The Use of Biomass for Electric Power Generation in the South African and Zimbabwean Saw-milling Industry

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April 1998

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in fulfillment of the requirements
for the degree
Master of Science in Engineering.

I claim that this is my own original work
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Abstract

This paper considers the opportunities for the South African and Zimbabwean Saw-milling Industry to be self-sufficient in the generation of power for its own industrial electrical energy requirements.

The analysis of the wood residue arising from saw-milling operations in the southern African context confirms that there is a substantial amount of fuel available for the main heating requirement of a wet saw-mill. This heat is generally supplied in the form of steam to the timber drying and conditioning kilns that form part of the timber production process.

One of the principal arguments put forward for cogeneration is that by passing steam through a condensing or back pressure turbine the entire power demand of a saw-mill can be met as well as the heat for the kilning process. Due to the situation of unbalanced load that persists at nearly all the saw-mills, there is a surplus of power that is often difficult to dispose of economically.

The low cost of electrical power as provided by ESKOM in South Africa discourages investment in the capital equipment for self-generation in that country. The situation in Zimbabwe is significantly different because of the higher power cost.

Consideration is also given to the generally beneficial aspects of growing timber and the combustion of this resource in correctly designed steam plant that can be used in cogeneration systems in saw-mills.

Acknowledgement

I would like to thank Professor R.K. Dutkiewicz for his advice, critical appraisal and redirection when appropriate, during the time that I have taken to prepare this dissertation.

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ACRONYMS

ESKOM	-	Electricity Supply Commission of South Africa
ZESA	-	Zimbabwe Electricity Supply Authority - Zimbabwe
NUG	-	Non Utility Generators
CHP	-	Combined Heat and Power plants
CSIR	-	Council for Scientific and Industrial Research - South Africa
NTRI	-	National Timber Research Institute - South Africa
SI	-	Spark Ignition
PURPA	-	Public Utilities Regulatory Power Act
EPA	-	Energy Policy Act
PG & EU	-	Public Generator and Electricity Utilities
QF	-	Qualified Facility
ODT	-	Oven Dry Ton
US-DOE	-	United States - Department of Energy
UNCOD	-	United Nations Conference on Desertification
NDVI	-	Normalised difference vegetation index
WA&F	-	Ministry of Water Affairs and Forestry -South Africa

FOA	-	Forest Owners Association - South Africa
ENEE	-	Empresa Nacional de Energia Electrica
IEA	-	International Energy Agency
ZFC	-	Zimbabwe Forestry Commission
TPF	-	Timber Products Federation (Zimbabwe)
BTL	-	Border Timbers Ltd. (Zimbabwe)
MFC	-	Marginal Fuel Cost
PB	-	Payback Period
ROI	-	Return on Investment
B/C	-	Benefit Cost Ratio
NPV	-	Net Present Value
PLC	-	Process Logic Controller (electronic)

CHAPTER ONE

1.0 Introduction

The increasing energy costs that are associated with the generation of electrical power supplied by public utilities such as ESKOM in South Africa and ZESA in Zimbabwe will ultimately cause the forest industries to evaluate their position in terms of their ability to self-generate their own power.

The main ingredient in this self generated power concept is that wet saw-mills are net producers of wood residue that is being used as a fuel for the production of steam; the main heat transport fluid for timber processing and for combined heat and power generation - cogeneration - a new name for an old technology.

Whilst for the present ESKOM has over capacity in electrical generation, the future demand both within South Africa and in the adjoining regions is likely to erode this margin in the medium to long term. There is however a potential for non-utility generators (NUGs) to provide additional power from resources other than coal or oil.

The opportunities for some of these non-utility generators are set down as follows:

TABLE 1

COGENERATION POTENTIAL IN SOUTH AFRICA[1]

	MW Installed	Potential	Surplus
Chemical and fuel processing	635	1290	485
Sugar	217	60	72
Wood pulp and paper	279	nil	12
Metal manufacturing	nil	121	nil
Totals	1131	1471	569

The sugar, wood and paper and pulp industries, because of their low fuel costs, generate large portions of their power requirement at a relatively low cost and at the same time insulate themselves from unforeseen power cost increases and power supply outages that affect some of these industries.

In the case of the forest and saw-mill industries their wood residues offer an opportunity to cogenerate electric power and process heat from their waste resources. There is the caveat that in the long term these residues may have such value for the pulp and paper industries that only remotely situated saw-mills will be able to viably use their waste wood for cogeneration.

1.1 Legislative Impetus affecting the Use of Biomass for Power Generation

The United States experience has shown that under the influence of appropriate legislation, an impetus can be provided that will, in the long term, sustain the growth of cogeneration or combined heat and power (CHP) plants for a wide range of industries in general and saw-milling in particular.

