stored. The lower energy value of biogas decreases the efficiency of internal combustion engines and requires minor burner modification for efficient combustion.

Water vapour in the biogas is an important contaminant which must be removed prior to use in most applications. Condensed water tends to accumulate in gas handling equipment and meters, causing malfunctions, frozen pipes, and corrosion of metal parts when combined with the hydrogen sulphide and carbon dioxide.

The degree of biogas cleaning needed depends on its eventual application, the least demanding use being for on-site direct burning. The minimum requirement in this case is moisture removal to prevent condensation in gas lines and excessive corrosion. This is of particular importance when considering its use as a fuel for internal combustion engines. This can be accomplished by simple frost-proof condensers and strategically located condensate traps. The concentration of H_2S in the biogas is generally not high enough to be a health or environmental hazard when oxidised during burning.

In general the removal of carbon dioxide is not done in the case of small scale digesters, the cost of the equipment being prohibitive on this scale. The removal of hydrogen sulphide is however advisable. One of the simplest and most common methods for its removal is the iron oxide (or iron sponge) process. In this process, the hydrogen sulphide reacts chemically with ferric oxide to form ferric sulphide. Regeneration is accomplished by passing clean air through the sponge to oxidise the ferric sulphide to elemental sulphur and ferric oxide. The ferric oxide is usually impregnated on wood shavings as a low-cost medium. Periodically, the ferric oxide must be recharged because the sulphur accumulation tends to reduce activity and increase the pressure drop through the bed.

9.2.3 Biogas Use

The two predominant uses of biogas are direct burning and fuelling of internal combustion engines. Examples of direct burning are for space heating of residential, commercial, or livestock facilities; crop drying and processing; and steam production. Use in stationary internal combustion engines is for prime movers and for generating electricity. Biogas is unlikely to be used to fuel mobile vehicles on a large scale because of its relatively incompressible properties. The ultimate use of the biogas will depend upon the specific on-site energy requirements and the scale of operation.

There are several advantages in using biogas as a fuel for internal combustion engines. Methane has a high octane rating and therefore, excellent anti-knocking qualities. It mixes well with air and results in more complete combustion, less residue in oil or exhaust gas, and less fouling of spark plugs. The only limitations on the use of gases in internal combustion engines are that they should be free of dust, noncorrosive (i.e. less than 1,4 g H_2S/m^3), not detonate, and not pre-ignite during the compression stroke. The gas can be used directly in spark-ignition engines, while a pilot quantity of diesel oil is required to provide the ignition in a Diesel cycle engine, as is the case with producer gas.

The overall efficiency of the internal combustion engine can be increased by recovering and using the heat losses from the engine. The recoverable heat as a percentage of the heat input are shown overleaf:

Engine heat losses	Efficiency %
Jacket cooling	20-30
Exhaust gases	26-30
Lubricating oil	5-7

These heat losses can be reclaimed as low temperature (75 to 85°C) process heat, and it is ideally suited to maintaining optimum digester temperatures for fermentation.

During 1985 a University of Cape Town Mechanical Engineering final year student successfully converted a three-cylinder diesel engine to run in a dual-fuel mode on biogas produced from chicken manure. Work is also being done on the use of biogas in internal combustion engines by the Department of Mechanical Engineering at the University of the Witwatersrand. This includes the use of biogas in both Otto and Diesel cycle engines. Several dual-fuelled and straight gas engine generators are in operation at various municipal sewage treatment works around the country (pers. comm. NIWR).

9.3 THE ECONOMICS OF GAS-FUELLED REMOTE AREA POWER GENERATION

9.3.1 Producer Gas

Although spark-ignition engines can be run directly on producer gas, the analysis of power costs from gasifier-powered electricity generation was determined on the basis of a diesel genset. This basis was used firstly, because of the minimal modification that is required to diesel engines as compared spark-ignition engines and secondly, because of the familiarity that exists in remote areas with the use of diesel engines. As regards the modifications, spark-ignition engines require the addition of some form of speed governing, whereas diesel engines have an integrated governor.

The gasifier and woodfuel costs used in the evaluations are based on those given by Johansson (pers. comm.). The gasifier cost is based on local production, and is inclusive of all necessary filtering equipment. The woodfuel is costed on the basis of wood grown by the user, and felled and cut into suitable blocks using unskilled labour.

The engine is run such that it uses 10% of its normal diesel fuel as the ignition source for the producer gas. In the calculations this was taken as 10% of the power being produced by the diesel component of the fuel. The table overleaf provides a summary of the basic assumptions made in the economic evaluation.

Table 9.1 Basic Assumptions

PROJECT LIFE	25.00	YEARS
ENGINE LIFE	15000	HOURS
DISCOUNT RATE	5.00	%
INFLATION	0.00	% PER ANNUM
% PILOT FUEL	10.00	%
DIESEL COST	0.55	RAND/LITRE
MAINTENANCE	50.00	% OF CAPITAL COST OVER ENGINE LIFE
GASIFIER COST	32000	RAND
WOODFUEL COST	3.85	c/kg

The systems used in these evaluations are the ones that have been used throughout this report, thus enabling comparisons to be made. The following table gives the basic parameters of the systems, first described in Chapter Five.

Table 9.2 System Parameters

SYSTEM	MAX DEM	USE	DEMAND	ENGINE MAKE & MODEL	kW	CAPACITY FACTOR
	kVA	HRS/DAY	kWh/DAY			
DOMESTIC 1	2.50	5.75	11.50	LISTER ST1	4.50	0.44
DOMESTIC 2	3.50	5.75	14.75	LISTER LR2	4.90	0.52
DOMESTIC 3	4.00	5.75	10.35	KUBOTA D750	6.71	0.27
DOM & WKSHP 1	10.00	11.50	68.98	LISTER ST3	13.40	0.45
DOM & WKSHP 2	15.00	11.50	85.23	DEUTZ F3L912	22.70	0.33
DOM & DAIRY 2	25.50	5.50	137.00	LISTER HR4	33.70	0.74
DOM & PUMP 1	10.00	13.00	100.35	DEUTZ F2L912	14.50	0.53
PUMPING	50.00	9.00	450.00	ADE 354T	64.60	0.77

Life-cycle costing of the systems was done using the above data, the results of which are shown in Table 9.3 overleaf. The third last column gives the unit power cost when 90% of the power is provided by producer gas, while the second last column gives the unit power cost for the genset being run 100% on diesel. It is of interest to note that the diesel fuelled genset provides quite significantly cheaper power in the lower demand systems.

It must be borne in mind that the capital cost of the gasifier is taken as uniform i.e. R32 000 across the power output spectrum. This would be largely true in practice, due to the fact that the System Johansson gasifier has a wide operating range (8 - 75 kW). In order to bring the unit cost of power for the first three systems down inline with those for pure diesel power, the gasifier system cost would have to be reduced to R8 000. This is clearly not feasible, making the producer gas powered generation of electricity attractive only to systems with higher maximum demands, and capacity factors.

Table 9.3 Power Costs Using Producer Gas in a Dual-Fuelled Genset

SYSTEM	GENSET COST	ENG LIFE	ENG-INES	DUAL-FUELLED COST/kWh	DIESEL COST/kWh	CAPACITY FACTOR
	RANDS	YEARS		c/kWh	c/kWh	
DOMESTIC 1	6679	7.15	3.50	104.47	63.22	0.44
DOMESTIC 2	7115	7.15	3.50	86.03	59.21	0.52
DOMESTIC 3	8944	7.15	3.50	130.48	80.90	0.27
DOM & WKSHP 1	14353	3.57	7.00	44.68	49.19	0.45
DOM & WKSHP 2	19785	3.57	7.00	46.36	53.53	0.33
DOM & DAIRY 2	24331	7.47	3.35	24.41	29.55	0.74
DOM & PUMP 1	15098	3.16	7.91	36.22	42.06	0.53
PUMPING	30726	4.57	5.48	16.65	27.49	0.77

Sensitivity analyses were carried out to determine the most influential parameters in determining the unit power cost. The DOM & WKSHP 2 data were used as the basis for the analyses.

As would be expected the most significant parameter appeared to be the percentage of power provided by the diesel pilot fuel. For every 10% increase in diesel fuel used in place of producer gas, the unit cost of power increased by 1,98 c/kWh. This sensitivity would suggest the desirability of converting to spark-ignition engines thus eliminating the need for a liquid fuel entirely. The diesel cost component represents from 3 to 16% of the total unit cost, which depending on the system, can be as much as 7c in 46c/kWh.

The cost of the woodfuel does not have a very significant effect on the unit cost, with a 1c/kg increase pushing up the unit cost by only 0.80 c/kWh. It must be remembered that the woodfuel costs used in these calculations include only tree felling and fuel preparation labour costs i.e. a free wood supply is assumed.

The capital cost of the gasifier does not greatly affect the unit cost of power from the DOM & WKSHP 2 system, where a R1 000 increase results in a 0,23c/kWh increase in the unit power cost. However in the case of the smaller demand systems, a R1 000 increase can result in as much as a 2c/kWh increase in the unit cost. However, as was pointed out earlier this would not greatly affect the viability of producer gas over diesel in the lower demand systems.

Finally, the cost of diesel obviously does not have as great an impact on the unit cost as it does in the case of straight diesel power generation, and a 5c/l increase brings about a 0,5c/kWh increase in unit cost.

Figure 9.1 gives an indication of the importance of the various cost components in their contribution to the overall unit cost of power.

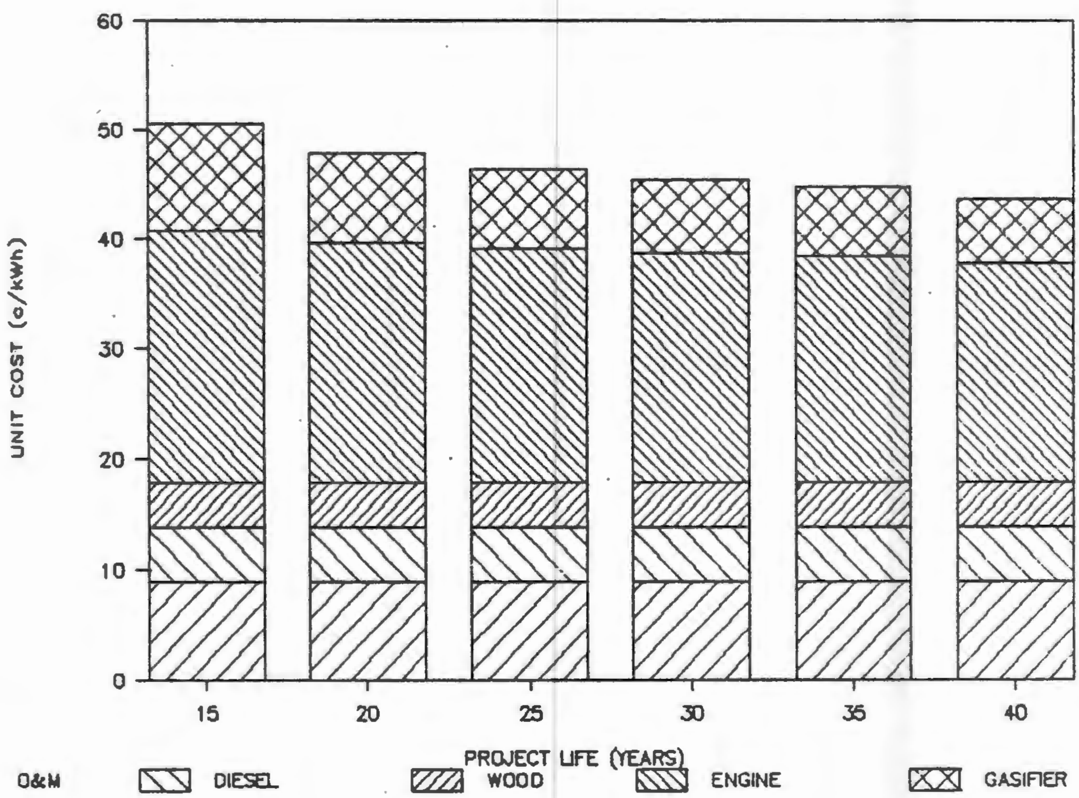

Figure 9.1

9.3.2 Biogas

Biogas, like producer gas, does not have a high enough cetane value to be used as the sole fuel in diesel engines. The economic evaluation for this fuel is therefore also based on the use of dual-fuelled diesel gensets. In the case of spark-ignition engines the same speed governing modifications are required as with producer gas fuelled spark-ignition engines.

Use of the technology required to produce biogas through anaerobic digestion is well within the capabilities of most remotely located communities, as has been shown by its application in many rural areas of the developing world. Fry, the Rustenburg pig farmer demonstrated its applicability to the commercial farming community, but unfortunately his example has never been followed to any significant extent in this country. Until recently a farmer from the Maclear district was also operating a digester, but has been plagued by seemingly irreparable leaks. This is indeed one of the major problems with digesters, because of the oxygen-free requirements of the micro-organisms which are essential to the biogas production process.

In Europe, however, in the same way that producer gas plants were used during World War II, so to were a number of biogas plant designs. Again the abundance of cheaper fossil fuels during the fifties and sixties caused many of these plants to be shut down. A combination of the oil crises of the seventies, and increasing pressure to dispose of organic wastes in a satisfactory manner, led to the revival of much of this technology, especially in the agricultural sector. The digester costs used in the following economic evaluation are therefore based on those found in the European agricultural sector, with farmers making use of their own labour (Demuynck et al, 1984). The cost includes the necessary ancillary equipment.

The basic assumptions made in the economic evaluations are given overleaf. In the calculations, the digester is sized so as to provide the exact volume of gas required to meet the power demand. A conservative specific volumetric gas production rate has been chosen which allows for some digester oversizing.

<u>Table 9.4 Basic Assumptions</u>

PROJECT LIFE	25.00	YEARS
ENGINE LIFE	15000	HOURS
DISCOUNT RATE	5.00	%
INFLATION	0.00	% PER ANNUM
% PILOT FUEL	10.00	%
DIESEL COST	0.55	RAND/LITRE
ENGINE MAINTENANCE	50.00	% OF CAPITAL COST OVER LIFE
GAS PRODUCTION	0.50	M^3/M^3 OF DIGESTER VOL/DAY
ENERGY VALUE OF GAS	22.00	MJ/M^3
DIGESTER COST	250.00	$RAND/M^3$
DIGESTER MAINTENANCE	10.00	% OF CAPITAL COST PER YEAR

Table 9.5 System Parameters

SYSTEM	MAX DEM	USE	DEMAND	DIGESTER VOL	ENGINE MAKE & MODEL	kW	CAPACITY FACTOR
	kVA	HRS/DAY	kWh/DAY	m^3			
DOMSTC-1	2.50	5.75	11.50	10.58	LISTER ST1	4.50	0.44
DOMSTC-2	3.50	5.75	14.75	13.58	LISTER LR2	4.90	0.52
DOMSTC-3	4.00	5.75	10.35	9.53	KUBOTA D750	6.71	0.27
WKSHP-1	10.00	11.50	68.98	63.49	LISTER ST3	13.40	0.45
WKSHP-2	15.00	11.50	85.23	78.45	DEUTZ F3L912	22.70	0.33
DAIRY-2	25.50	5.50	137.00	126.10	LISTER HR4	33.70	0.74
PUMP-1	10.00	13.00	100.35	92.37	DEUTZ F2L912	14.50	0.53
PUMPING	50.00	9.00	450.00	414.20	ADE 354T	64.60	0.77

The nomenclature for the systems corresponds to that used previously Using the above data, the life-cycle costing of power production was determined, the results of which are presented in Table 9.6. Once again the unit costs based on 100% fuelling by diesel are shown by way of comparison. It is apparent that quite significant savings can be made by using biogas for power generation. An additional benefit of anaerobic digestion is the digester effluent which is a nitrogen-rich fertiliser. The potential value of this by-product has not been costed into these calculations as it would not be of equal worth to all users of biogas.

Lower cost digester construction methods can be used, but as is shown by the figures in Table 9.7, the effect of this on the final unit power cost is not that significant. The digester costs used here are based on estimated costs of Indian Khadi Village Industries gobar gas plants (Rivett-Carnac, 1982).

Table 9.6 Unit Power Costs Using Biogas in a Dual-Fuelled Genset

SYSTEM	DIGESTER COST	GENSET COST	ENG LIFE	ENG-INES	DUAL-FUEL COST/ kWh	DIESEL COST/ kWh	CAPACITY FACTOR
	RANDS	RANDS	YEARS		c/kWh	c/kWh	
DOMSTC-1	2646	6679	7.15	3.50	49.24	63.22	0.44
DOMSTC-2	3394	7115	7.15	3.50	42.43	59.21	0.52
DOMSTC-3	2382	8944	7.15	3.50	69.47	80.90	0.27
WKSHP-1	15873	14353	3.57	7.00	34.43	49.19	0.45
WKSHP-2	19613	19785	3.57	7.00	37.69	53.53	0.33
DAIRY-2	31526	24331	7.47	3.35	19.22	29.55	0.74
PUMP-1	23092	15098	3.16	7.91	29.02	42.06	0.53
PUMPING	103551	15701	4.57	5.48	14.31	27.49	0.77

Table 9.7 Unit Power Costs (Indian Digester Costs)

SYSTEM	DIGESTER COST	COST/ kWh
	RANDS	c/kWh
DOMSTC-1	1409	46.86
DOMSTC-2	1706	39.89
DOMSTC-3	1299	67.15
WKSHP-1	5577	31.12
WKSHP-2	6561	34.29

Sensitivity analyses were then carried out, again based on the data for the WKSHP-2 system, and using the higher digester costs i.e. those based on the European data.