In the consideration of the economic evaluation of a saw-mill's potential for CHP, the cost of the regional grid power and the self-generated power costs will be the most important determinators of the viability of such a project.

1.2 Studies on the Use of Saw-mill Waste for Generation in South African Saw-mills

A substantial body of statistical data is contained in the two reports by the CSIR - Hout 264[18] and Hout 282[14] which were titled `Energy at Saw-mills' and `The Economics of Saw-mills' respectively. These reports were commissioned following a request by the South African Timber Millers Association. The reports were published in 1982 and 1983. In order to update certain aspects of these reports, questionnaires were issued to a number of organisations and enterprises. These questionnaires are set out in Appendix E.

It would appear that the energy demand and consumption in the South African saw-mill has not changed significantly since the CSIR reports were prepared, even to the extent that the number of saw-mills with cogeneration plants have remained the same, with some CHP plants closing down and others being installed.

There is little data on the consumption of steam by the timber conditioning or drying kilns, although these units demand the largest energy input in the saw-mill complex - 95-96%. It would appear that because the wood residue is available as a nil-cost fuel, the matter of improved thermal plant efficiency is not regarded as a particularly important target to be achieved within the saw-milling industry.

In the chapter dealing with the cogeneration of electric power it will be seen that opportunities are available in which economically viable projects can be undertaken using the wood fuel residues produced in a saw-milling operation.

1.3 An Overview of the Utilisation of Biomass for Energy Generation in the International Arena

The international enthusiasm for the use of renewable energy technologies which includes biomass, has a great deal to do with its major environmental benefits. In particular, these benefits are seen in reducing the CO_2 emissons world-wide.

However, to fulfil this substantial expectation for renewable technologies in the future. the hopes and aspirations need to be linked to specific and realistic action to transfer where necessary, and apply this technology.

In developing countries, the opportunities for biomass residues to be utilised as a source of energy supply are often overshadowed by the lack of institutional policy to encourage and foster these aims.

In Table 2, the actual and potential electrical power generation of five selected countries is shown. The potential output is set against the current electrical energy produced from the use of wood residue.

It is apparent from the review of current biomass orientated projects in the International Energy Agency (IEA) member countries, that 13 out of the 21 members all have strategic projects or targets for increasing the utilisation of renewables. These renewables are focused mainly on the use of biomass.

The market incentives take the form of direct subsidy of the cost of electric power in the case in the United States, where the Energy Policy Act (1992) provides for up to 1.5 (US) cents per kWh for electricity generated from biomass. This concession is to continue for 10 years after commissioning.

The Canadian option is to allow an accelerated write down of capital cost against federal tax on plant generating power from renewable resources.

The Danish approach is to apply an energy and carbon tax to fossil fuels. The strongest incentive is to use biomass in such applications as district heating.

The Swedish Government has since 1994 offered grants of up to 25% of the capital cost of biofuelled CHP plants. The objective of this initiative is to facilitate the conversion of energy systems towards biomass fuels.

In considering the situation in developing countries, there appears to be little or no incentive to encourage the use of biomass fuels, when in fact it would be to the advantage of these countries to place a high priority on a policy of maximising the utilisation of wood residue for energy generation for economic reasons, as is the case in Honduras.

TABLE 2: RATIOS OF POTENTIAL TO ACTUAL POWER GENERATION FROM WOOD BIOMASS RESOURCES

ELECTRICAL POWER GENERATION PRESENT AND
POTENTIAL OUT PUT USING WOOD BIOMASS
IN SELECTED COUNTRIES - 1993 BASE

	PERCENTAGE UTILISATION OF POTENTIAL WOOD BIOMASS	POTENTIAL ENERGY TWh	POTENTIAL MW OUTPUT	PRESENT MW OUTPUT
SWEDEN[36]	33.8%	13 TWh	1484	502
USA[37]	32.5%	80 TWh	9132	2968
RSA[38]	13%	0.46 TWh	52	6.8
HONDURAS[32]	9.3%	0.054 TWh	6	0.6
ZIMBABWE[30]	NIL	0.12 TWh	14	NIL

The relationship between potential energy capacity and potential energy output is that in which the potential capacity is divided by the number of plant operational hours per year, which in turn is a function of the plant efficiency.

The data reflected in Table 2 suggests that developed country economies are able to afford the costs involved in the abatement of the `greenhouse gases' - carbon dioxide and oxides of nitrogen.

In developing countries the critical issue in most cases is to use biomass to reduce their dependence on imported fossil fuels. However it is often the case that the capital cost of the energy conversion plant is out of reach for many communities. Circumscribed state budgets are concerned with priorities such as health, education and housing, which leaves little in the way of funds to deal with environmental matters.

CHAPTER TWO

Review of Literature

This chapter reviews a range of current and historical literature which deals with the following main issues that concern the substance of the dissertation:

1. The research that has been carried out to determine the amount of wood waste or residue from saw-milling operations that could be used in energy conversion systems

2. The international experience.
    a) The use of biomass waste in the USA in general, and California in particular. The emissions from the combustion of wood residues.

    b) Honduras - Energy from Saw-mill Wastes - Industry Overview

    c) Sweden - Bioenergy Project

3. The combustion characteristics of biomass fuels with particular regard to the combustion of S.A. grown fuel woods.

4. The importance of air distribution in wood fuelled furnaces.

5. The limitations of the growth and supply of wood biomass in the South African and Southern African context.

6. The beneficial effect of silviculture in the sequestration of atmospheric carbon dioxide and the production of oxygen in the growing cycle of the forest.

2.1 Fuel Wood Resources in South Africa and Adjoining Countries

In 1984 a report was prepared by the National Timber Research Institute (NTRI) for the CSIR - Project TP/4375[2].

The aim of the above report was to consider the utilisation of wood residues that arise from the operation of such industries as saw-mills and secondary wood processors. The objective was to consider how these residues may be converted into a wood fuel derived gas that could be used in a spark ignition engine so as to generate electric power.

A considerable portion of the report is appropriately concerned with the use of the wood fuel in suitable gasifiers in order to produce a fuel gas. The amount of fuel wood that is considered to be available is of importance in terms of the combined heat and power (CHP) approach to wood fuel use.

In the CSIR Report Hout 287[27] the estimated amount of timber residue available in 1980, with trends to 1990, was shown as follows:

Table 3: Typical amounts of residue from saw-milling operations per m^3 of round softwood.

TABLE 3

THE ESTIMATED WET AND DRY RESIDUE FROM $1m^3$ OF ROUNDWOOD INPUT

WET RESIDUES		DRY RESIDUES	
Bark	$0.12m^3$	Sawdust and Shavings	$0.03m^3$
Sawdust	$0.13m^3$	Solids	0.015m
Solids	$0.37m^3$		
Total Wet	$0.62m^3$	Total Dry	$0.046m^3$

The total residue is made up of $0.62m^3$ wet and $0.045m^3$ dry residue or 66.5% of the round softwood making a total of $0.665m^3/m^3$. This loss is compared with figures by Border Timbers Ltd (BTL) of Zimbabwe in their annual report that quotes the following: Mutare Factory wet mill wood waste is 51.5% and the Nyakamete Factory dry mill wood waste is 60%.

A report by P. Sorfa `Hout 287'[27] sets out the actual and predicted softwood residues for the period 1980 to 1990 as follows:-

TABLE 4

THE ACTUAL AND PREDICTED SOFTWOOD RESIDUES FOR THE PERIOD 1980 TO 1990 FOR SOUTH AFRICAN SAW-MILLS

	ACTUAL	ACTUAL	PREDICTED
	1980	1985	1990
Total Wet Residue	2.344	2.778	3.472
Total Dry Residue	0.17	0.201	0.252
Total	2.514	2.979	3.724

in millions of cubic metres of timber per year.

This shows a 4% growth. The data provided by the Forest Owners' Association[16] suggests that the predicted growth of the saw-milling industry in South Africa will vary between 1.5% to 4% per year.

However, historical data[17] for the years 1981 to 1996 shown in Figure 10 indicates an average growth of less than one percent per year. Notwithstanding this limited growth in the industry, saw-mills have an inherent surplus of wood residue as a fuel resource to provide adequately and economically for the purposes of self-generation of electrical power.

The Department of Water Affairs and Forestry Statistics[15] for 1993/1994 indicates that the production of round wood in its various forms was 12.02 million tonnes of pulpwood, mining timber, matchwood and charcoal and 3.65 million m^3 of saw logs, veneer and poles. The total volume of commercial sales is thus 15.67 million m^3 for the year 1993 - 1994.

In the case of pulpwood, which amounts to 10 million tonnes for this period, there is relatively little saw-mill waste generated. The Sappi and Mondi pulp and paper operations have to augment their pulpwood requirements with up to 50% from other saw log producers.

2.2 Combustion Data on Biomass Fuels

A crucial issue in the consideration of the combustion of biomass in general and wood fuels in particular, are the various fuel calorific values and combustion characteristics that apply to these fuels. There is a considerable body of information and data available, with special reference to SA grown fuel woods.

In a paper `Packaged Power Stations for Export'[8] the author refers to the need for careful furnace and boiler design when burning heterogeneous fuels that generally have low calorific values.