As was pointed out earlier, anaerobic fermentation is sensitive to temperature. The lower the digester temperature, the lower is the gas production rate. Thus, unless another source of heat is available, some of the biogas may have to be used to maintain the digester temperature at an acceptable level. This would have to be investigated in each case according to the prevailing conditions at the digester site. In this evaluation therefore, a specific volumetric gas production rate of 0,5 m^3/m^3 of digester/day has been chosen, and is achievable under most conditions in South Africa. Figure 9.2 shows the extreme sensitivity of the unit power cost to this parameter.

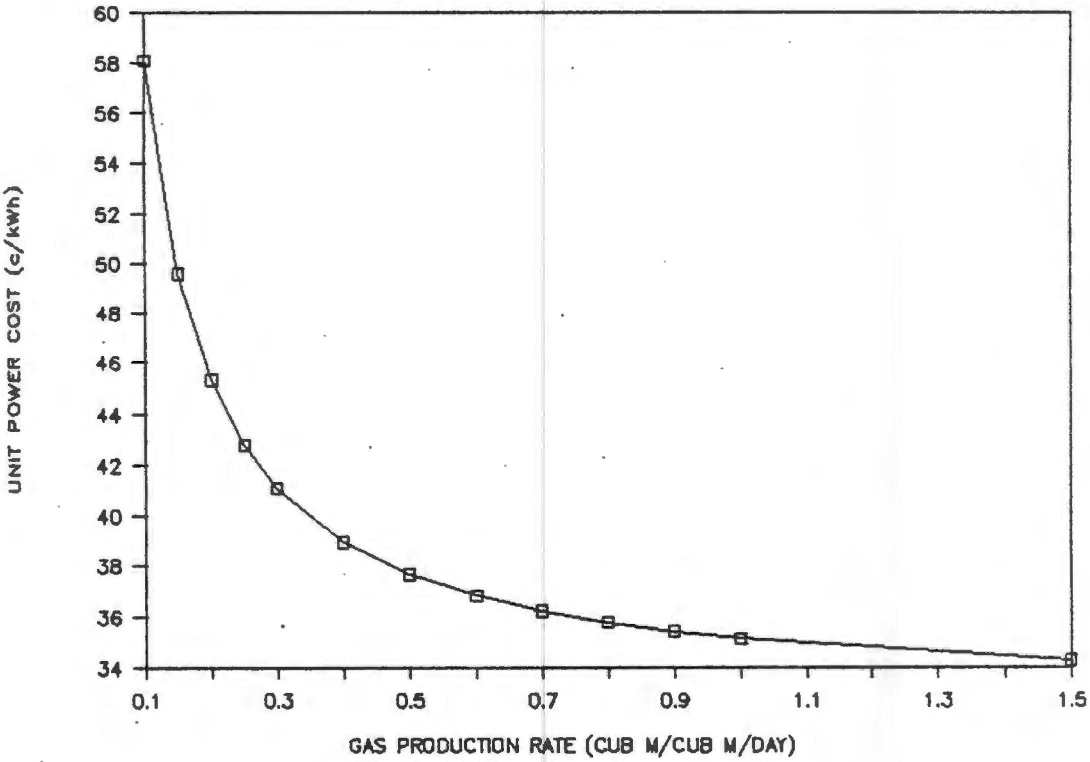

Figure 9.2

As in the case of the producer gas powered system, the sensitivity of the unit power cost to the other significant parameters is linear. The pilot fuel percentage has a fairly strong influence on the unit power cost, with a 10% increase in diesel consumption causing a 1,91 c/kWh increase in the unit cost.

For each R50,00 increase in the digester construction costs per m³, the unit power cost increases by 1,02 c/kWh. The unit cost is not therefore too sensitive to the digester construction costs.

The final figure, Figure 9.3 overleaf, shows the contribution made by each cost component to the overall unit cost of power.

9.4 CONCLUSION

The use of producer gas or biogas can be seen to have some merit. However the advantages of producer gas are only really apparent in larger systems with high capacity factors (Table 9.8), while biogas has the edge over diesel for all system sizes (Table 9.9). The main disadvantages of these systems are their initial capital costs, and the necessity for additional O & M. Their real benefits will begin to emerge as the cost of diesel fuel increases.

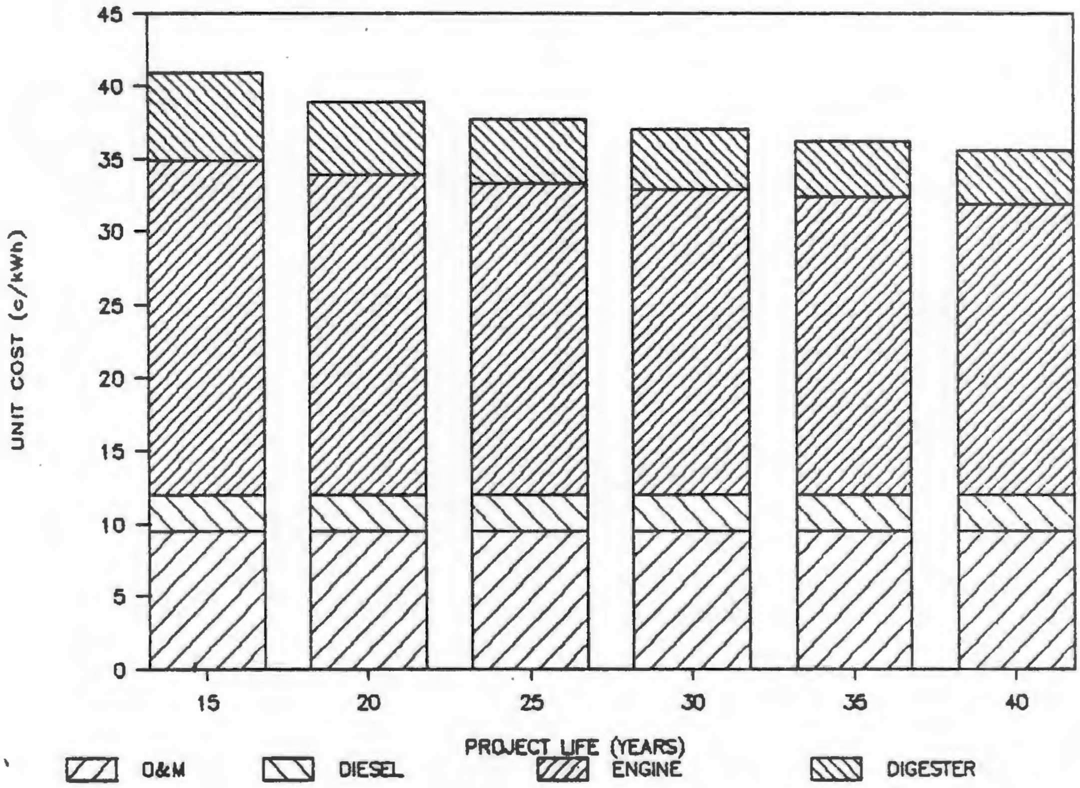

Figure 9.3

Table 9.8 Summary of Unit Power Costs Using Producer Gas

SYSTEM	DUAL-FUEL COST/ kWh	DIESEL COST/ kWh	CAPACITY FACTOR
	c/kWh	c/kWh	
DOMESTIC 1	104.47	63.22	0.44
DOMESTIC 2	86.03	59.21	0.52
DOMESTIC 3	130.48	80.90	0.27
DOM & WKSHP 1	44.68	49.19	0.45
DOM & WKSHP 2	46.36	53.53	0.33
DOM & DAIRY 2	24.41	29.55	0.74
DOM & PUMP 1	36.22	42.06	0.53
PUMPING	16.65	27.49	0.77

Table 9.8 summarises the unit costs of power generated using producer gas in dual-fuelled gensets. The costs of power from straight diesel-powered gensets is included for comparison purposes. Table 9.9 is a similar summary for dual-fuelled biogas gensets.

Table 9.9 Summary of Unit Power Costs Using Biogas

SYSTEM	DIGESTER COST	DUAL-FUEL COST/ kWh	DIESEL COST/ kWh	CAPACITY FACTOR	INDIAN DIGESTER COST	UNIT POWER COST
	RANDS	c/kWh	c/kWh		RANDS	c/kWh
DOMESTIC 1	2646	49.24	63.22	0.44	1409	46.86
DOMESTIC 2	3394	42.43	59.21	0.52	1706	39.89
DOMESTIC 3	2382	69.47	80.90	0.27	1299	67.15
DOM & WKSHP 1	15873	34.43	49.19	0.45	5577	31.12
DOM & WKSHP 2	19613	37.69	53.53	0.33	6561	34.29
DOM & DAIRY 2	31526	19.22	29.55	0.74		
DOM & PUMP 1	23092	29.02	42.06	0.53		
PUMPING	103551	14.31	27.49	0.77		

CHAPTER TEN

ANCILLARY POWER GENERATION EQUIPMENT

Given the nature of remote area power supply systems, and in particular, those using renewable sources of energy, many such systems require ancillary equipment of various forms and degrees of sophistication. This can basically be divided into two groups, energy storage equipment and power conditioning equipment. As energy storage is of such significance, this topic will be dealt with in some detail.

10.1 ENERGY STORAGE

Because of the intermittent nature of most renewable energy sources, one of the most important components in most renewable energy based power installations is some form of power storage. This storage is necessary to provide a buffer which will allow the matching of the energy source with the peak demands of the system being supplied with power. Thus, for example, the sun's energy received during the daylight hours can be converted into electrical energy through photovoltaic cells, stored in batteries as chemical energy, and then converted back into electrical energy during the hours of darkness or other times when it is required.

Pump storage has been mooted as another form of energy storage suitable for alternative power supply schemes. However this technology is very much site dependent, and can involve high capital input for a relatively small storage capacity. This alternative has been investigated by the Department of Agricultural Engineering, and is not recommended as a first option for reasons of cost (pers. comm.).

10.1.1 Storage Batteries

As batteries can play such an important role in the supply of power in remote areas, they will be dealt with in some detail. The most common form of storage used in renewable energy installations at present is the secondary (or rechargeable) storage battery. A secondary storage battery consists of an assemblage of cells that are chemically reversible to a degree that permits electrical recharging. In this report the term battery will be used to exclusively denote an assembly of electrochemical cells electrically connected in series.

By way of explanation, a primary battery system is one in which the reagents contained in the constituent cells are the source of electrical energy e.g. torch battery. A secondary battery on the other hand depends on electrical energy initially being produced elsewhere by some form of electrical generator. For detailed explanations of the electrochemistry and construction of batteries, the reader is referred to the many specialist texts on the subject.

Despite the great deal of research that has been done into batteries, their construction and characteristics, they probably constitute the most complex and sensitive component of a renewable power supply system. As lead-acid batteries are the most commonly used storage media, this section will discuss their characteristics which are of importance in their selection and use as stationary power system storage media.

<u>Battery Design</u>

The electrical energy that a battery delivers during discharge is derived from the electrochemical reactions taking place between the electrolyte and the active materials of lead oxide and spongy lead. The former is held in a paste on the negative plate while the latter is in the paste of the positive plate. The greater the amount of these materials the greater will be the capacity of the battery. The theoretical amounts of active material required for 1 Ah of electricity can be determined from basic principles, but in reality from three to five times this amount is used in the construction of the cell.

For a cell to give the maximum output for a given mass of material, it is essential for the active material to be readily accessible to the electrolyte. This is achieved by using a large number of thin plates made up of a lead grid covered with a high ratio of active material to grid. The same mass of active material distributed in a few thick plates containing a dense or hard paste would result in a cell of much lower capacity, because of the reduced accessibility by the electrolyte. A plate with porous active material is capable of producing a greater output, particularly at high rates of discharge, than a plate with a dense, hard, active material. Porosity is achieved by adding small amounts of carbon or other expanders to the paste mix. Too high a porosity is to be avoided for plates regularly subjected to cycles of charge and discharge, as this is conducive to short life caused by premature shedding of the active material.

The formation of lead sulphate during the normal discharge of a cell reduces the porosity of both plates, because of the lead sulphate occupying more space than the original active material. Normally this crystalline expansion is taken up by the pores being compressed, and no harm results. If however, the sulphation is excessive, owing to the cell being persistently over-discharged and undercharged, or left for long periods in a discharged condition, the sulphation expands beyond the normal absorbing ability of the pores. The active material is then subject to pressure which results eventually in fracture of the grid, or loss of active material from the plate. If the condition is not remedied soon enough, the cell loses capacity and will not accept charge.

The electrolyte used in lead-acid batteries is a solution of pure sulphuric acid in pure water. It is important that the water used to top up batteries is either distilled or de-ionised, otherwise contamination of the active material can occur, with subsequent reduction in battery performance and capacity. The water used should therefore meet the following specifications (Smith, 1980):

Impurity	**Max. Conc. (ppm)**
Chlorine	15,0
Copper	10,0
Iron	10,0
Ammonia	10,0
Arsenic	3,0
Manganese	0,1
Nitrates and nitrites	10,0
Total fixed residue	250,0

Sulphuric acid should only be added to a battery if the specific gravity of the electrolyte is to be altered, and then only after consultation with the manufacturer.

<u>Rating of Battery Capacity</u>

The capacity of a storage battery may be expressed either as the ampere-hour (Ah) or watt-hour (Wh) capacity. The ampere-hour capacity is a measure of the electrochemical reaction taking place in the cells, while the watt-hour capacity is a measure of the batteries ability to do work. The watt-hour capacity is obtained by multiplying the ampere-hour rating by the average value of the voltage during the discharge period.

In stating the capacity of any battery it is necessary to specify the rate at which the battery is discharged, the final or cut-off voltage, the full charge specific gravity and the temperature. These four factors affect the battery's capacity to a marked degree, that is apart from other factors related to the design or condition of the battery.

The most commonly adopted ampere-hour capacity rating is the time rating. By this it is meant that the capacity of the battery is stated to be a certain number of ampere-hours that can be delivered within a specified time. The most commonly used basis is the 8-hour rate which is used for stationary batteries, while automotive batteries are customarily rated on a 5-hour rate basis (Willard, -). Thus the capacity of a battery is stated as, for example, 80 Ah at the 8-hour rate, meaning that the battery can deliver 10 A for 8 hours. At discharge rates of more than 10 A the battery will provide less than 80 Ah, whilst at rates less than 10 A it will provide more than 80 Ah.

The entire theoretical capacity of a battery can not be obtained for several reasons. The electrolyte does not diffuse into the pores of the plate with sufficient rapidity, the resistance of the active material and the electrolyte increases as the discharge progresses, and finally it is not practical to discharge the battery to zero voltage. As the the battery discharges, the voltage at the terminals falls gradually from its open-circuit value until the end of discharge is approached, at which point it falls much more rapidly.

If a curve is plotted, showing the voltage throughout the period of the discharge, the rapid fall begins at what is commonly known as the 'knee' of the curve. The discharge may be continued slightly beyond this point, but only a small percentage of the total capacity can be obtained after the 'knee' is passed. The amount of the actual capacity remaining after the 'knee' depends on the rate at which the battery is being discharged, the percentage remaining being greater, the higher the rate of discharge.

The term final voltage is used to designate the minimum useful and accepted voltage at various rates of discharge, and is the value at which the maximum number of ampere-hours can be obtained. It is found just below the 'knee' of the curves described above, and is lower with higher rates of discharge. The choice of final voltage will depend either on the battery application or the discharge voltage characteristics of the battery. For example, a lighting load requires a fairly high stable voltage and this will be the case with most remote power supply systems, whilst a heavy engine starting load requires a high current at a lower working voltage. When final voltage is determined by the discharge characteristics, it is usually fixed to allow a fall of 0,3 V/cell from the initial voltage. In the case of most lead-acid batteries a nominal standard final voltage of 1,75 V/cell is commonly used (Willard, -).

Most chemical reactions are accelerated at higher temperatures, and those taking place within an electrochemical cell are no exception. In addition the resistance and viscosity of the electrolyte are are reduced at higher temperatures, thus reducing the voltage drop or loss within the cell and maintaining its terminal voltage at a higher value. These effects combine to increase a battery's capacity at higher temperature and reduce it with lower temperature. Because of the effect of temperature on the internal resistance of the battery, the capacity varies with the rate of discharge as well. The standard reference temperature used almost universally is 25°C.

The specific gravity of a cell is a measure of the concentration of the acid electrolyte contained in it. The value of the specific gravity when the battery is fully charged is a matter of design and is affected by many factors. In the first place the gravity must be high enough for the electrolyte top contain a sufficient amount of actual sulphuric acid to fulfill the requirements of the cell. On the other hand if the gravity is too high the acid content may be strong enough to have a direct chemical effect on various parts of the cell.

Between these two extremes there are other factors such as capacity, operating temperature, conditions of service and battery life, which dictate the best gravity for the situation. The full charge gravity most commonly used for heavily worked cycling batteries is 1,290 whereas partially cycled batteries, such as those used for railway car lighting are run at 1,245 (Willard, -). As the battery discharges the gravity decreases and can thus be used as an approximate indication of the state of charge of the battery.

It must be remembered haowever that the specific gravity will vary with temperature, and therefore corrections must be made for this. The change is equal to three points (,003) of gravity for every 5°C change in temperature (Willard, -). Likewise the gravity will vary as the electrolyte level falls and rises with the consumption of water through gassing and evaporation. Both these effects require that a gravity measurement taken at a specific time should be corrected to the normal reference temperature of 25°C and normal level. As the battery ages small losses of acid will occur and result in a slow decrease in the full charge gravity of the battery.

Given all the above it can now be seen that a battery rating must be qualified to accurately represent its performance. The following is an example of a full specification of a particular battery:

> 12 cell battery with a capacity of 500 ampere-hours at the 8 hour rate, at a temperature of 25°C, to a final voltage of 1,75 volts per cell, full charge specific gravity 1,250.

which can be abbreviated to:

> 12 cell 50 Ah/8 hr/1,75V p.c./25°C/s.g. 1,250

<u>Discharge Characteristics</u>

In general, a battery may be discharged without harm at any rate of current it will deliver, but the discharge should not, however, be continued beyond the point where the cells approach exhaustion or where the voltage falls below a useful value.

Discharging at a constant current value, the initial voltage will depend on the rate of discharge and the normal characteristics of the cell. As the discharge continues, the cell voltage will slowly decrease during the first 70 to 80% of the total time period. It will then fall more rapidly passing over the 'knee' as full time and capacity are reached. The 'knee' is more pronounced at low rates of discharge.

As mentioned earlier, the total ampere-hours available vary with the rate of discharge, being lower at higher rates. This lower capacity does not however represent any specific loss of energy - it simply means that the cell voltage falls to its minimum useful value in a shorter period of time. To illustrate this, assume a cell rated at 100 Ah at the 8-hour rate. From the following figure it can be seen that the 2-hour capacity is about 66 Ah.

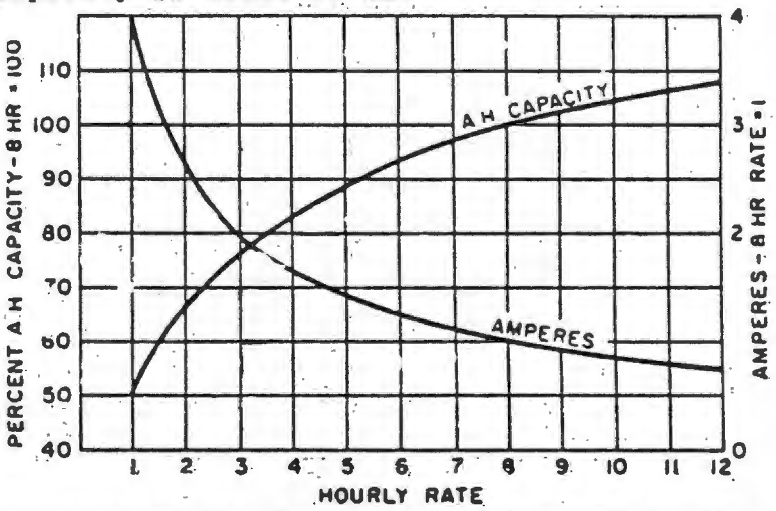

Figure 10.1

If it is discharged at the 2-hour rate, i.e. 33 A, the voltage will fall to its established minimum or final voltage in 2 hours, but if the discharge rate is then decreased, the voltage will 'recover' or rise, and further Ah can be obtained before the voltage again falls to the same minimum value. In fact if the current is reduced to 5,5 A for the remaining 6 hours, the total 100 Ah can still be obtained over the 8 hour period to the same final voltage.

It is generally true, therefore, that where decreasing current rates are used, approximately the total ampere-hours for a given hourly rate can be obtained over that time period, regardless of higher rates of discharge during the earlier portion of the discharge. The following figure shows the approximate effect of discharging a cell at successively lower rates, carrying each one to the same final voltage. This result is not obtained, however, when the higher rates of discharge are in the latter part of the discharge period, as there is then no opportunity for sufficient diffusion of the electrolyte to maintain the cell voltage.

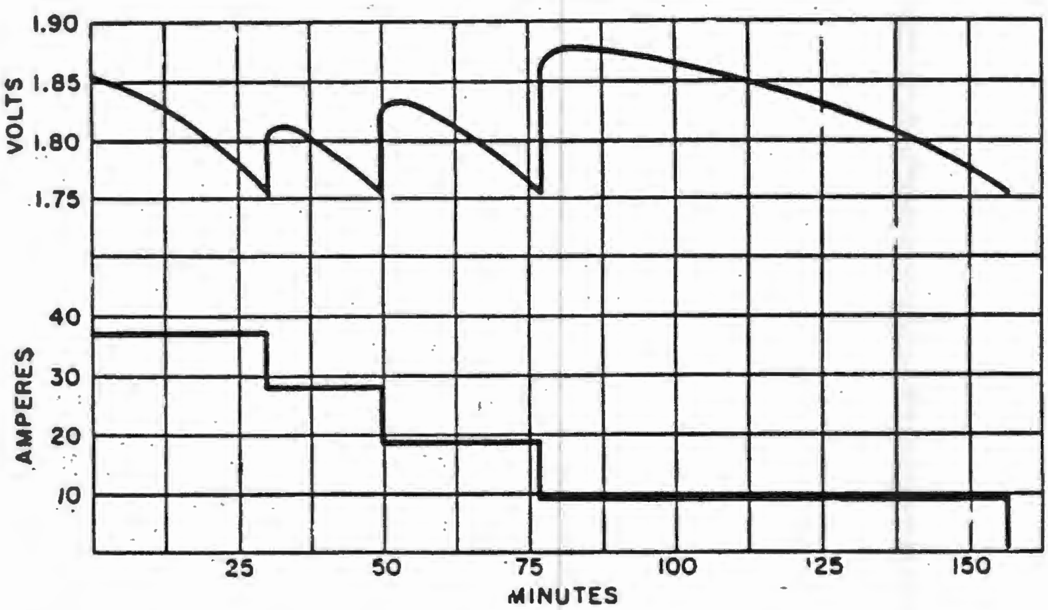

Figure 10.2 Effect of Discharge Rates on Cell Voltage

As mentioned earlier, a battery should not be discharged beyond the point where the cells approach exhaustion, as this can have harmfull results, particularly if the battery is not promptly recharged. During normal discharge, a certain amount of lead sulphate is formed. If over-discharge occurs this material may expand to the point where portions of it separate and lose proper contact with the grid, and therefore with the electrical circuit. On recharge, it cannot receive the charge and reamins as sulphate instead of returning to its normal fully charged state and form.

The above can also occur when a partially discharged battery is allowed to stay in this state for a long period before being recharged. In this case some of the normal sulphate may become crystalline in nature and is not easily reconverted to its original state. These phenomena decrease the capacity of the battery, and the sulphate tends to wash from the surface of the plates and fall to the bottom of the cell as sediment. As this sediment accumulates in the sump of the cells it can rise to a depth such that it causes shorting across plate bottoms.

<u>Charging Characteristics</u>

In general, a battery may be charged at any ampere rate that will not produce excessive gassing or temperatures above 43°C. Gassing is the phenomenon that occurs when a battery cell cannot absorb all of the energy from the charging current due to the slow diffusion of molecules through the electrolyte, resulting in the electrolysis of water into its component gases hydrogen and oxygen at the negative and positive plates respectively.

The charging of a battery can be divided into three stages, during which different reactions are predominant:

The **efficient charge stage** during which the predominant reactions are the transformation of $PbSO_4$ to lead and lead dioxide. Charge acceptance i.e. that part of the current flowing through the cell which is used for charging, is $\pm$100%. During this period, the state-of-charge reaches 70-80%. This stage is over when the cell voltage reaches 2,35 V and gas evolution starts.

During the **mixed stage** water decomposition processes proceed simultaneously with the charging reactions. The charge acceptance is gradually and continuously reduced, and the battery is completely charged at the end of the stage. Cell voltage is increased from 2,35 V to 2,50 V.

Once the cell is completely charged the **gas evolution stage** begins and water decomposition and self-discharge processes begin in the battery.

Manufacturers of batteries usually specify a normal or 'finish-rate' in amperes for each type and size of cell made. This rate is a charge current which can be used safely at any time that charging is required, and can be continued to the completion of charge without causing excessive gassing or high temperature. This rate is usually between 4 and 10 amperes per 100 Ah of the battery's 8-hour capacity, depending on the cell structure and battery assembly. Where a number of high capcity cells are assembled as a battery in close proximity, the available surface for heat dissipation is reduced and comparatively lower finish-rates must be used to avoid overheating of the battery.

A battery which is partially or completely discharged can safely absorb much higher currents than the finish-rate, up to possibly 10 times that value, but as full charge is approached, the current must be reduced, either gradually or in one or more steps, to the finish-rate or less. In practical applications, it is seldom necessary to use currents of more than 4 or 5 times the finish-rate to charge in the time available. When the charge is complete, it should be stopped or reduced to a very low value.

In any type of service under- or over-charging of a battery should be avoided. An insufficient charge, even to a small degree - but continued, will cause gradual sulphation of the negative plates with eventual loss of capacity and reduction of battery life. An excessive amount of charge results in the grids of the positive plates `forming up` into lead peroxide, physically weakening them and increasing their resistance. If the overcharging is at a comparatively high rate, excessive gassing will result tending to wash active material from the plates. All of these effects reduce the life and efficiency of the battery.

<u>10.1.1.2 Battery Types and Costs</u>

Various types of lead-acid cells are obtainable, but not all are suited to use in power supply systems. The most important characteristic of batteries to be used in such systems is their ability to be put through numerous cycles of charge and discharge. Typically this should be in excess of 2 500 cycles of 30-50% depth of discharge without significant loss of capacity.

Batteries designed to withstand this mode of operation are the so-called tubular cells and traction batteries. Tubular cells are used in stationary applications for uninterruptable power supplies (UPS), and backup emergency systems. Traction batteries are used to power milk floats and forklift trucks, and are thus ideally suited to this mode of operation. Both these types of battery, if maintained correctly it is claimed by the manufacturers, can achieve service lives of 10 years and more.

Automotive batteries on the other hand are designed for shallow discharges, delivering a high current over a short period. Thus when operated in a deep discharge cycling mode they deteriorate, and lose capacity rapidly. Even with careful maintenance it is doubtful that they will achieve more than a two year service life.

It is possible however to make relatively minor modifications to automotive batteries that would render them more suitable to a cycled mode of operation. These would entail changes in the plate thickness, alloys and paste mixtures, enveloping of the plates, alterations to the electrolyte composition, and a deepening of the battery casing. This type of modification has been made to automotive batteries in Colombia, where they are now widely used by people who do not have access to conventional power sources. Recharging in many areas is achieved through the use of micro-hydro power, while in others PV cells are used. Unfortunately details of the Colombian initiative have not been documented, and were received through personal communication.

Special application batteries are currently being developed for PV power systems in particular. These are in general low-maintenance cells, and are presently very expensive, thus placing them out of contention for most remote area power systems.

In this report tubular cell, traction and automotive batteries have been used in the economic evaluations of the various remote area power supply systems. The data used are those supplied by the manufacturers as there is unfortunately very little documented on the expected life of batteries in such systems.

Type of Battery	Cost [Rand]	Service life [years]
Tubular cell	383 x kWh + 47.5	10
Traction	231 x kWh + 52.3	10
Automotive (Standard)	132 x kWh	2

Enquiries directed to manufacturers of batteries in Europe met with similar responses, and there is little in the literature regarding battery performance in small remote power systems. A subsidiary of Phillips has carried out independent test on a wide range of batteries for use in photovoltaic systems. However, it is claimed that when the results were released to the manufacturers they were so alarmed that they asked that not be released for publication, and that the manufacturers be given time to rectify the problems identified (pers. comm.).

10.2 POWER CONDITIONING EQUIPMENT

The emergence of renewable sources of power has reopened the debate on which is the better option, AC or DC power. Given the losses of power resulting from the conversion of DC power into AC power, it would seem appropriate to be considering the use of DC appliances. Without entering into a lengthy discussion of this subject, suffice it to say that were DC appliances to be developed alongside lower cost renewable sources of power such as micro-hydro battery chargers, windchargers and PV panels, they would be assured of a market in the remote areas of South Africa.

Having said the above, the principal piece of power conditioning equipment used in remote power systems is the inverter. It is used to convert the DC of the storage batteries into the AC required by most modern appliances. In the past they were principally of the rotary type, using a DC motor to drive an AC generator to produce constant frequency AC current. Modern inverters are almost all static, and make use of solid state components.

Inverters are available in varying degrees of sophistication, ranging from those that produce a square wave form alternating current through quasi-sine wave inverters, to those that produce a perfect sine wave. The first, which is less complex and therefore cheaper than the others, is suitable for operating many AC appliances, but may cause overheating in some.

It must also be remembered that inverters are only efficient when operated at close to their rated capacity, with the efficiency dropping off to typically 60% at 50% of rated capacity. The upshot of this is that they should be sized so as to be operated as close to full rated capacity as possible. A recommended strategy is to operate as few AC appliances as possible, and to use accurately sized dedicated inverters for each of these. This also obviates the necessity to oversize to allow for the surge caused by all inductions motors on the inverter circuit starting simultaneously. Indeed, most inverters can deal with a small surge i.e. over rated capacity, for a few seconds, or even up to a minute.

There are a number of local manufacturers of inverters producing a range of products suitable for various applications. The principal market for their equipment is in UPSs for computer installations. The bulk of the equipment is therefore designed for use in a clean well-controlled environment. It became apparent while researching this report, that these inverters had, with some exceptions, not performed to specification when used in the harsher environments found in remote areas. Certain manufacturers are however making a concerted effort to rectify this situation. The S.A. Bureau of Standards, in conjunction with some of the local inverter manufacturers is currently developing performance standards for inverters and UPSs.

An objective of this project was to evaluate locally produced inverters. Contact was made with various experts in the field in this regard, and it was established that this was a rather ambitious undertaking. Nonetheless, a microcomputer-based inverter test rig was set up at UCT. The main object of the rig was to subject the inverter to various simulated modes of operation, and to evaluate its performance, mainly in terms of its efficiency. The project was plagued by technical problems such as reverse currents emanating from the inverters, and was therefore not regarded as reliable enough for use in wide scale evaluation of locally available inverters.

The South African Post Office, being a user of inverters, has carried out its own evaluation of those available locally. However, the engineers involved were unable to release the results of their tests. These tests were also carried out with the view to using the inverters in UPSs, and so it is doubtful whether they would be applicable to the less protected harsher conditions found in remote areas.

10.3 CHARGE REGULATING EQUIPMENT

It is evident that correct battery charging procedure is important in ensuring satisfactory battery performance and life. Modern charging eqipment provides safe and flexible control of battery charging either automatically or with the minimum of manual attention.

In the production of batteries the raw pasted plates are converted to the active states of lead dioxide and spongy lead in the presence of dilute sulphuric acid during a process known as formation charge. The plates are then washed and dried before assembly into cells and batteries. After the addition of the electrolyte and before placing the battery in service it is then necessary to give the battery an initial charge. This consists of passing a current into the battery for a number of hours. This initial charge is very important in that it serves to complete the electrochemical conversion of the remaining lead sulphate, thus ensuring that the battery starts its life capable of delivering the rated capacity.

Batteries which are cycled initially increase in capacity by as much as 10 - 20% more than the nominal capacity. Given that batteries used in remote area power supply systems are subjected to cycling, it is likely that this phenomenon should occur with them.

10.3.1 Battery Charging Methods

Correct battery charging techniques entail the control of the current and time of charge to suit the size and operating conditions of the battery. In the case of a power supply system, the batteries are usually permanently connected to both the load they are serving and the source of charging current. However, it is often the case that the major demand for power is largely confined to one part of the day, usually the evening. The charging source, however, being from a renewable source such as solar or wind energy, is intermittent, although in the former case it is generally more predictable, at least in the times that it can be expected to be available.

Given the above it is evident that some form of charge and discharge control is necessary to ensure the satisfactory operation of the battery system. The basic principle which must be followed during charge is : maximum admissable current during the efficient charging period, and optimum low current during the mixed stage. This can be achieved by applying charging regimes with a versatile profile and current or voltage control.

Constant-current charging.
The true constant-current method is not necessary for the efficient charging of batteries and is not widely used. It was used in the past, mainly because it allowed for quick and accurate determination of the number of ampere-hours put into the battery.

Constant-voltage charging.
In this case a voltage equivalent to 2,3 to 2,4 V/cell is applied without any ballast resistance in the circuit. This allows for a large initial charge current which falls fairly quickly as the back-e.m.f. increases, and near the completion of charge, the current falls to a value less than the finishing rate. This method is quite safe, but is rarely used for batteries that are deeply-discharged as it requires a charger capable of a very high output for a short time, and would thus not be cost-effective. It is used mainly in situations where batteries are discharged no more than 25% of their capacity.

Modified constant-voltage charging.
The very large current at the beginning of a constant-voltage charge makes it necessary to limit the initial or starting current, and to accomplish this a fixed resistance of small value is placed in series with the battery.

Controlled current-voltage charging.
During the efficient initial stage of charging constant-current conditions are used, followed by a crossover to constant-voltage conditions when a voltage of 2,4 V/cell is reached. The value of the cell voltage is chosen to give slight gas evolution. The current for the initial charge depends on the temperature and age of the battery. For example the current through heated batteries is higher than through cooled ones. To avoid systematic undercharging of separate cells in the battery, equalizing charges should be carried out periodically at higher voltages.

Tapered charging.
In this method the maximum charging current is limited by the voltage of the cell. Charging commences at the maximum current at a cell voltage of 2,1 V and is then reduced to a defined value upon the cell reaching 2,6 V. Also at a voltage of 2,5 V/cell, the current must not exceed 8,33% of the 5-hour capacity. Under these conditions, the rate of gas evolution will not surpass the permissible limit, and no damage will be caused to the battery. The gassing will however be sufficient to ensure good mixing of the electrolyte. The correct choice of a tapered charger depends on the capacity of the battery and the duration of the process. In order to reduce charging time, a two-step taper charge can be used, with a higher initial charge current.