The cellulosic renewable fuel resources have a relatively narrow band of calorific values in an oven dry condition.[9]

All woods	average CV	19.80 MJ/kg
Hardwoods	average CV	19.70 MJ/kg
Softwoods	average CV	20.43 MJ/kg
Pinus Patula	average CV	20.42 MJ/kg

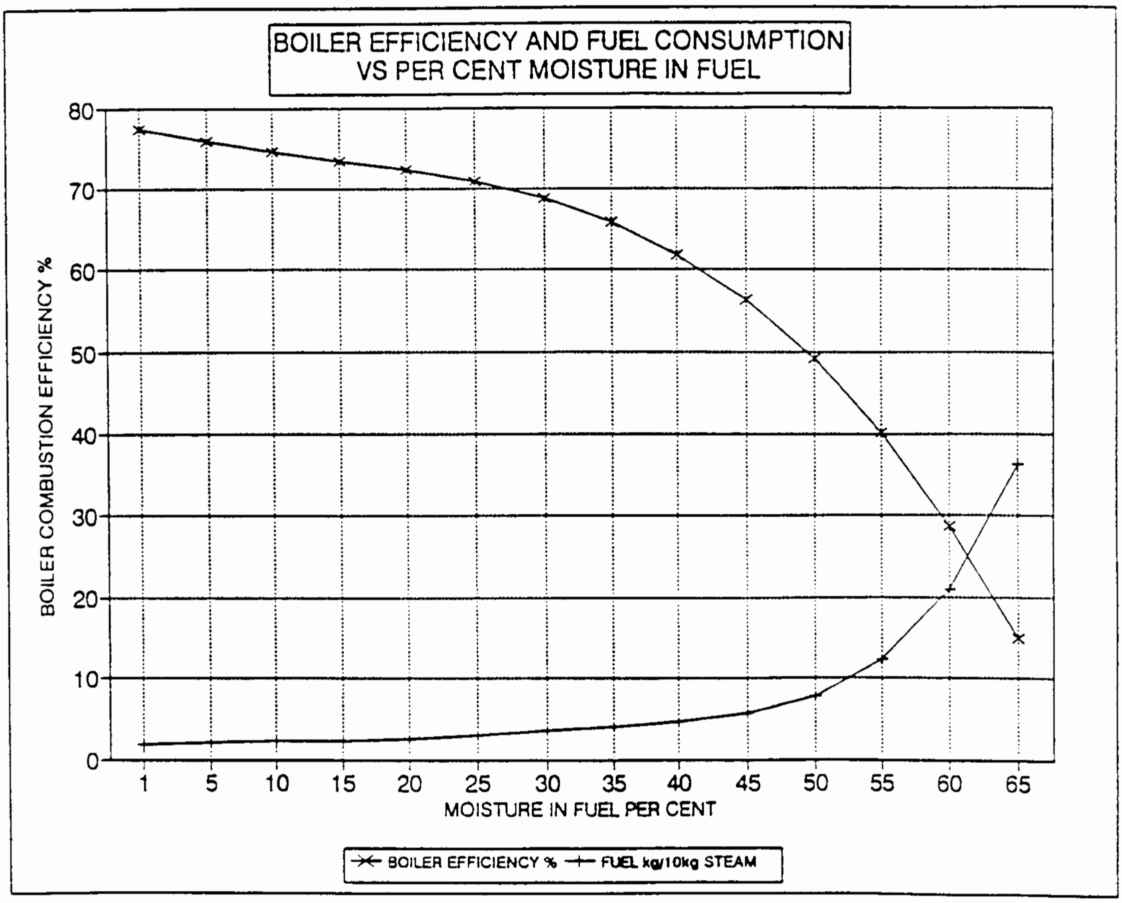
Further research on the combustion characteristics of SA grown fuelwoods was contained in the report by M Davis in 1990.[10] This report states that "There is remarkably small variation in the elemental composition of wood. Carbon generally comprises 49-50% of the substance, hydrogen 6%, oxygen 43-44% and nitrogen sulphur and ash 0.5 to 1% together". These values are important in the combustion efficiency of fuelwoods in boiler furnaces. Just as important is the moisture content of the wood which can be as high as 50 - 55% on the wet basis as received from a wet saw-mill. The calorific values (gross)[9] may be determined from the following relationship"

$$CV\ (gross) = 1624H + 518.5C + 1.05O_2 - 17860\ \text{kJ/kg}.$$

where, H, C and O_2 are percentages of hydrogen carbon and oxygen respectively. This equation assumes there is no moisture or sulphur in the fuel and that the nitrogen content is less than 1%.

The effect of moisture content in wood used as fuel is to reduce its calorific value in two dimensions. The first is that the water content reduces the net mass of combustible matter from the gross `as received mass' and the second effect is that the residual heat generated must evaporate the entrained moisture to superheated steam at the furnace condition. Figure 1 illustrates the overall effect.