Equalizing charge.
A battery is both charged and gas is evolved during the mixed-charge state. A clear-cut point which defines the end of charging does not exist. This problem is usually solved by following manufacturer recommendations, or through user experience. In addition, the cells are not always all in an equally charged state. To avoid this charge mismatch and to ensure maximum life from the battery, manufacturers recommend that the battery be subjected to a once or twice monthly equalizing charge. It is essentially a prolonged charge at the finishing charge rate or less. The equalizing charge is considered

finished when the concentration of the electrolyte in each cell remains the same over a two-hour period, provided the charge current has been held constant over that period. Equalizing charges tend to nullify the effects of deep cycling on negative plates, and some manufacturers recommend that the best means of maintaining plates in a healthy condition is to subject them to an occasional deep discharges with a full equalizing recharge.

10.3.2 Charging Equipment

Battery charge regulators are made in a wide range of voltage and current output to suit any number of cells and capacity. Monitoring is accomplished with sophisticated electronic control, and the termination of the charge when the battery is fully charged is automatic.

A number of local companies are manufacturing the equipment needed for the monitoring of battery charging in remote power systems. No extensive systematic evaluation of this equipment has been done as yet. The ERI is currently running a number of pilot PV power projects making use of some of this equipment.

10.4 HYBRID POWER PLANTS

To be effective hybrid power plants rely substantially on much of the equipment discussed in this chapter, and it is for this reason that they are briefly discussed here.

In many remote areas the levels of available power from an alternate resource such as solar radiation, wind or water may be insufficient to meet the full needs of the consumer. In other cases the cost of the equipment needed to meet the full power needs at desired level of reliability may be prohibitively high. To overcome these problems, the consumer should consider the use of an hybrid power generation system making use of a combination of power sources, exploiting the strong and avoiding the weak points of the technologies available.

Clearly, there are no easy rules to follow in selecting an autonomous power system. Almost every application requires careful analysis. This involves the examination of the energy resource to be used, investigation of the competitive technologies, and the evaluation of the total costs over the lifetime of the system. The following are a few hybrid combinations, and some of the common problems associated with them.

10.4.1 PV-Diesel

As has been pointed out already, part of the initial capital cost of a PV system is generated by the need for autonomy i.e. that it will be able to support its load under all conditions. This worst-case design can lead to an extremely high capital outlay. To reduce this cost, a diesel genset can be used to provide the "cushion", and provide power during the periods of low insolation. Although the design of such a system is dependent on a number of factors, the addition of a diesel genset typically allows a 15 to 20% reduction in array size and a cut in battery bank by a factor of three or four.

In economic terms, comparing diesel to PV power systems is a trade-off between operating and initial capital costs. This trade-off will obviously play a big role in determining the extent to which power will be provided by each source. As a general rule, loads with small power requirements are generally best served by standalone PV systems. In such cases, the array cost saved by hybridization is far exceeded by the cost of the diesel fuel required. Furthermore, the smallest diesel genset generates 3 kW, and operating such a machine for a small load is very inefficient.

Hybrid systems prove the most valuable where reliability is of paramount importance, such as for telecommunications installations and remote clinics with operating facilities. They are also cost effective in areas where available insolation varies greatly. The Western Cape provides such an example, where the summer insolation levels are high, but the winter rainfall conditions necessitate large power storage banks.

10.4.2 Wind-Diesel

Hybrid systems combining wind turbines with diesel generators have a number of inherent problems. The most important is the fluctuating character of the wind - variations being of both short and long duration. Because of these fluctuations the available wind power can never be exactly matched to the demands of the user. Solutions to the above problem will vary from installation to installation, and are mainly dependent on wind characteristics.

In a hybrid system without battery storage, any shortage in wind power will have to be made up by the diesel genset. If the wind is gusty i.e. variations are of a short duration, this can result in the diesel engine running for short periods which is clearly unsatisfactory in terms of engine efficiency. Such a situation can be dealt with either by electronically-controlled shedding of unecessary loads, or else by installing battery storage which would make up the shortfall in power required. If on the other hand there are long periods of calm, the diesel genset can probably be run at closer to its optimum efficiency. This would obviate the need for either load shedding or battery storage.

The wind characteristics are are obviously the most important factor in determining the optimum combination of equipment in a hybrid wind-diesel power system. Design of the system therefore depends very much on the availability of reliable wind data for the site in question.

<u>10.4.3 Genset-Plus Systems</u>

These are not true hybrid power plants, but embody some of the elements of the philosophy behind hybrids. In these systems an appropriately sized battery bank is installed between the diesel genset and the load. The original diesel could even be replaced with a much smaller unit as the genset output itself no longer needs to be matched to the peak demand of the system, but rather the inverter supplying the power to the system. The diesel genset is now run under complete electronic control, based on the state of charge of the battery bank. The engine is run at a specific load to give optimal performance. Engine running times are reduced to less than one third of those found under direct generator power supply, thus extending time between replacement or overhaul of the engine.

With the above arrangement the system load can be split, with the 220V AC loads being supplied via an inverter, while those devices which can be run off DC power are powered directly from the battery bank. The battery bank acts as a load levelling device, as peak demands, such as the power required to start an induction motor, can be provided by the battery.

Because the need no longer exists to meet the abovementioned peak demands, the battery charging diesel genset does not need to be as large. Although it is possible to modify existing plant to conform to the required battery charging criteria, best economy is achieved by installing smaller, new plant. For example, for a systems with a 20 kW peak demand an 8 kVA generator set is adequate (Langworthy and Costi, 1983).

Genset-plus systems offer fuel savings of up to 90% over a conventional diesel installation. Payback of the marginal capital cost of the engine and charge controller, battery bank and inverter is conceivably achievable through fuel savings in one year (Langworthy and Costi, 1983)

As mentioned, storage is required in genset-plus systems to even out the load and to match peak demands, while in wind and photovoltaic systems it is required to provide power in calm and clouded periods respectively.

10.5 CONCLUSION

It became apparent during the course of this project that the area of ancillary equipment for alternative power supply systems requires a research project of its own. This project would look primarily at batteries, battery protection and charging equipment, and power conditioning equipment. This investigation should include that electronic equipment required for the implementation of hybrid autonomous power systems.

CHAPTER ELEVEN

CONCLUSION AND RECOMMENDATIONS

In general, the overriding considerations in choosing a power source are its cost and reliability, and most consumers will make a choice that provides some degree of both. However, the factors which constitute the cost effectiveness and reliability of a system are infinitely more complex than either its initial cost or its robustness.

It is probably true to say that most decisions regarding remote power systems are based mainly on consideration of the initial capital cost, without sufficient awareness of the true running costs. This report has attempted to analyse the various options available to remote power consumers in a more holistic fashion, taking account of all factors.

In this final chapter the various options are compared, as far as is possible, on an equal basis, bearing in mind the already familiar rider regarding the site-specificity of a number of the technologies. In order to allow some form of comparison the cost of power from the various technologies has been calculated on the basis of their providing AC power at a specific level over a 24-hour period. This power is continuous, except where indicated.

The equipment being compared is as specified in the various chapters relating to each technology, which is briefly as follows:

Imported:
- photovoltaic panels
- wind turbines

Locally manufactured:
- diesel engines
- gasifiers
- biogas digesters
- hydropower turbines
- tubular cell batteries
- power conditioning equipment

Figure 11.1 is a graphic representation of the comparison of power cost from the various alternatives available for remote areas.

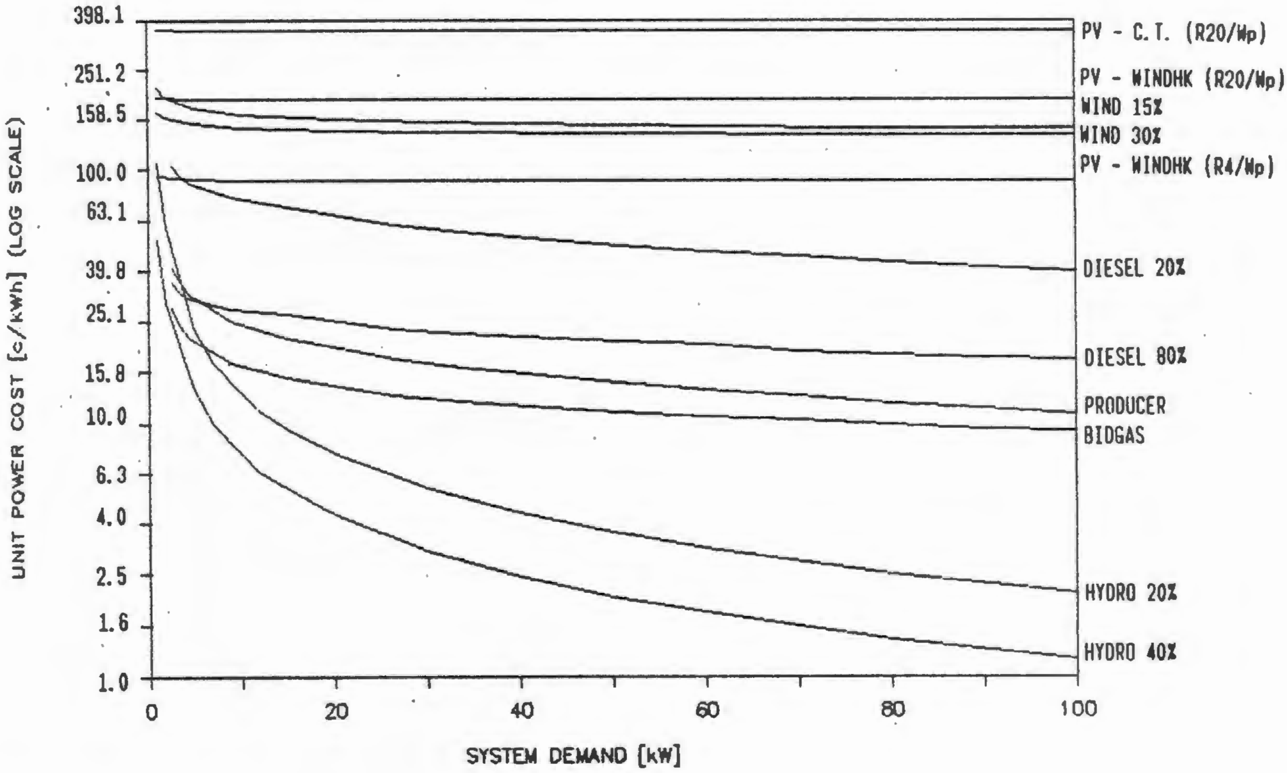

Figure 11.1

Bearing in mind that the y-axis in the above is on a log scale, it is apparent that remote area power supply options separate themselves into three categories.

From the figure it is apparent that small hydropower provides the cheapest power over almost the whole range under investigation, even at the low load factors shown i.e. 20 and 40%. Note, however a marked influence of economies of scale on the unit power cost. This is mainly attributable to the costs of the civil works required. Unfortunately, despite the low cost of power, South Africa is not well-endowed with perennially flowing rivers or streams. However, there are certainly areas, many currently without power, where small hydropower could definitely be considered. Included in these would be large areas of the Transkei and other areas along the Eastern Escarpment of the country.

The next group of power supply options are the internal combustion engines fuelled by diesel, producer gas and biogas. The cost of power from these is roughly an order of magnitude higher than that from the small hydropower plant. These options can, however, be more economical than hydropower at low demand levels i.e. around the 5kW demand level.

However, the two straight diesel curves give an indication of the effect of the load factor on the unit cost of power. It is probably true to say that the majority of gensets in remote areas are operated under conditions closer to the 20% load factor curve than the 80% curve. It is apparent therefore, that wind and PV power are already within striking distance of conventional diesel power at the lower demand end of the range.

The most costly category of power supply options are the wind generators and solar photovoltaic systems. The percentages given alongside the wind curves refer to the turbine capacity factors. Both of the wind systems are costed on three days of battery storage. It is difficult to determine what LOEP this represents, as it would require an in-depth analysis of the wind at a particular site.

The PV unit power costs are almost constant over the range 1 - 100 kW. This is to be expected given the modular nature of the systems. The high initial capital cost of the equipment used in wind and PV systems is the main reason for the high unit power costs shown by these systems. Reduction in the equipment cost will thus have some effect on the unit cost of power. This is shown, for example, by the curve of the cost of power from photovoltaic systems sited at Windhoek, assuming that the cost per peak Watt of photovoltaic cells were to drop to R4,00 from the present R20,00 per Wp. (R4,00/Wp is the module price expected to be achieved in the 1990s).

At the domestic end of the demand range, i.e. 1 - 10 kW, the reduction in the cost of photovoltaic panels brings the unit cost of power down to levels competitive with that from diesel engines running at low load factors. The replacement of batteries is another significant cost component for both PV and wind systems. It is clear therefore that effort devoted to developing lower cost energy storage equipment would yield appreciable returns in terms of reduction of unit power costs.

When considering the use of PV systems it must be remembered that at the small end of the power demand spectrum i.e. less than 2 kW, power is currently supplied either from petrol powered generators, or from lead-acid batteries. The cost of power from the former has been calculated to be over R10,00 per kWh (Muller, 1987). As this was based on DC output, it should be compared with a comparable PV system. The costs in Table 6.6 give the unit cost of DC power from a system capable of supplying 10,35 kWh/day as R1,94/kWh. Power from the PV system is thus almost an order of magnitude cheaper than that from the petrol genset.

Lead-acid automotive batteries are used, mainly in peri-urban areas, to power television sets and other audio-visual equipment. They are recharged by local garage or store owners who have access to power. The economics of battery use in this mode have not been thoroughly investigated. Costs of recharging in the Western Cape are known to be between R2,00 and R3,00. Assuming a battery life of two years, which is optimistic under deep discharge cycling conditions, the unit cost of power is of the order of R2,50 - R3,00. In practice the cost will probably be much higher, given that the batteries are generally abused in the charging and discharging processes. Once again therefore, power from PV systems provides a cheaper alternative.

It is apparent that a wide spectrum of options exists for power supply to remote areas of South Africa. Because of a number of factors such as cheap grid power, past self-generation habits, unfamiliarity with and high initial costs of alternative energy sources, they have not been as extensively exploited as they could have been. However, many of these factors are beginning to lose their impact. The cost of grid power is increasing in remote areas, both because of longer transmission lines and rising generation costs. The diesel fuel price has increased over the last decade. Both these have resulted in remote power consumers turning to at least consider alternatives. Those that could afford them, such as the state and provincial enterprises have in many cases made the change and thereby shown others the potential for these alternatives.

Aside from the above, other factors, which can most concisely be termed political, have opened up a whole new demand for remote area power supply. Development of rural areas, mainly populated by subsistence farmers, has revealed the need for cheap low demand power generation techniques. The characteristics of these areas are very similar to those of developing regions throughout the so-called Third World, and the power supply methods used in those instances could provide valuable pointers.

The power required in these areas has a number of characteristics which differ from those in the "developed" rural areas. The power demand is, in general, low and points of consumption are dispersed. The availability of power is often not crucial, as essential services are seldom being supplied. It must be pointed out that in the case of such "unsophisticated" consumers, availability and reliability of power supply are not synonymous. The remoteness of the areas in question would require that the equipment be reliable, even though it need not supply power on demand. An example of this would be a photovoltaic system sized on the basis of a loss of energy probability (LOEP) of 0,2 or 0,3 rather than the usual 0,1, thus reducing the size of the array and the battery storage required.

* * * * *

In conclusion, it is hoped that this report highlights some of the potential for the use of alternative power generation technology in South Africa. It should also be stressed that South Africa with its relatively sophisticated, by Third World standards, manufacturing industry, is well placed to develop and produce power generation equipment appropriate to the needs of rural communities.

With the above in mind, the following recommendations are given as indicators for future research and development in remote area power supply. These are not ranked in any order of priority, but rather in the order in which they appeared in the body of the report.

1. It would appear that wind power may have some potential to supply power in remote areas of South Africa. However, more detailed assessments of the wind regimes prevailing in the remote areas requiring power are required before exploitation of this resource can take place.

2. The development of lower cost, locally-produced wind turbines and generators would also greatly facilitate the use of this resource.

3. Extensive irrigation development of South African rivers has already taken place, but little effort has been made to combine these developments with the genration of power. In the case of straight hydro-electric power (HEP) generation, the cost of power generation is higher than that from the equivalent thermal power station, primarily because of the high civil works cost component. However, in a multi-purpose scheme most of the civil costs would be borne by the irrigation and water supply component of the scheme. In addition to new schemes installation of run-of-river small or micro generators could be considered on existing irrigation schemes.

4. All existing studies on HEP potential have concentrated mainly on large-scale exploitation, and in general have disregarded small and micro hydropower. More detailed assessment of this potential requires surveys of the specific remote areas for which power is required. This option should therefore be borne very much in mind when considering the alternatives, particularly in the Escarpment areas, the Ciskei, Transkei and parts of Kwazulu.

5. It became apparent during the course of this project that the area of ancillary equipment for alternative power supply systems requires a research project of its own. This project would look primarily at batteries, battery protection and charging equipment, and power conditioning equipment. This project should also investigate the development of lower cost components more appropriate to the needs of remote rural consumers.

6. While photovoltaics are still expensive, their costs are falling rapidly and they are finding increasing application in remote areas, chiefly because of their reliability and low maintenance requirements. International developments in terms of cost trends and technology innovation should be tracked and local applications should be monitored in order to evaluate their cost effectiveness and also to identify areas which require further technical research.

7. The cost of power produced from producer and biogas seems promising and demonstration projects should be supported.

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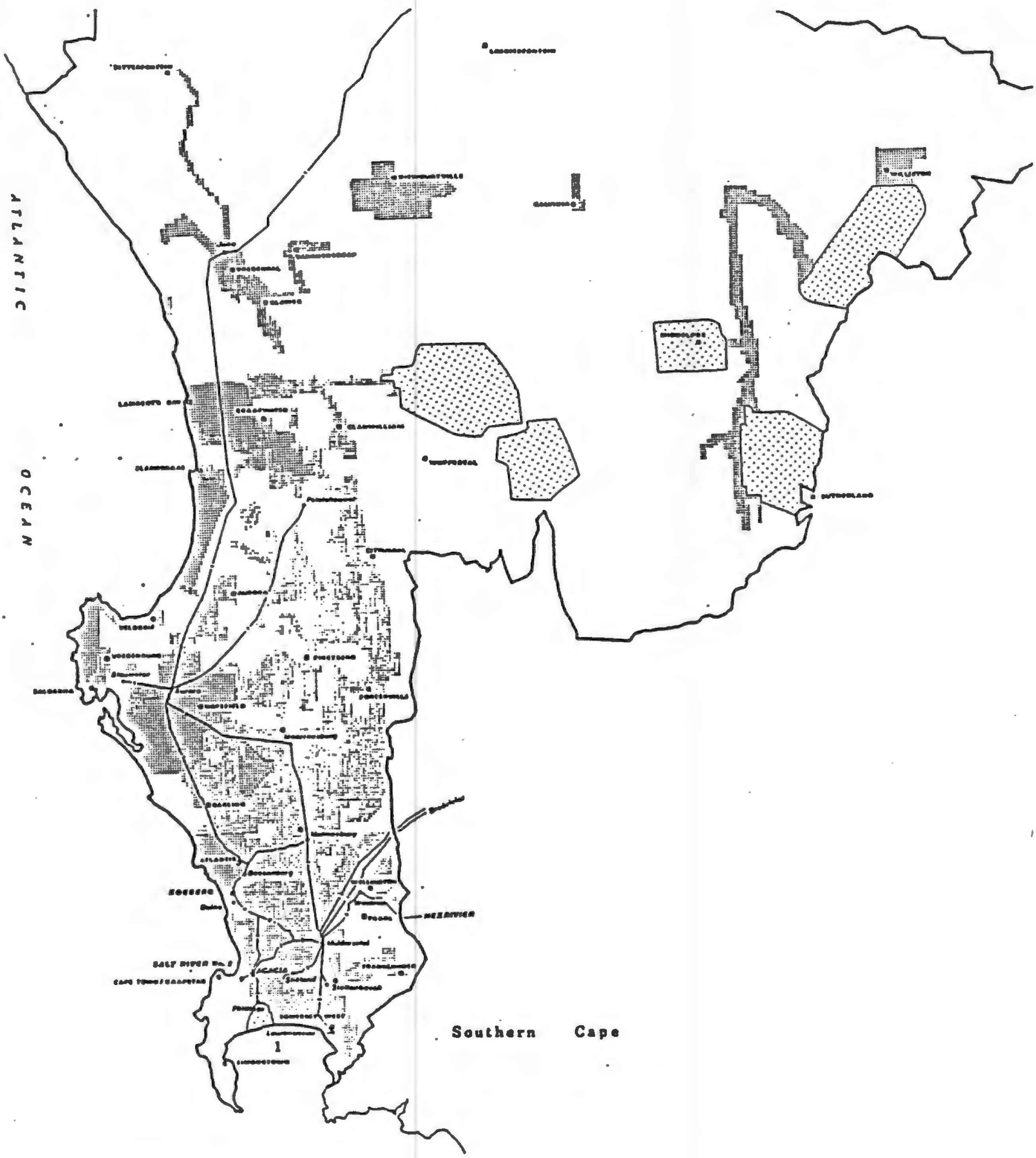
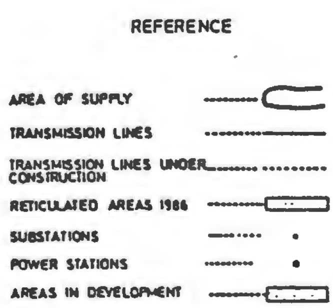
APPENDIX A

MAPS OF OFF-GRID AREAS

MAP 1 WESTERN CAPE ESKOM REGION
MAP 2 SOUTHERN CAPE ESKOM REGION
MAP 3 NORTHERN CAPE ESKOM REGION
MAP 4 EASTERN CAPE ESKOM REGION AND THE TRANSKEI

The maps are based on those provided by Eskom.

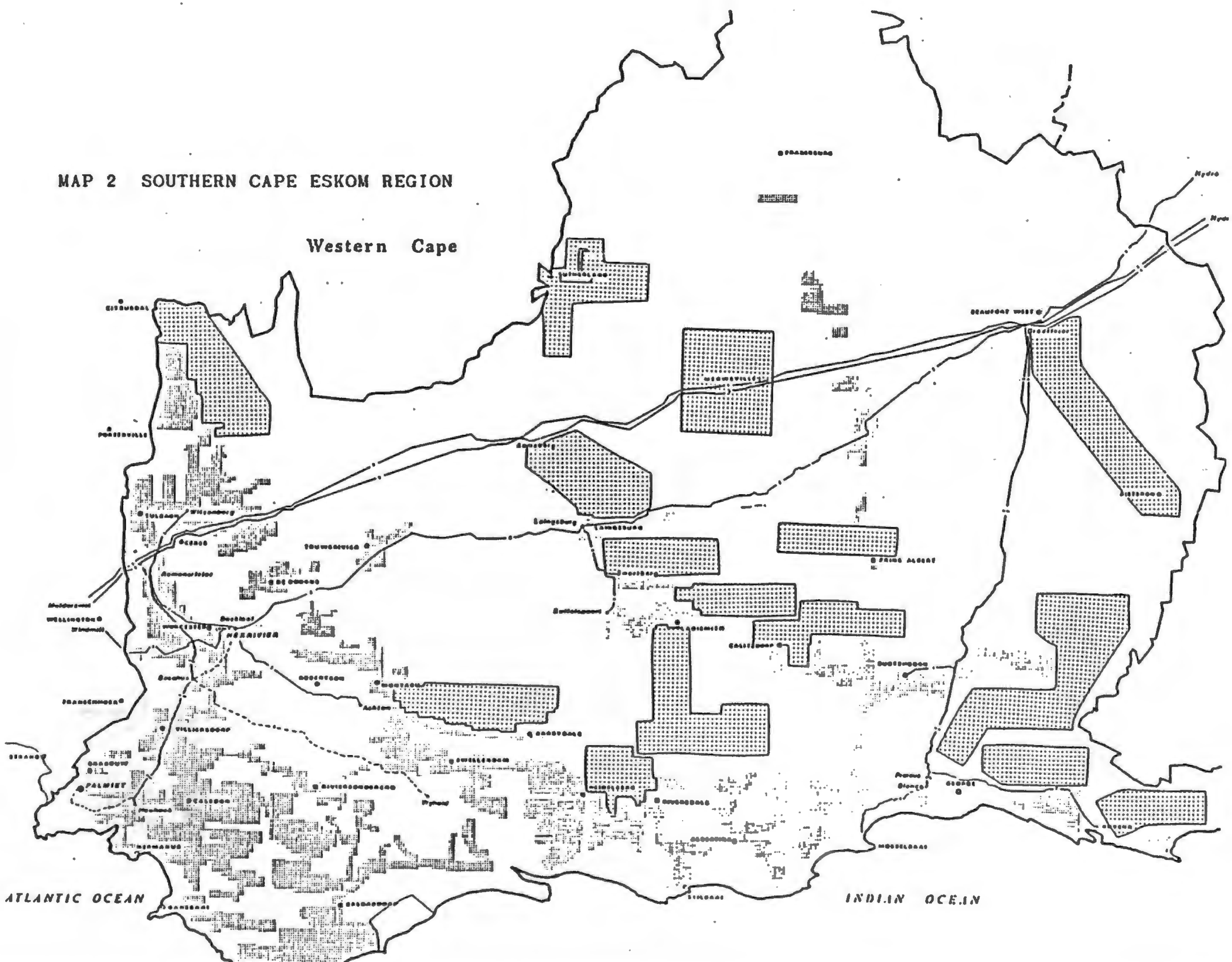


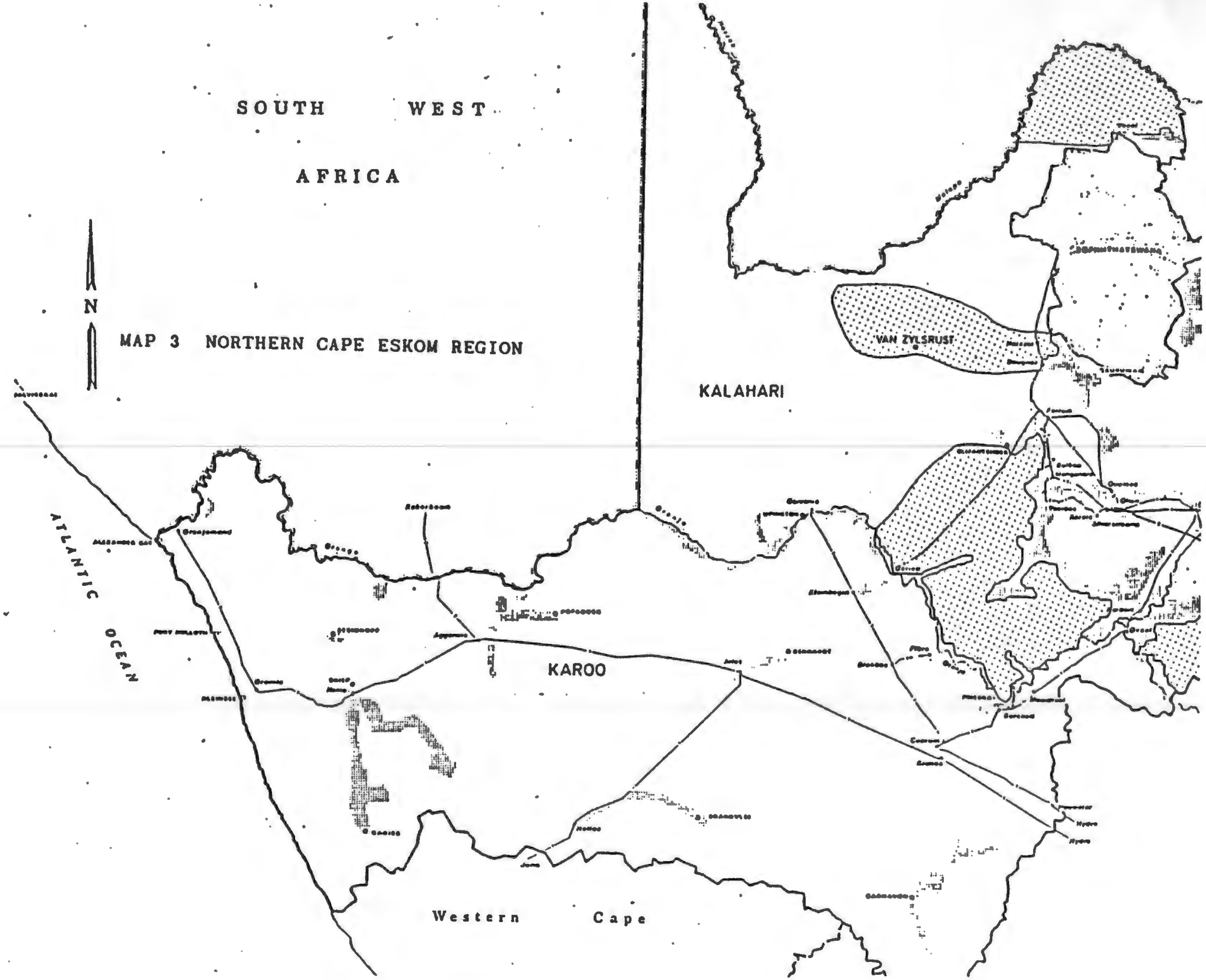


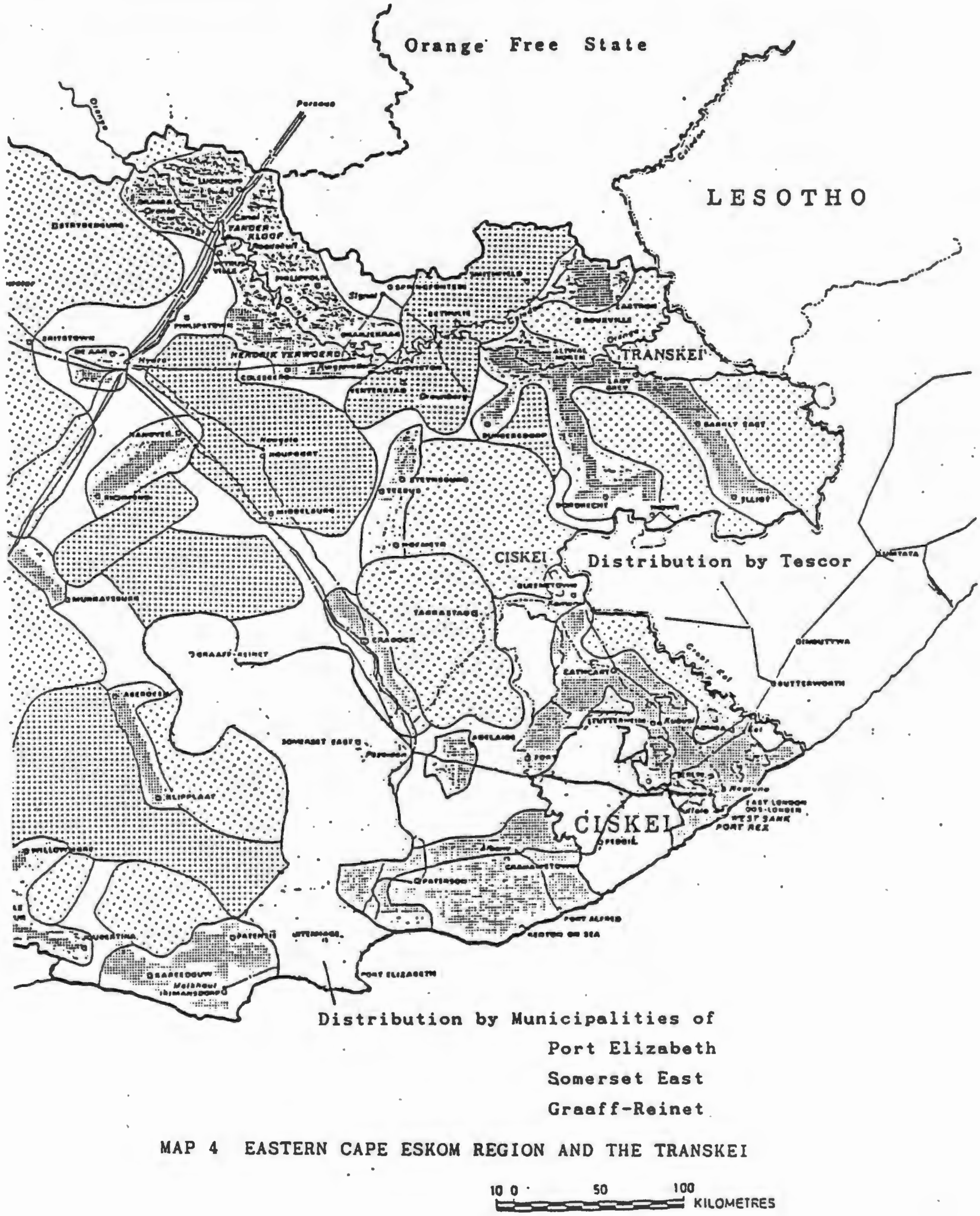
MAP 1 WESTERN CAPE ESKOM REGION

MAP 2 SOUTHERN CAPE ESKOM REGION

Western Cape




SOUTH WEST
AFRICA
N
MAP 3 NORTHERN CAPE ESKOM REGION
KALAHARI
VAN ZYLSRUST
ATLANTIC OCEAN
KAROO
Western Cape



MAP 4 EASTERN CAPE ESKOM REGION AND THE TRANSKEI

APPENDIX B - FARM ENERGY SURVEY QUESTIONNAIRES

FARM ENERGY SURVEY (Afrikaans op keersy)

Name of farmer:..
Address:...
....
....
Type of farming operation:...
No of people living on farm: Farmer & family ....
Single contract labourers .... Labourers and their families ....

Is your farm connected to the ESCOM electricity grid?..................................
If yes, what is the maximum power supply? (eg 25kVA, 100kVA, etc)..................
How much is your monthly (i) extension charge?...
(ii) service charge?..
(iii) unit consumption charge?...

Do you use diesel generators?...
If yes, what make and capacity diesel generators?..................................
....
How old are they? (engine hours)..
How much diesel do you use every month for your generators?..........................
And how much is used each month for other farm machinery and vehicles?............
How much do you pay for the diesel?..
Do the generators start automatically once power is drawn?..........................
Or are the generators run for a specific period each day?.............................
How many hours do they run each day?...
What capacity batteries do the generators charge?.................................
How regularly do your generators require maintenance?..............................

Do you use a wind generator, solar cells, water turbine, wood gasifier, etc to generate electricity? ....If yes, give details: ....
....
....