FIG. 1



The behaviour of wood undergoing a combustion process passes through the following stages.

i) Driving off the moisture from the sample.

ii) Devolatilisation of non-pyrolysis products

iii) Pyrolysis of constituents

iv) Transfer of pyrolysis products to boundary layer and combustion of the vapours.

v) Combustion of the char.

In the case of the combustion of carbonaceous fuels, these steps do not occur sequentially. In actual combustion conditions these different stages often occur at the same time in different parts of the wood sample. However the importance of the combustion process, as described, is seen in its application to the practical design of industrial furnaces for the efficient burning of wood fuels. These furnaces take various forms, such as pile burning, flat grates, stepped grates spreader stokers, or cyclonic furnaces for small particle burning.

In a research programme by the US Department of Energy[11] (US-DOE) six types of woodfuels were used in a series of combustion efficiency tests. The report refers to the assessment of some 1700 wood-fired furnaces in the USA, of which over 50% were of the spreader stoker type.

In these tests, the spreader type of fuel application to a flat grate was simulated. The most important aspect of this research was to highlight the need to provide substantial overfire air. The analysis of the results confirms that the overfire air should be of the order of 57% of the total air required for combustion, with 43% undergrate air.

These tests were concerned with combustion efficiency and atmospheric emissions. In the case of combustion efficiency, one of the conclusions reached was that "as the wood fuel size was increased to a ring size of 27mm, the size of the fixed carbon pieces will be such that these pieces remain on the grate and oxidise to form carbon monoxide or carbon dioxide. As the particles become smaller they will reach a size whereupon they will become entrained in the gas/air flow. In so doing, these particles will tend to increase the air pollution emissions and consequent reduction of combustion efficiency if these particles do not burn completely in the furnace."

The report outlines the beneficial effect of overfire air which provides the combustion oxygen for the entrained small wood particles. The increased proportion of overfire air has a significant effect in the reduction of particulate emissions. The residue wood fuel types tested were:

i) Douglas fir hogged bark

ii) Douglas fir planer shavings

iii) Eastern White Pine and Douglas fir planer shavings

iv) Red Alder bark

v) Ponderosa Pine bark

vi) Hemlock bark

The average higher heating value or gross calorific value of oven dried wood fuel of the above species is 20.7 MJ/kg which is approximately the same as the calorific values of SA grown softwoods.[9] It should be possible to use the experience gained in this report of the U.S. DOE to improve the design of boiler furnaces using wood residue fuels.

In the saw-mill power plant careful attention must be paid to evaluating the undergrate and overfire air supply conditions with the particular objective of improving combustion efficiency and reducing atmospheric pollution.

2.3 **Fuel Wood Resources in Zimbabwe**

In the African Studies Report on Zimbabwe[3] published in 1986 by the Beijer Institute of Sweden, reference is made to the level of efficiency of the conversion of wood into commercial use. The claim made in the report is that nearly 80 per cent of the wood designated for commercial use goes to waste in the saw-milling process. This report states that of the 637 000 tonnes of indigenous and exotic timber that was harvested in Zimbabwe in 1982, only 130 000 tonnes was converted into commercial products. The inference from these figures is that the efficiency of conversion was approximately 20%.

A further point that is made in this report is to the effect that about 40% of the commercial timber harvested was supplied to the saw-mills, the balance being supplied to the paper and board-making industry. Of the timber delivered to the saw-mills about 50% is produced in merchantable or commercial form. This figure of 50% is somewhat higher than the experience of some of the main commercial operators who report saw-mill input to output ratios in the order of 43%.[4]

In a current report by the Stockholm Environmental Institute and Swedsteam AB[5] (Jan 1996) reference is made to the situation that will arise when the two new saw-mills planned for Zimbabwe are brought into operation. It is estimated that more than 100 000 m^3 per year will be produced by these new mills.
In order to produce this amount of finished product, the recoverable forest and saw-mills residue will amount to some 250 000 m^3 per year - this in addition to the current industry waste generated capacity.

This report suggests that "about 55% of the timber feedstock brought into a saw-mill is normally turned into offcuts and sawdust. The fuel energy in residues is substantial but seldom utilised in an efficient way in saw-mills operating in developing countries". Often large quantities of residue are either left in piles in the vicinity of saw-mills or are incinerated in primitive installations.

2.4 United States Experience

In a 1978 publication of the American Forest Products Research Society, which aims to assess the viability of renewable energy conservation opportunities, consideration is given to determining the quantity of wood and wood residue that might be available for the generation of electric power.