Apart from household purposes, do you use electricity for irrigation, agricultural processing, workshops, etc? ....If yes, give details: ....
....
....

For water pumping do you use (state number): windmills ...... diesel pumps .... hand pumps ...... solar pumps ...... mains electricity ....other ....

What do your labourers use for	electricity	**wood**	coal	paraffin	gas	other
cooking and heating?	....	....	....	....	....	....
lighting?	....	....	....	....	....	....
If possible, state how much is used each month:	....	....	....	....	....	....

If firewood is used, is it from: a farm plantation? ..... or natural bush? ......

ENERGIEOPNAME VIR PLASE

Naam van boer:..
Adres:..
....
....
Tipe boerdery:..
Aantal persone wat op plaas woon: Boer en familie ....
Enkel kontrakarbeiders .... Arbeiders en hul families ....

Is u plaas aan die EVKOM elektrisiteitsnetwerk gekoppel?
Indien wel,wat is die maksimum kragtoevoer? (bv 25kVA, 100kVA, ens)..............
Hoeveel betaal u maandeliks vir (i) uitbreidingskoste?.........................
(ii) dienskoste?...............................
(iii) eenheidsverbruikskoste?.................

Gebruik u dieselkragopwekkers (generators)?..................................
Indien wel,watter fabrikaat en kapasiteit?...................................
....
Hoe oud is hulle? (masjien ure)...
Hoeveel diesel gebruik u elke maand vir u opwekkers (generators)?............
En hoeveel gebruik u elke maand vir u ander plaasgereedskap en voertuie?..........
Hoeveel betaal u vir die diesel?...
Skakel u opwekkers outomaties aan indien krag gebruik word?...................
Of loop die opwekkers vir 'n spesifieke periode elke dag?.....................
Vir hoeveel ure per dag loop hulle?..
Watter kapasiteit batterye word deur die opwekker gelaai?......................
Hoe gereeld benodig u opwekkers onderhoud?....................................

Gebruik u 'n windgenerator, sonsel, waterturbine, houtvergasser, ens om
elektrisiteit op te wek? ....Indien wel, gee besonderhede: ....
....
....

Huishoudelike doeleindes uitgesluit, gebruik u elektrisiteit vir besproeiing,
landboukundige doeleindes, werkswinkels, ens? ....
Indien wel, gee besonderhede: ....
....

Om water te pomp gebruik u (gee aantal): windpompe ...... dieselpompe ....
handpompe ...... sonaangedrewe pompe ...... EVKOM ....ander ....

Wat gebruik u arbeiders	elek.	hout	steenkool	paraffien	gas	ander
om te kook en vir verhitting?	....	....	....	....	...	....
vir verligting?	....	....	....	....	...	....
Indien moontlik se hoeveel word elke maand gebruik	....	....	....	....	...	....

Indien hout gebruik word, is dit van: 'n plantasie? .... of natuurlike bos? ......

APPENDIX C - BASIC Listing of Diesel Genset Computer Model

```
1 SAV$="B:OPSPROG"+CHR$(34)+",A"+CHR$(13)
2 KEY 6,SAV$
10 '*******************************************************
20 '            DIESEL CONSUMPTION FOR OFF-GRID
30 '                   POWER GENERATION
40 '*******************************************************
50 '                          MAIN MENU
60 '*******************************************************
70 '       THIS FIRST SECTION SETS UP THE LIST OF CURRENTLY
80 '            AVAILABLE ENGINE AND LOAD CURVE DATA
90 '*******************************************************
100          NUM = 8 'THE NUMBER OF ENGINE MAKES
110          DATA "B:LISTER.ENG", "B:DEUTZ.ENG", "B:ADE.ENG",
                  "B:FORD.ENG", "B:ONAN.ENG", "B:KUBOTA.ENG",
                  "B:PETTER.ENG", "B:VM.ENG"
120          FOR J% = 1 TO NUM
130              READ DATAFILES$(J%)
140          NEXT'
150          PARANUM = 5
160          FOR K% = 1 TO PARANUM
170              READ PARAM$(K%)
180          NEXT'
190          DATA "1. SLOPE  - ", "2. INTERCEPT  ", "3. CAPACITY
                   (kW)", "4. MECH/ELEC  ","5. GENSET COST (R)"
200          NCUR = 11' NUMBER OF LOAD CURVES
210          DATA  "B:DAIRY1.CUR",   "B:DAIRY2.CUR",
                   "B:DOMESTC1.CUR", "B:DOMESTC2.CUR",
                   "B:DOMESTC3.CUR", "B:WORKSHP1.CUR",
                   "B:WORKSHP2.CUR", "B:PUMPING1.CUR",
                   "B:PUMPING2.CUR", "B:PUMPING3.CUR",
                   "B:PUMPING4.CUR"
211          DIM CURVEFILE$(NCUR)
220          FOR J% = 1 TO NCUR
230              READ CURVEFILE$(J%)
240          NEXT
250 '********************************************************
260 DIM MAKE$(NUM), LENGTH(NUM), ENGLODED(NUM)
270 DIM MODEL$(NUM,25), SLOPE(NUM,25), INCEPT(NUM,25),
        FULLPOWER(NUM,25), COST(NUM,25), MECHELEC(NUM,25)
280 DIM DIESEL(NUM,25),  WATTSCURVE(23,4), CHANGE(NUM),
        MAKEMOD$(NUM,25)
290 KEY OFF
300 CLS: COLOR 15,0: LOCATE 2,1
310 PRINT TAB(23) "DIESEL CONSUMPTION FOR OFF-GRID"
320 PRINT TAB(30) "POWER GENERATION"
330 COLOR 0,7: PRINT'
340 LOCATE 6,20:PRINT" * * * * * * * * * * * * * * * * * *  * "
350 LOCATE 7,20:PRINT" *           ** MAIN MENU **           * "
360 LOCATE 8,20:PRINT" *                                     * "
370 LOCATE 9,20:PRINT" * 1. ENGINE DATA MANIPULATION         * "
380 LOCATE 10,20:PRINT" * 2. LOAD CURVE DATA MANIPULATION  * "
390 LOCATE 11,20:PRINT" * 3. DETERMINE DIESEL CONSUMPTIONS * "
400 LOCATE 12,20:PRINT" * 4. BATCH RUN DIESEL CONSUMPTION  * "
410 LOCATE 13,20:PRINT" * 5. END RUN - EXIT FROM PROGRAM   * "
420 LOCATE 14,20:PRINT" *                                  * "
430 LOCATE 15,20:PRINT" * * * * * * * * * * * * * * * * *  * "
440 COLOR 7,0: PRINT: PRINT TAB(30) "CHOOSE A NUMBER": GOSUB 7030
450 IF CHOICE% < 1 OR CHOICE% > 5 THEN BEEP: GOTO 300
460 ON CHOICE% GOSUB 1000,3000,4000,510,480
```

```
470 GOTO 300
480 PRINT:PRINT TAB(23)"ARE YOU SURE YOU WANT TO EXIT ?": GOSUB 8000
490 IF AN$ = "Y" OR AN$ = "y" THEN GOTO 500 ELSE GOTO 300
500 KEY ON: END
510 CLS: LOCATE 5,1: Q = 1: PRINT TAB(28) "** BATCH RUN **":PRINT
520 PRINT TAB(16)    "THIS WILL USE ALL AVAILABLE ENGINE DATA"
530 OFFSET = 9: LOCATE 8,16: GOSUB 3150: GOSUB 3200'*** LOAD CURVE
    DATA
540 GOSUB 1370'                     *** LOAD ENGINE DATA
550 PRINT: PRINT TAB(16): INPUT "WHAT % ENGINE OVER-RATING IS
    ALLOWED"; OVERCAP
560 IF OVERCAP < 0 OR OVERCAP > 100 THEN PRINT TAB(16) "OUT OF RANGE":
    GOSUB 6000: GOTO 550
570 FAC = 1+(OVERCAP/100): CALCNUM = CALCNUM + 1 '*** FOR LABELLING
    RESULT FILES
580 GOSUB 4370: GOTO 300'


1000 '*****************************************************
1010 '        SUBROUTINE FOR INPUT AND CHANGING
1020 '                 OF ENGINE DATA
1030 '*****************************************************
1040 CLS: LOCATE 10,1: COLOR 15
1050 PRINT TAB(23) "    ** LOAD/CHANGE ENGINE DATA **"
1060 PRINT TAB(23) "              MAIN MENU": COLOR 7,0:PRINT
1070 PRINT TAB(23) "1. LOAD DATA FROM DISK DATA FILES":PRINT
1080 PRINT TAB(23) "2. CHANGE LOADED ENGINE DATA":PRINT
1090 PRINT TAB(23) "3. VIEW LOADED ENGINE DATA":PRINT
1100 PRINT TAB(23) "4. RETURN TO MAIN MENU":PRINT
1110 PRINT TAB(30) "CHOOSE A NUMBER": GOSUB 7030
1120 IF CHOICE% < 1 OR CHOICE% > 4 THEN BEEP: GOTO 1040
1130 ON CHOICE% GOTO 1150,1550,1550,1140
1140 RETURN
1150 '*****************************************************
1160 '     THIS SECTION INPUTS ENGINE DATA FROM DISK FILES
1170 CLS: LOCATE 10,1: COLOR 15
1180 PRINT TAB(25) "** LOAD ENGINE DATA **": PRINT: COLOR 7
1190 PRINT TAB(23) "1. ALL AVAILABLE DATA FILES":PRINT
1200 PRINT TAB(23) "2. SINGLE MAKE DATA FILE":PRINT
1210 PRINT TAB(23) "3. RETURN":PRINT
1220 PRINT TAB(30) "CHOOSE A NUMBER": GOSUB 7030: PRINT
1230 IF CHOICE% < 1 OR CHOICE% > 3 THEN BEEP: GOTO 1170
1240 ON CHOICE% GOTO 1370,1250,1040
1250 '*****************************************************
1260 '   THIS SECTION LOADS SINGLE DISK DATA FILE
1270 CLS: LOCATE 10,1: PRINT TAB(23) "THE FOLLOWING ARE AVAILABLE:":
     PRINT
1280 FOR J% = 1 TO NUM: N = CSNG(J%)'
1290     LOCATE 11+J%,28: PRINT USING "££. \              \"; N;
       DATAFILES$(J%)
1300 NEXT
1310 PRINT: PRINT TAB(23)
1320 INPUT "WHICH WOULD YOU LIKE TO LOAD"; J%
1330 IF J% < 1 OR J% > NUM THEN BEEP: GOTO 1170
1340 OPEN DATAFILES$(J%) FOR INPUT AS £1
1350 GOSUB 1430: GOSUB 6000: GOTO 1170
1360 '*****************************************************
```

```
1370 '   THIS SECTION LOADS ALL AVAILABLE DISK DATA FILES
1380 FOR J% = 1 TO NUM'
1390     OPEN DATAFILES$(J%) FOR INPUT AS £1: GOSUB 1430
1400 NEXT: IF Q = 1 THEN RETURN ELSE GOSUB 6000: GOTO 1040
1410 '*****************************************************
1420 '     INPUT/OUTPUT ENGINE DATA FROM/TO DISK FILES
1430 '************** INPUT FROM DISK **********************
1440 INPUT £1, MAKES$(J%), LENGTH(J%)
1450 FOR K% = 1 TO LENGTH(J%)'
1460     INPUT £1, MODELS$(J%,K%), SLOPE(J%,K%), INCEPT(J%,K%),
         FULLPOWER(J%,K%), MECHELEC(J%,K%), COST(J%,K%)'
1470 NEXT: ENGLODED(J%) = 1: IF Q = 1 THEN GOTO 1480 ELSE PRINT
     TAB(25) DATAFILES$(J%); " LOADED "
1480 CLOSE: RETURN'
1490 '************** OUTPUT TO DISK ***********************
1500 WRITE £1, MAKES$(J%), LENGTH(J%)
1510 FOR K% = 1 TO LENGTH(J%)'
1520     WRITE £1, MODELS$(J%,K%), SLOPE(J%,K%), INCEPT(J%,K%),
         FULLPOWER(J%,K%), MECHELEC(J%,K%), COST(J%,K%)
1530 NEXT: PRINT TAB(23) DATAFILES$(J%); " UPDATED"
1540 CLOSE: RETURN
1550 '*****************************************************
1560 ' THIS SECTION ALLOWS ENGINE DATA TO BE VIEWED/CHANGED
1570 '************* ENGINE MAKES ON FILE *****************
1580 LOCATE 23,20
1590 FOR J% = 1 TO NUM
1600     IF LENGTH(J%) > 0 THEN GOTO 1630
1610 NEXT
1620 PRINT "THERE IS NOTHING ON FILE": GOSUB 6000: GOTO 1000
1630 CLS: LOCATE 10,15
1640 PRINT "THE FOLLOWING ARE THE MAKES ON FILE:": PRINT: LOCATE 12,10
1650 FOR I = 1 TO NUM
1660     PRINT USING "££. \          \"; I; MAKES$(I),
1670     IF I = NUM/2 THEN LOCATE 14,10 ELSE GOTO 1680
1680 NEXT: IF CONCAL = 1 THEN RETURN
1690 PRINT: PRINT: PRINT TAB(15)'
1700 IF CHOICE% = 3 THEN INPUT "WHICH DO YOU WISH TO VIEW (0 FOR
     NONE)"; MAK: GOTO 1720
1710 INPUT "WHICH DO YOU WISH TO CHANGE (0 FOR NONE)"; MAK
1720 IF MAK < 0 OR MAK > NUM THEN BEEP: GOTO 1580
1730 IF MAK = 0 THEN GOTO 1040
1740 '************ MODELS ON FILE ************************
1750 CLS: LOCATE 10,15: PRINT "THE FOLLOWING ARE THE "MAKES$(MAK)"
     MODELS ON FILE:": PRINT
1760 FOR J% = 1 TO LENGTH(MAK)
1770     IF J%=6 OR J%=11 OR J%=16 OR J%=21 THEN PRINT: PRINT
1780     PRINT USING "££. \          \"; J%; MODELS$(MAK,J%),
1790 NEXT
1800 PRINT: PRINT: PRINT TAB(15): IF CONCAL = 1 THEN RETURN
```

```
1810 '**************** VIEW ENGINE DATA ******************
1820 IF CHOICE% = 3 THEN GOTO 1830 ELSE GOTO 1960
1830 INPUT "WHICH DO YOU WISH TO VIEW (0 FOR NONE, 100 FOR ALL)";
     MODL: IF MODL <> 100 THEN GOTO 1840 ELSE GOTO 1850
1840 IF MODL < 0 OR MODL > LENGTH(MAK) THEN BEEP: GOTO 1740
1850 IF MODL = 0 THEN GOTO 1630
1860 IF MODL = 100 THEN CLS: GOTO 1880
1870 L = 10: M = 15: CLS: GOSUB 2280: GOTO 1930
1880 FOR N% = 1 TO LENGTH(MAK)'
1890     LIN% = ((N%-1)\3)+1: DIV%=((N%-1)\6)+1
1900     L=(LIN%\DIV%)*7:M=(((N%-(3*(LIN%-1)))-1)*26)+5: MODL=N%:
         GOSUB 2280
1910     IF N% MOD 6 = 0 THEN GOSUB 6000: CLS
1920 NEXT: PRINT
1930 PRINT TAB(15) "DO YOU WISH TO VIEW MORE ?": GOSUB 8000
1940 IF AN$ = "Y" OR AN$ = "y" THEN GOTO 1630 ELSE GOTO 1040
1950 '*************** CHANGE ENGINE DATA *****************
1960 CHANGE(MAK) = 1
1970 INPUT "WHICH DO YOU WISH TO CHANGE (O FOR NONE)"; MODL
1980 IF MODL < 0 OR MODL > LENGTH(MAK) THEN BEEP: GOTO 2150
1990 IF MODL = O THEN GOTO 1040
2000 L = 10: M = 15: CLS: GOSUB 2280: PRINT: PRINT TAB(15)
2010 INPUT "WHICH DO YOU WISH TO CHANGE (0 FOR NONE)"; PARA%
2020 IF PARA% < 0 OR PARA% > 4 THEN BEEP: GOTO 2000
2030 IF PARA% = 0 THEN GOTO 1040
2040 LOCATE 11+PARA%,40: INPUT "NEW VALUE"; NEWPARA
2050 LOCATE 11+PARA%,60: PRINT "ARE YOU SURE ?": GOSUB 8000
2060 IF AN$ = "Y" OR AN$ = "y" THEN GOTO 2080
2070 LOCATE 11+PARA%,40: PRINT SPC(40): GOTO 2040
2080 ON PARA% GOTO 2090,2100,2110,2120,2130
2090 SLOPE(MAK,MODL) = NEWPARA: GOTO 2140
2100 INCEPT(MAK,MODL) = NEWPARA: GOTO 2140
2110 FULLPOWER(MAK,MODL) = NEWPARA: GOTO 2140
2120 MECHELEC(MAK,MODL) = NEWPARA: GOTO 2140
2130 COST (MAK,MODL) = NEWPARA
2140 CLS: GOSUB 2280: PRINT
2150 PRINT TAB(15)"ANOTHER CHANGE TO THIS MODEL ?": GOSUB 8000
2160 IF AN$ = "Y" OR AN$ = "y" THEN PRINT:PRINT TAB(15):GOTO 2010
2170 PRINT:PRINT TAB(15) "ANY CHANGES TO ANOTHER MODEL OF THIS MAKE
         ?": GOSUB 8000
2180 IF AN$ = "Y" OR AN$ = "y" THEN PRINT:PRINT TAB(15):GOTO 1740
2190 PRINT: PRINT TAB(15) "ANY CHANGES TO ANOTHER MAKE ?": GOSUB 8000
2200 IF AN$ = "Y" OR AN$ = "y" THEN GOTO 1630
2210 PRINT:PRINT TAB(15) "DO YOU WANT TO WRITE THE CHANGES TO DISK ?":
         GOSUB 8000
2220 IF AN$ = "Y" OR AN$ = "y" THEN GOTO 2230 ELSE GOTO 1040
2230 FOR J% = 1 TO NUM
2240     IF CHANGE(J%) = 1 THEN GOTO 2250 ELSE GOTO 2270
2250     OPEN DATAFILES$(J%) FOR OUTPUT AS £1
2260     GOSUB 1490: CHANGE(J%) = 0
2270 NEXT: GOTO 1040
2280 '****************************************************
```

```
2290 ' SUBROUTINE TO PRINT MAKE AND MODEL PARAMETERS
2300 '**************************************************
2310 LOCATE L,M: PRINT "    "MAKE$(MAK)" "MODEL$(MAK,MODL)":":PRINT
2320 FOR J% = 1 TO PARANUM'
2330     ON J% GOTO 2340,2350,2360,2370,2380
2340     PARAVAL = SLOPE(MAK,MODL): GOTO 2390
2350     PARAVAL = INCEPT(MAK,MODL): GOTO 2390
2360     PARAVAL = FULLPOWER(MAK,MODL): GOTO 2390
2370     PARAVAL = MECHELEC(MAK,MODL): GOTO 2390
2380     PARAVAL = COST(MAK,MODL)
2390     LOCATE L+1+J%,M: PRINT PARAM$(J%); PARAVAL
2400 NEXT: RETURN'
3000 '**************************************************
3010 '     SUBROUTINE TO LOAD AND CHANGE LOAD CURVE DATA
3020 '**************************************************
3030 CLS: LOCATE 10,1
3040 PRINT TAB(23) " ** LOAD/CHANGE LOAD CURVE DATA **"
3050 PRINT TAB(23) "              MAIN MENU":PRINT
3060 PRINT TAB(23) "1. LOAD DATA FROM DISK FILES":PRINT
3070 PRINT TAB(23) "2. DISPLAY/CHANGE LOADED DATA":PRINT
3080 PRINT TAB(23) "3. RETURN TO MAIN MENU":PRINT
3090 PRINT TAB(30) "CHOOSE A NUMBER": GOSUB 7030
3100 IF CHOICE% < 1 OR CHOICE% > 3 THEN BEEP: GOTO 3030
3110 ON CHOICE% GOTO 3130,3290,3120
3120 RETURN
3130 '******** INPUTS LOAD CURVE DATA FROM DISK FILE ******
3140 CLS: LOCATE 8,23: OFFSET = 9
3150 PRINT "THE CURVES AVAILABLE ARE:"
3160 FOR J% = 1 TO NCUR'
3170     LOCATE OFFSET+J%,24: PRINT USING "££. \                    \"; J%;
         CURVEFILE$(J%)
3180 NEXT'
3190 PRINT: PRINT TAB(25):INPUT "CHOOSE A NUMBER ",LOADS%: IF Q = 1
     THEN RETURN: IF LOADS% > NCUR THEN GOTO 3140
3200 IF LOADS% < 1 OR LOADS% > NCUR THEN BEEP: GOTO 3130
3210 OPEN CURVEFILE$(LOADS%) FOR INPUT AS £1
3220 INPUT £1, CURVE$, MAXDEM, CALCNUM
3230 FOR J% = 0 TO 23
3240     FOR K% = 1 TO 4
3250         INPUT £1, WATTSCURVE(J%,K%)
3260     NEXT
3270 NEXT:
3280 CLOSE: IF Q = 1 THEN RETURN ELSE GOTO 3030
3290 '******* DISPLAYS/CHANGES LOAD CURVE DATA ************
3300 IF LOADS% = 0 THEN BEEP: PRINT: PRINT TAB(23) "NO CURVE LOADED":
     GOSUB 6000: GOTO 3000
3310 CLS:LOCATE 10,21: PRINT "THE CURVE LOADED IS FOR ";CURVE$
3320 PRINT TAB(18) "POWER NEEDS, WITH A MAX DEMAND OF"; MAXDEM;"kW"
3330 PRINT: PRINT TAB(20) "THE DATA IS IN SIX-HOUR BLOCKS:":PRINT
3340 PRINT TAB(25) "1. 00.00 - 06.45"
3350 PRINT TAB(25) "2. 07.00 - 12.45"
3360 PRINT TAB(25) "3. 13.00 - 18.45"
3370 PRINT TAB(25) "4. 19.00 - 23.45"
3380 PRINT TAB(25) "5. WRITE CHANGES TO DISK"
3390 PRINT TAB(25) "6. RETURN TO MAIN MENU":PRINT
3400 PRINT TAB(30) "CHOOSE A NUMBER": GOSUB 7030: CLS
3410 IF CHOICE% < 1 OR CHOICE% > 6 THEN BEEP: GOTO 3310
3420 ON CHOICE% GOTO 3440,3450,3460,3470,3750,3430
3430 RETURN
3440 ST% = 0 : EN% = 5 : GOTO 3480
```

```
3450 ST% = 6 : EN% = 11: GOTO 3480
3460 ST% = 12: EN% = 17: GOTO 3480
3470 ST% = 18: EN% = 23'
3480 FOR J% = ST% TO EN%
3490     LOCATE 5,20: PRINT CURVE$; " LOAD CURVE DATA IN kW"
3500     POSI% = J%-((J%\6)*6): DIV% = POSI%\3
3510     LIN% = (DIV%+1)*8: MAR% = ((2*POSI%-(DIV%*6))+1)*10
3520     LOCATE LIN%,MAR%: PRINT " TIME      kW"
3530     FOR K% = 1 TO 4: QTR = (K%-1)*.15: HR = J% + QTR
3540         LOCATE K%+LIN%,MAR%
3550         PRINT USING "££.££  £££.££";HR, WATTSCURVE(J%,K%)
3560     NEXT: IF CHANJ = 1 THEN GOTO 3640: IF POSI% = 5 THEN GOTO
         3590
3570 NEXT:'
3580 '********* CHANGE LOAD CURVE DATA ********************
3590 PRINT: PRINT TAB(25) "ANY CHANGES ?": GOSUB 8000
3600 IF AN$ = "Y" OR AN$ = "y" THEN GOTO 3610 ELSE GOTO 3310
3610 PRINT TAB(25): INPUT "HOUR"; HOUR%
3620 IF HOUR% < 0 OR HOUR% > 24 THEN BEEP: GOTO 3610
3630 ST% = HOUR%: EN% = HOUR%: CHANJ = 1: CLS: GOTO 3480
3640 CHANJ = 0:PRINT:PRINT TAB(MAR%):INPUT "QUARTER (0 FOR ALL OR 1 -
     4)";QRTR%
3650 IF QRTR% < 0 OR QRTR% > 4 THEN BEEP: GOTO  3640
3660 IF QRTR% = 0 THEN GOTO 3700 ELSE PRINT TAB(MAR%)
3670 INPUT "NEW VALUE"; NEWKW: CHANJ = 0
3680 WATTSCURVE(HOUR%,QRTR%) = NEWKW
3690 GOTO 3740
3700 FOR J% = 1 TO 4'
3710     PRINT TAB(MAR%) J%;: INPUT "NEW VALUE"; NEWKW
3720     WATTSCURVE(HOUR%,J%) = NEWKW
3730 NEXT
3740 CLS: GOTO 3420
3750 '*********** WRITE CHANGES TO DISK ******************
3760 OPEN CURVEFILE$(LOADS%) FOR OUTPUT AS £1
3770 WRITE £1, CURVE$, MAXDEM, CALCNUM
3780 FOR J% = 0 TO 23
3790     FOR K% = 1 TO 4'
3800         IF K% < 4 THEN PRINT £1, WATTSCURVE(J%,K%); CHR$(44);
             ELSE PRINT £1, WATTSCURVE(J%,K%);
3810     NEXT: PRINT £1,
3820 NEXT
3830 CLOSE: RETURN'
4000 '****************************************************
4010 '     SECTION TO DETERMINE DIESEL CONSUMPTION
4020 '****************************************************
4030 CLS: LOCATE 10,1: COLOR 15
4040 PRINT TAB(23) "  ** DETERMINE DIESEL CONSUMPTION **"
4050 PRINT TAB(23) "                MAIN MENU": COLOR 7,0:PRINT
4060 PRINT TAB(23) "1. CONSUMPTION CALCULATION":PRINT
4070 PRINT TAB(23) "2. VIEW CONSUMPTION DATA":PRINT
4080 PRINT TAB(23) "3. RETURN TO MAIN MENU":PRINT
4090 PRINT TAB(30) "CHOOSE A NUMBER": GOSUB 7030
4100 IF CHOICE% < 1 OR CHOICE% > 3 THEN BEEP: GOTO 4030
4110 ON CHOICE% GOTO 4130,1550,4120
4120 RETURN
4130 '****************************************************
```

```
4140 '      CONSUMPTION CALCULATIONS FOR ONE MAKE
4150 CLS: LOCATE 10,1
4160 IF LOADS% = 0 THEN PRINT TAB(23) "NO LOAD CURVE DATA LOADED":
     GOSUB 6000: GOTO 3000
4170 FOR J% = 1 TO NUM
4180     IF ENGLODED(J%) = 1 THEN GOTO 4200
4190 NEXT: PRINT TAB(23) " NO ENGINE DATA LOADED": GOSUB 6000: GOTO
     1000
4200 PRINT TAB(16) " ** DIESEL CONSUMPTION DETERMINATION **"
4210 PRINT TAB(23)        "THE MAX DEMAND IS "MAXDEM"kW"
4220 PRINT: PRINT TAB(23) "DO YOU WISH TO INVESTIGATE:"
4230 PRINT TAB(23) " 1. ALL SUITABLE ENGINES ?"
4240 PRINT TAB(23) " 2. SUITABLE ENGINES FROM ONE MAKE ?"
4250 PRINT TAB(23) " 3. ONLY ONE MODEL ?"
4260 PRINT TAB(23) " 4. NONE - RETURN ?"
4270 PRINT: PRINT TAB(23) "   CHOOSE A NUMBER": GOSUB 7030
4280 IF CHOICE% < 1 OR CHOICE% > 4 THEN BEEP: GOTO 4150
4290 ON CHOICE% GOTO 4310,4310,4310,4300
4300 RETURN
4310 CALCNUM = CALCNUM + 1 '*** FOR LABELLING RESULT FILES
4320 PRINT: PRINT TAB(26): INPUT "WHAT % ENGINE OVER-RATING IS
     ALLOWED"; OVERCAP
4330 IF OVERCAP < O OR OVERCAP > 100 THEN PRINT TAB(26) "OUT OF
     RANGE": GOSUB 6000: GOTO 4320
4340 FAC = 1+(OVERCAP/100)
4350 ON CHOICE% GOSUB 4370,4480,4570: GOTO 4150
4360 '***************** ALL SUITABLE MODELS ****************
4370 FOR J% = 1 TO NUM
4380     IF ENGLODED(J%) = 0 THEN GOTO 4460'
4390     FOR K% = 1 TO LENGTH(J%)
4400         KWNEEDED = MAXDEM*MECHELEC(J%,K%)
4410         IF FULLPOWER(J%,K%) > KWNEEDED THEN GOTO 4420 ELSE GOTO
             4450
4420         IF OVERCAP > 0 AND FULLPOWER(J%,K%) < FAC*KWNEEDED THEN
             GOTO 4430 ELSE GOTO 4440
4430         FUEL = 0: GOSUB 4660:  MAKEMOD$(J%,K%) = MAKE$(J%) +
             CHR$(32) + MODEL$(J%,K%)
4440 '
4450     NEXT K%
4460 NEXT J%: GOSUB 4800: GOSUB 6000: RETURN
4470 '****************** ONE MAKE ************************
4480 CONCAL = 1:GOSUB 1630'*** CONCAL FLAG FOR ROUTINE AT 1640
4490 PRINT: PRINT TAB(23): INPUT "WHICH MAKE"; J%: MAK = J%
4500 FOR K% = 1 TO LENGTH(J%)
4510     KWNEEDED = MAXDEM*MECHELEC(J%,K%)
4520     IF FULLPOWER(J%,K%) > KWNEEDED THEN GOTO 4530 ELSE GOTO 4550
4530     IF OVERCAP > 0 AND FULLPOWER(J%,K%) < FAC*KWNEEDED THEN GOTO
         4540 ELSE GOTO 4550
4540     FUEL = 0: GOSUB 4660: MAKEMOD$(J%,K%) = MAKE$(J%) + CHR$(32)
         + MODEL$(J%,K%)
4550 NEXT K%: GOSUB 4800: GOSUB 6000: CONCAL = 0'
4551 PRINT: PRINT TAB(20) "ANOTHER RUN WITH THIS MAKE AND LOAD CURVE
     ?": GOSUB 8000
4552 IF AN$ = "Y" OR AN$ = "y" THEN GOTO 4553 ELSE RETURN
4553 PRINT: PRINT TAB(20): INPUT "WHAT % ENGINE OVER-RATING IS
     ALLOWED"; OVERCAP
4554 IF OVERCAP < O OR OVERCAP > 100 THEN PRINT TAB(26) "OUT OF
     RANGE": GOSUB 6000: GOTO 4553
4556 FAC = 1+(OVERCAP/100)
4557 J% = MAK: GOTO 4500
```

```
4570 '***************** SINGLE ENGINE **********************
4580 CONCAL = 1:GOSUB 1630'*** CONCAL FLAG FOR ROUTINE AT 1640
4590 PRINT: PRINT: PRINT TAB(23): INPUT "WHICH MAKE"; MAK
4600 GOSUB 1750: INPUT "WHICH MODEL"; K%: J% = MAK:KWNEEDED =
     MAXDEM*MECHELEC(J%,K%)
4610 IF FULLPOWER(J%,K%) > KWNEEDED THEN GOTO 4620 ELSE GOTO 4640
4620 GOSUB 4660: MAKEMOD$(J%,K%) = MAKE$(J%) + CHR$(32) +
     MODEL$(J%,K%)
4630 GOSUB 4800: GOSUB 6000: CONCAL = 0: RETURN
4640 PRINT: PRINT TAB(20) "ENGINE UNDER RATED": GOSUB 6000
4650 GOTO 4600
4660 '*****************************************************
4670 '   SUBROUTINE TO CALCULATE DIESEL CONSUMPTION
4680 '*****************************************************
4690 '  THE ALGORITHM IS FUEL = A * % FULL POWER + C
4700 '  NOTE WATTSCURVE IS FOR QUARTER HOURS HENCE FUEL/4
4710 A = SLOPE(J%,K%)*MECHELEC(J%,K%)*100: C = INCEPT(J%,K%)
4720 FOR H% = 0 TO 23
4730     FOR Q% = 1 TO 4'
4740          FIRSTERM = (A*WATTSCURVE(H%,Q%)) / FULLPOWER(J%,K%)
4750          IF FIRSTERM = 0 THEN GOTO 4770
4760          FUEL = FUEL + FIRSTERM + C
4770     NEXT Q%
4780 NEXT: DIESEL(J%,K%) = FUEL/4
4790 RETURN'
4800 '*****************************************************
4810 '   RESULT OUTPUT TO DISK/SCREEN
4820 '*****************************************************
4830 CLS: LOCATE 1,1
4840 PRINT TAB(5) "DIESEL CONSUMPTION FIGURES FOR "CURVE$" POWER
     SUPPLY"
4850 PRINT TAB(10) "ENGINE OVERATING: "OVERCAP"%": PRINT
4860 PRINT TAB(8) "MAKE & MODEL       POWER [kW]   CONSUMPTION
     [litres]": PT = 0 ' LINE POINTER (16)
4870 FOR J% = 1 TO NUM'
4880     FOR K% = 1 TO LENGTH(J%)
4890          IF MAKEMOD$(J%,K%) = "" THEN GOTO 4900 ELSE PT = PT + 1:
              LOCATE 6+PT,9: PRINT USING "\               \     £££.££
              ££££.££"; MAKEMOD$(J%,K%); FULLPOWER(J%,K%);
              DIESEL(J%,K%)
4900     NEXT K%
4910 NEXT J%: LOCATE 7+PT,15: PRINT "WRITE TO DISK (Y OR N)?":
              GOSUB 8000: IF AN$ = "y" OR AN$ = "Y" GOTO 4920 ELSE GOTO
              300
4920 '*********** WRITE RESULTS TO DISK ******************
4930 IF CALCNUM > 9 AND CALCNUM < 20 THEN QUAL$ = CHR$(49) +
     CHR$(48+CALCNUM-10) ELSE QUAL$ = CHR$(48 + CALCNUM)
4931 IF CALCNUM > 19 AND CALCNUM < 30 THEN QUAL$ = CHR$(50) +
     CHR$(48+CALCNUM-20)
4932 WRITEFILE$ = "B:"+ CURVE$ + CHR$(46) + QUAL$
4940 OPEN WRITEFILE$ FOR OUTPUT AS £1
4950 WRITE £1, CURVE$, MAXDEM, OVERCAP, CALCNUM
4960 FOR J% = 1 TO NUM'
4970     FOR K% = 1 TO LENGTH(J%)
4980          IF MAKEMOD$(J%,K%) = "" THEN GOTO 4990 ELSE WRITE £1,
              MAKEMOD$(J%,K%); FULLPOWER(J%,K%); DIESEL(J%,K%):
              MAKEMOD$(J%,K%) = ""
4990     NEXT K%
5000 NEXT J%
5010 CLOSE: GOSUB 3750: RETURN
```

```
6000 '*****************************************************
6010 '  SUBROUTINE WHICH HOLDS UP UNTIL ANY KEY IS PRESSED
6020 '*****************************************************
6030 PRINT: COLOR 15
6040 PRINT TAB(23) "PRESS ANY KEY TO CONTINUE"
6050 GOSUB 7030
6060 COLOR 7,0: RETURN
7000 '*****************************************************
7010 '          NUMERIC INKEY SUBROUTINE
7020 '*****************************************************
7030 LOCATE ,,0
7040 RP$=INKEY$:IF RP$="" THEN 7040 ELSE CHOICE% = ASC(RP$)-48:LOCATE
        ,,1: RETURN
8000 '*****************************************************
8010 '         YES/NO INKEY SUBROUTINE
8020 '*****************************************************
8030 LOCATE ,,0
8040 RP$=INKEY$:IF RP$="" THEN 8040 ELSE AN$ = RP$:LOCATE ,,1: RETURN
```

APPENDIX D

REMOTE AREA DIESEL-POWERED GENSETS IN THE TRANSKEI

Installed Diesel Generating Capacity

The total installed capacity of diesel generating plant in the Transkei in 1986 was in the order of 20 000 kVA. However at many installations the total generating capacity is not equal to the installed capacity because there is no means of synchronising the generators, nor of splitting the load. At most sites there is at least one set as standby. Many of the generators in use are very old and unable to maintain their nominal output. Taking the above into consideration the aggregate demand of the loads supplied by these gensets does not exceed 10 MVA (pers. comm. Department of Works and Energy)

Potential New Isolated Loads

The Transkei Police have many small isolated guard posts, many of which are in the foothills of the Drakensberg, close to the Lesotho Border. Some of these do already have small gensets, but irregular maintenance and fuel supplies are a problem.