The report admits that at the time were was insufficient data to accurately determine the wood residue from all aspects of the saw-milling industry in the USA. In the US Forest Department of Agriculture Report to the Federal Energy Administration in 1978, it is estimated that from timber harvesting operations, 120 million oven-dry tons

(ODT) of bark and wood residues are generated annually in the USA. Whilst subsidiary industries use the bulk of this production, about 11 million tons of oven-dry bark per annum are disposed of in incineration and landfill. In addition to these substantial resources, is the volume of non-commercial timber which includes rough wood matter plus salvable dead trees. The Forest Service estimates this non-commercial residue to amount to 1000 million oven-dry tons per year. The value of these resources which is conservatively estimated at 160 million ODT of wood, is equivalent to 2.7 billion barrels of oil. However, the recovery and conversion of this wood fuel into potential electrical energy is still far from an accomplished fact.

The USA Public Utilities Regulatory Power Act (PURPA) legislation has had the desired effect of creating power generating industries that are economically viable and wherein the use of wood residue is the main fuel element.

The paper by J. Hughes Turnbull[6] (1992), `Use of Biomass in Electric Power Generation: the California Experience', illustrates the manner in which the utilisation of wood fuel residue in power generation and CHP operations has increased since 1978. As mentioned earlier, the PURPA legislation passed in 1978 was a watershed in that perceived and real opportunities for the use of renewable fuels were now seen in economically viable terms.

Whilst there were some 9000 MW of signed contracts between Pubic Generator and Electricity Utilities (PG&EU) and qualified facilities (QFs) in 1992, many of which were to be fuelled with wood fuel residue, there were 46 plants generating about 750 MW of power into the California grid system.

One of the environmental aspects of this modest shift to power generation utilising biomass, arises from the observation that the past practice of open field burning of agricultural waste has declined significantly. The reason for this environmental improvement is due to the biomass-fuelled power generators having obtained emission permits, based on the exchange of permits issued to farmers for using these agricultural residues, which would otherwise have been burnt in open fields.

The demand for wood waste and agricultural residues for the California grid connected electric power generators has increased from 100 000 ODT per year (ODT $year^{-1}$) in 1981 to more than 7 million ODT $year^{-1}$ in 1990. The effect of this increase in demand saw the price of appropriate biomass rise from $45 to $58 per ODT. With the development of the fuel supply market this price for biomass has since stabilised at about $35 per ODT.

The inference that must be drawn from these fuel cost changes is that whereas the biomass residues were probably seen as having little or no commercial value, the effect of a sustained demand with a strong economic element has now placed a real value on this commodity.

The US experience will no doubt be repeated elsewhere in the world in the assessment of fuel cost in power generation systems that will be, or are using biomass.

2.5 Honduras - Central America

In a report "Energy from Saw-mill Wastes in Honduras",[32] the view is expressed that many of the saw-mills in that country could be self-sufficient in generating their own electric power. At the same time some of these saw-mills could supply a significant amount of their surplus power to the national electrical energy supply system.

At the time of the report in 1991, only two saw-mills were self-sufficient in generating their electric power from saw-mill wastes. The primary form of energy used by existing saw-mills in Honduras is electricity and this is usually generated on site using diesel engine driven generators. Where saw-mills are situated within the national grid system, the power is purchased from the national electric utility company Empresa Nacional de Energia Electrica (ENEE). However about 90% of the saw-mills produce their own electric power using diesel engine generators.

The extent of the forested area of Honduras which covers approximately 60% of the country is about 5 million hectares (ha); of these about 2.6 million ha are hardwood forests and 2.4 million ha are pine.

Although hardwoods, including the Honduran mahogany, once represented a significant portion of the country's timber production, pine is now the primary timber for both domestic and export markets.

It is estimated that some 300 000 tonnes per year of wood waste is produced by the saw-mills in the country. This wood waste is typically either green (wet) sawdust or solid pieces of slabs and edgings. Most Honduran saw-mills do not debark the logs prior to sawing, consequently most of the bark is disposed of with the slabs and edgings.

The current waste management is in the form of dumping and open pit burning at the perimeter of the saw-mill site. Often these are situated near rivers. These disposal methods give rise to ground level smoke and serious soil and water contamination. Saw-mill waste disposal is a major environmental problem in rural Honduras.

As mentioned earlier, the saw-mill industry is largely powered using diesel-driven electrical generators which consumes some 4 million litres of fuel oil per year. This fuel type is fully imported and represents a considerable outflow of national financial resources.

The main aim of the report is to show that it is economically feasible for almost the entire saw-milling industry to be self-sufficient in generating its own electrical power from the use of its saw-mill wastes.

It is assessed that nearly 10 GWh per year could be produced by the saw-mill industry for self-sufficiency together with enough steam to kiln-dry 25% of the Honduran timber output. This power demand would consume less than 50% of the available saw-mill wood waste. It is estimated that with the use of a low capital cost plant design, a further 20 GWh per year could be generated for export of power from the saw-mill sites. For this type of power generation, importation of technology would be required to move away from diesel engine driven generators to steam powered plant. The plant would typically comprise the wood waste handling equipment into a stepped or flat grate furnace from which the products of combustion would be carried through a suitable boiler. The steam so generated would be passed through a condensing turbine or steam engine.