Work has commenced on a countrywide rural water supply scheme. There will therefore be an increasing need for pumping power.

Most of the hospitals have diesel gensets. However, there is a need for a small power supply at many of the remote clinics. This power would be used for lighting for emergencies and to run small refrigerators for the storage of drugs and other perishables.

Rural community centres presently have no power supply. The introduction of some form of lighting would provide communities with a focal point. Such a facility could also be used for educational purposes, and in particular for adult education. Television could also be introduced into these areas, although the benefits of this are debatable.

Many general trading stores dotted around the countryside use diesel gensets to run their deep freezes, and to provide security lighting at night.

LEGEND
1 DEPT OF WORKS AND ENERGY
2 TRANSKEI DEV CORP
3 PRIVATE
4 TESCOR SUPPLIED
5 DEPT OF LOCAL GOVT

REMOTE AREA DIESEL-POWERED GENSETS

	LOCATION	NO.	kW	TOT kW	l/MNTH	MWh	MAX DEM
	AMANZYMJANA (SAW)	1	325	325			
	AMANZYMJANA (SAW)	1	250	250			150
1	BAMBISANA (HOSPITAL)	2	100	200			100
	BAZIYA (SAW)	2	250	500			
2	BAZIYA (SAW)	1	200	200			200
	BIZANA (HOS AND DOM)	3	138	414	10000	42	140
3	CLARKEBURY			50			50
	COFIMVABA (80 DOM)	2	137	275			
	COFIMVABA (80 DOM) sync	1	125	125	15000	46	140
1	DALIWONGA (SCH)	1	80	80			100
1	DWESA CAMP	2	100	200			100

	LOCATION	NO.	kW	TOT kW	1/MNTH	MWh	MAX DEM
1	ELLIOTDALE (DOM)	1	60	60			100
1	FREEMANTLE (2 SCH AND PRIS)	2	150	300			
1	FREEMANTLE (2 SCH AND PRIS)	1	200	200	12000		200
1	GREENVILLE (HOSPITAL)	1	63	63	6000		80
1	HLULEKA CAMP	2	100	200			100
	HOLY CROSS (HOSPITAL)	1	100	100			100
	ILLINGE	1	50	50			50
1	LADY FRERE (GOVT)	2	125	250			150
1	LADY FRERE (GOVT)	1	250	250			
1	LADY FRERE (HOSPITAL)	2	100	200	20000	65	200
1	LADY FRERE (HOSPITAL)	1	200	200			
1	LADY FRERE (HOSPITAL)	1	137	137			
	LAGGEWACHT (SAW)	1	175	175			175
	LANGENI (SAW)	2	250	500			250
3	LIBODE			20			20
1	MADWALENI (HOSPITAL)	2	125	250	13000		100
	MADWALENI (HOSPITAL)	1	137	137			
	MAJOLA TEA ESTATES	4	250	1000			750
	MAJOLA TEA ESTATES	1	50	50			
1	MFUNDISWENI	1	80	80			80
2	MNGAZI MOUTH BUNGALOWS			0			100
1	MOSHESHE (SCH)	1	25	25			25
1	MQANDULI	2	20	40	600		20
1	MT AYLIFF (HOS AND STREET)	2	80	160	9000		150
1	MT AYLIFF (HOS AND STREET)	1	137	137			
1	MT AYLIFF (POLICE)	1	35	35			
2	MT AYLIFF (SAW)	2	250	500			550
2	MT AYLIFF (SAW)	1	875	875			
2	MT AYLIFF (SAW)	1	520	520			
1	MT FLETCHER (GOVT)	3	125	375			150
1	MT FLETCHER (HOSPITAL)	2	125	250	7000		100
1	MT FLETCHER (HOSPITAL)	1	100	100			
2	MT FLETCHER (IND)	1	180	180			
4	MT FRERE (HOS AND DOM)	2	410	820			450
1	NESSIE KNIGHT (HOSPITAL)	1	80	80			
1	NESSIE KNIGHT (HOSPITAL)	1	100	100			80
1	QACHA'S NEK BORDER POST	1	12	12			12
2	QAMATA (IND)	1	150	150			150
3	QUMBU	1	50	50			50
1	RAMA'S GATE BORDER POST	1	12	12			12
1	RHODA HIGH SCHOOL	1	80	80			80
1	SIGCAU TRAINING SCHOOL	2	35	70			35
	SINGISI FOREST PRODUCTS	10	250	2500			1500
	SINGISI FOREST PRODUCTS	1	375	375			
1	SIPETU (HOSPITAL)	2	75	150			100
1	SIPETU (HOSPITAL)	1	100	100			
1	ST BARNABAS (HOSPITAL)	1	175	175	12000		130
	ST BARNABAS (HOSPITAL)	1	137	137			
1	ST LUCY'S (HOSPITAL)	2	80	160	8000		80
1	ST LUCY'S (HOSPITAL)	1	125	125			
5	STERKSPRUIT (HOS AND 60 DOM)	2	250	500	23000	80	300
	STERKSPRUIT (HOS AND 60 DOM)	1	125	125			
	TABANKULU SAWMILL	1	150	150			
3	TABANKULU SAWMILL	1	125	125			70
	TABANKULU SAWMILL	1	100	100			
2	THE HAVEN			0			50
1	TSOLO (2 SCH) sync	2	150	300			
1	TSOLO (2 SCH) sync	1	125	125	10000		150
2	TSOLO (IND)	1	175	175			

	LOCATION	NO.	kW	TOT kW	1/MNTH	MWh	MAX DEM
4	TSOMO (40 DOM)	1	31	31			50
	UMLAMILI (HOSPITAL)	1	90	90			150
	UMLAMILI (HOSPITAL)	1	50	50			
	UMLAMILI (HOSPITAL)	1	125	125			
	UMLAMILI (HOSPITAL)	1	100	100			
4	UMLAMILI (HOSPITAL)	1	75	75			
	WILLOWVALE	2	100	200			120
	ZITHULELE (HOSPITAL)	1	175	175			
1	ZITHULELE (HOSPITAL)	2	80	160			200
	TOTALS	111		17581	145600	233	7999

REMOTE AREA DIESEL-POWERED GENSETS
THESE PLACES NOW HAVE, OR ARE SOON TO RECEIVE TESCOR SUPPLIES

	LOCATION	NO.	kW	TOT kW	1/MNTH	MWh	MAX DEM
4	CALA (HOSPITAL)	2	100	200			50
4	CALA (MUN)	2	100	200			150
4	CANZIBE (HOSPITAL)	3	80	240			80
4	COFFEE BAY (HOTEL)	1	137	137			
4	COFFEE BAY (HOTEL)	1	250	250			120
4	ENGCOBO (H_2O PUMPS AND DOM)	2	265	530	50000		
	ENGCOBO (H_2O PUMPS AND DOM)	1	250	250			
2	ENGCOBO (HOS AND SCH)	2	156	312			500
4	FLAGSTAFF (IND)	1	150	150			100
4	GREENVILLE (HOSPITAL)	2	80	160			100
4	GREENVILLE (HOSPITAL)	1	100	100			
1	HOLY CROSS (HOSPITAL)	2	150	300			150
4	ISILIMELA (HOSPITAL)	2	80	160			80
3	KENTANI			50			
2	KOB INN (HOTEL)			0			75
4	LANGENI (SAW)	1	325	325			150
4	LUSIKISIKI	1	100	100			200
	LUSIKISIKI	1	450	450			
	LUSIKISIKI	1	175	175			
4	MAGWA TEA ESTATES	1	1700	1700			1000
4	MALUTI (DEPOT)	2	80	160	4000		
4	MALUTI (DEPOT)	1	250	250			
2	MAZEPPA BAY (HOTEL)			0			75
1	MJANYANA (HOSPITAL)	1	3	3			500
3	MKAMBATI	3	80	240			100
4	NQELENI			50			50
	PORT ST JOHN'S (COM AND DOM)	1	125	125			
4	PORT ST JOHN'S (COM AND DOM)	1	75	75	33000		150
	PORT ST JOHN'S (COM AND DOM)	1	250	250			
	PORT ST JOHN'S (COM AND DOM)	1	100	100			
	PORT ST JOHN'S (HOTEL)			0			
2	TRENNERIES (2 HOTELS)			0			100
2	UMTATA MOUTH (HOTEL)			0			100
2	WAVECREST (HOTEL)			0			50
4	XONXA DAM (H20 PUMPS)	1	1500	1500			1200
	TOTALS	39		8542	87000	0	5080

APPENDIX E PHOTOVOLTAIC INSTALLATIONS

NAMIBIA

LOCATION	MODULES	NO	EACH Wp	TOTAL Wp	TOT COST RAND	BATT. Ah	LOAD Ah/DAY
Blockberg	ARCO 16-2300	48	35	1680	33000	2400	216
Gabis	ARCO 16-2300	48	35	1680	33000	2400	216
Bontveld	ARCO 16-2300	48	35	1680	33000	2400	216
Boegoeberg	ARCO 16-2300	48	35	1680	33000	2400	216
Nordufer	ARCO 16-2300	48	35	1680	33000	2400	216
Hohenheim	ARCO 16-2300	72	35	2520	38000	1280	384
Zebrapan	ARCO 16-2300	84	35	2940	45000	1280	552
Hamilton	ARCO M51	120	40	4800	64000	1280	624
Rishon	ARCO M51	84	40	3360	45000	1280	552
Kokerboom	ARCO M51	72	40	2880	40000	1280	456
Kubub	ARCO M51	72	40	2880	40000	1280	456
Nakop	ARCO M51	72	40	2880	40000	1280	456
8 Microwave Stn	ARCO M53	84	43	28896	49000	2400	384
Microwave Stn	ARCO M53	96	43	4128	55000	2400	528
2 Car.Rpeater Stn	ARCO 16-2300	1	35	70	600	120	24
7 Car.Rpeater Stn	ARCO 16-2300	2	35	490	1000	120	24
1 Car.Rpeater Stn	ARCO 16-2300	3	35	105	15000	120	72
35 Car.Rpeater Stn	ARCO 16-2300	4	35	4900	2000	224	50
16 Car.Rpeater Stn	ARCO 16-2300	6	35	3360	3000	224	30
6 Car.Rpeater Stn	ARCO 16-2300	8	35	1680	3500	224	48
1 Car.Rpeater Stn	ARCO 16-2300	10	35	350	5000	224	72
1 Car.Rpeater Stn	ARCO 16-2300	14	35	490	6000	224	84
Kalkfeld	ARCO 16-2300	48	35	1680	33000	864	288
Kalkrand	ARCO M55	60	53	3180	67000	864	168
Narib	ARCO M53	144	43	6192	75000	1280	420
Gibeon	ARCO M53	144	43	6192	75000	1280	420
Die Kalk	ARCO M53	144	43	6192	75000	1280	420
Kongola	ARCO M53	48	43	2064	35000	1280	192
Baganie	ARCO M53	48	43	2064	35000	1280	192
Tsumis	FOTOW.BPX47A	144	40	5760	65000	2360	420
Kalkrand	FOTOW.BPX47A	144	40	5760	65000	2360	420
Gariganus	ARCO M53	144	43	6192	75000	2560	420
Brukkaros	ARCO M53	144	43	6192	75000	2560	420
Asab	ARCO M53	216	43	9288	100000	3840	540
Mangetti	ARCO M55	1	10	10	67000	1280	168
350SOR18 Car.Stn	SOLEC	1	10	10	300	2.5	12
				135905	1459400	50330	10376

SOUTH AFRICA

The Department of Posts and Telecommunications

A full listing of the location of these installations can be obtained from the Department. They are not reproduced here for confidentiality reasons. A total of 135 installations exist, and are widely spread over the country.

Northern Transvaal	9
S.E. Transvaal	2
Orange Free State	22
Natal	7
Northern Cape	30
Western Cape	46
Eastern Cape	19
	135

All the installations are DC, the bulk of which are 24V systems with a few running at 12V, 48V and 50V.

South African Broadcasting Corporation

The SABC uses photovoltaic cells to power a number of its repeater stations. However, the engineer in charge of these systems refused to divulge any information regarding them.

Bophutatswana

The Bophutatswana security forces have installed a communications network powered almost entirely by photovoltaics. The Department of Education is also using photovoltaics to power audio-visual equipment in remote schools.

APPENDIX F - SMALL HYDROPOWER PLANT

INSTALLED BY:
MR M. COTTERRELL
AILSA
P.O. THOMAS RIVER

CROSSFLOW TURBINES

kVA	TURBINE COST	R/kW	TRANSMISSION COSTS	CIVIL COSTS	TOTAL COSTS	R/kW
3	8000	2666	2000	500	10500	3500
4	8000	2000	1000	3000	12000	3000
5	8000	1600	3000		11000	2200
5	3000	600	2000	2000	7000	1400
5	12000	2400	3000	8000	23000	4600
8	10000	1250	4000	3000	17000	2125
15	12000	800	5000	3000	20000	1333
18	11000	611	5000	10000	26000	1444
FRANCIS TURBINES						
2	4000	2000	800	2000	6800	3400
2	5000	2500	2000	1000	8000	4000
5	5000	1000	2000	500	7500	1500
5	3000	600		4000	7000	1400
6	8000	1333	3000	500	11500	1916
10	8000	800		10000	18000	1800
PELTON TURBINES						
0						
1	400	400			400	400
1	3000	2000			3000	2000
0	1000	1250	1000	3000	5000	6250
0	900	1000	500	800	2200	2444
0	900	1000	500	500	1900	2111
1	2000	2000	500	1500	4000	4000
1	3000	2727	800	500	4300	3909
1	2000	1333	800	1000	3800	2533
2	3000	1500	1000	4000	8000	4000
2	4000	2000	2000	2000	8000	4000
2	800	400	800	1000	2600	1300
3	3000	1000	300	4000	7300	2433
3	3000	1000	2000	3000	8000	2666
3	3000	1000	1000	500	4500	1500
3	3000	1000	2000	2000	7000	2333
4	4000	1000	2000	3000	9000	2250
4	5000	1250	3000	7000	15000	3750
5	1800	360	2000	4000	7800	1560
5	800	160	500	500	1800	360
5	3000	600	2000	8000	13000	2600
11	4000	363	1000	4000	9000	818
15	7000	466	500	10000	17500	1166
40	15000	375	5000	8000	28000	700

AVERAGE DATA FROM ABOVE

kVA	TURB	R/kW	TRANS	CIVIL	TOTAL	R/kW
5.82	4881	1217	1843	3181	9906	2528
	49.27%		18.61%	32.11%	% OF TOTAL COST	

INSTALLED BY:
MR P. DOWNEY
VICTORY ENTERPRISES,
P.O. BOX 132,
HOFMEYR 5930.

TYPE OF TURBINE	HEAD m	FLOW l/s	RATING kVA	COST R
Pelton 2 nozzles	9,1	9	0,5	
Pelton 1 nozzle	109,0	5	3,5	1 100
Pelton 2 nozzles	49,0	45	13,0	4 217
Pelton 6 nozzles	30,0	180	28,0	8 400
Pelton 1 nozzle			1,2	810
Pelton 1 nozzle			0,2	540
Pelton 1 nozzle	15,0	4	0,25	810
Pelton 1 nozzle	20,0	17	2,25	3 800
Pelton 2 nozzles	7,5	18	0,7	3 230
Pelton	19,7	30	2,6	3 175
Crossflow	7,3	1350	54,0	12 500
Crossflow	4,8	585	10,8	8 550

REPORT NO. GEN 130

OFF-GRID SMALL POWER SUPPLY OPTIONS FOR RURAL AREAS

FINAL REPORT

A T WILLIAMS SEPTEMBER 1989