Whilst the condensing turbines will use a significant amount of water for steam condensing purposes, this is not seen as a problem in the Honduran[33] context. One of the reasons for selecting the condensing option as opposed to the back pressure turbine, is that at the time of the report less than 2% of the saw-mills in the country process their sawn timber by kiln drying. However, the view is that up to 70% of the timber production in Honduras could be kiln-dried. This process improves the timber quality, dimensional stability and reduces the volumetric density which in turn reduces the transport cost.

The export market for sawn timber products now requires timber to be dried for the reasons mentioned above and in addition, in order to eradicate wood parasites.

The estimated efficiency of the Honduran saw-mills in terms of sawn timber output set against roundwood intake is about 47% hence the amount of waste is approximately 52-53%. These values are comparable to the average saw-mill efficiencies achieved in the South African timber industry.

An important energy measurement in the saw-milling industry world-wide is the electrical energy demand to produce sawn timber. The power required is based on the volume of roundwood intake and is expressed as kW/m^3.

In the Honduran case[34] two sizes of saw-mill were considered. The large mill had a capacity of $195m^3$/day and the small mill about $60m^3$/day. The power demand for the large mill is estimated to be $33kW/m^3$ and $74kW/m^3$ for the small mill. This disparity in energy input per m^3 makes the small mill very much less competitive than the large mill, as at the time of the report the bulk of energy used in the Honduran timber industry was based on imported liquid fuels.

The impact of self-generated power would have a very significant effect on the economic competitiveness of timber products exported from Honduras. These benefits would arise from the low power cost operation using a nil fuel cost, the improved quality of kiln-dried timber, and lower transport costs.

In order to change from the established diesel engine generator power supply to the relative complexity of a wood fired steam plant with turbine or steam engine. This change will require basic technology transfer of the order that was available in the United States saw-mill industry at the beginning of this century.

This steam plant technology, whilst fundamentally, simple requires a wide understanding of a number of important issues in the operation of such plant. These issues would cover the following points: water treatment to boiler quality, fuel handling and preparation, efficient combustion of the wood fuel in the boiler furnace. In addition the expertise would have to cover safe operation of the boiler, water level and pressure control equipment; the generation of suitable exit steam conditions for the turbine. Also required is the understanding of the operation of the steam condenser, air pumps and cooling water systems, the removal of ash from the boiler, and grit arrestors.

The gas handling circuit would require an understanding of the need for controlling combustion air together with the requirement for air preheating, as the estimated average moisture content of the wood waste produced is 45%.[35] The operation and maintenance of the steam turbine will require specialised training.
It is clear that the potential economic opportunity exists for self-generated electricity derived from saw-mill waste. The change to this type of power plant from the self-contained package diesel generation will require a substantial technology transfer programme if the aim of the report is to be achieved.

2.6 Sweden Bioenergy[36]

The main focus of Sweden's use of forest biomass residues is as a fuel resource to substitute as far as possible for the energy produced by the present combustion of fossil fuels in that country.

A study, "Bioenergy Project 1993", considered in some detail the opportunities for increasing forest industry wood residue utilisation. At the time of the report, oil provided 42% and coal 6% of the total Swedish energy supply of 442 TWh . Of the balance, 30% of its energy requirement comes from renewable resources which includes hydropower. This latter energy source accounts for 17% of the total demand. Forest waste and saw-milling residues account for 8% of the national energy requirement and is equivalent to 36 TWh.

For the future, the main emphasis for Sweden's biofuel utilisation will be on the use of tree fuel. It is considered that it will be possible to extract about 100 TWh from the residue fuels produced by their forest industries within the next two or three years.

One of the significant developments in the Swedish forest residue recovery has been in the form of purpose-designed mobile chippers. The chippers which are combined diesel powered mobile units, recover and chip the tree tops and branches which are discarded during the clear felling operation when extracting roundwood from the forest. The mobile trailers attached to the chippers are then towed by tractors to a collection point or taken to the mill itself.

The Swedish approach to the utilisation of wood waste is to recover the whole tree stem and 75% of the branches and needles. This fuel is then burnt in modern boilers, usually operating at pressures of 60 - 70 bar with efficiencies of up to 85%. The steam so generated would be supplied to a turbine of the pass-out condensing type designed to optimise the efficiency of the plant in meeting the energy demand of the kilns or district heating, together with provision of electric power for the saw-mill itself. Surplus electric power is supplied to the national grid.

To a very large extent the Swedish use of biomass is to do with the state's concern with, and intention to reduce the output of greenhouse gases - CO_2 and oxides of nitrogen. To this end, the combustion of wood residue from forest industries is not seen to increase the net amount of carbon dioxide in the atmosphere.

There is the further and important matter of acidification of the soil, which provides the incentive for the Swedish forest industries to remove the clear felling residues: branches and needles from the forests.

Of particular concern is the southern part of the country, that has been subjected to atmospheric depositions of acidifying sulphur and nitrogen compounds. These acids have leached out large quantities of plant nutrients such as calcium, magnesium and potassium.

Where clear felling of the trees takes place without the removal of the trimmings - branches and needles - this biomass becomes a source of organically bound nitrogen. Over a period of time this nitrogen becomes available to plants and bacteria. This progression leads to increased leaching from the soil and subsequent acidification.

If the branches and tree tops are removed from the forest, the nitrogen effect on the soil is reduced to a point where optimum growing conditions can be stabilised.

The importance of this research into the control of acid conditions in Swedish forests by means of whole tree removal has in turn increased the amount of biomass available for energy generation.

2.7 Emissions from the Combustion of Wood Residues

Studies have been carried out to determine the NO_X emissions and the thermal efficiencies of small scale biomass fuelled power plants in developing country scenarios.

In one of the studies published in the International Journal of Energy Research in 1996,[7] a number of sites in Sri Lanka were examined. The purpose of the study was to supplement the rather meagre information that is currently available in regard to the thermal efficiencies and nitrogen oxide emissions from biomass fuelled heat plants in developing countries. There is evidence that the products of combustion from the use of biomass, and particularly woody biomass in power plants are less harmful to the environment than the combustion of fossil fuels.

Where wood fuel is resourced from managed forests that are planted on a planned basis, the new growth is a sink for the carbon dioxide element of the carbon combustion. Furthermore, these biomass fuels have little or no sulphur content and this means that the emissions of the oxides of sulphur are insignificant. The oxides of nitrogen NO and NO_2 are generally referred to as NO_x and occur in combustion processes which are generated in three routes:

a) thermal NO_x

b) prompt NO_x

c) fuel NO_x

The conversion of atmospheric nitrogen to NO_x is referred to as prompt NO_x. The thermal NO_x follows high temperature reactions in the combustion process at temperatures of about 1500^0C. The conversion of the fuel-bound nitrogen tends to depend largely on the fuel to air ratio. In the conclusion, the report states that the average NO_x emission for biomass fuelled combustion processes is averaged at 47g NO_2 GJ^{-1}. The NO_x values for these biomass fuels are significantly less than the legislated target values for the UK and EU countries. This average value for NO_x was derived from the analysis of some 14 power plants which ranged in power output from 132 kW to 20 MW and thermal combustion efficiencies from 35% to 67%.

This report concluded with the comment that with modest improvement in combustion control of fuel supply, combustion air, with or without preheat, and flue gas heat recuperation, the combustion efficiencies of the power plant surveyed could be substantially increased.

2.8 Carbon Sequestration - Managed Forests

New Zealand plantation forests amounted to 1.24 million ha in 1989.[26] It was estimated that these forests stored approximately 4.5 million tonnes of carbon between

April 1988 and April 1989. This increased the total plantation storage to an estimated 88 million tonnes of carbon. The average annual carbon uptake is approximately 6.4 tonnes carbon per hectare.

Plantation roundwood removals were equivalent to 2.7 tonnes of carbon per hectare. This means that the average carbon storage residual was approximately 3.6 tonnes per hectare of plantation forest. It was estimated that the annual storage of carbon in the New Zealand plantation forests amounted to 70% of the carbon in the fossil fuel emissions of that country in the period 1988-89. This situation of high carbon uptake by the forests is dependant on continued new planting without which the net annual carbon uptake would approach zero.

The South African commercial timber plantations were 1.37 million hectares in extent as reported in the 1993-94 survey by the Department of Water Affairs and Forestry. This figure is not dissimilar in size to the New Zealand plantation forest area.

In the South African context approximately 100 million trees are planted annually into 130 000 hectares of new plantation and 62 000 hectares are replanted. The importance of the carbon uptake assessment in terms of South African and Zimbabwean forestry is seen in its diminution of the amount of carbon dioxide released into the atmosphere through the combustion of fossil fuels, these being mainly coal.

In terms of carbon storage and uptake the local forests make a significant contribution in the matter of atmospheric carbon dioxide reduction emitted by the combustion of fossil fuels.[25]

There is now considerable interest in the matter of carbon budgets i.e. sources and sinks of carbon dioxide, and in the potential of measures such as growing forests to offset the carbon dioxide emissions from fossil fuel combustion.

Research in New Zealand[25] has shown that it is possible to calculate the annual carbon storage in forests using the following equation:

$$S = \Delta V . \rho . \alpha . k$$

in which S is the stored carbon in tonnes per hectare and where ΔV is the average change in wood volume (m^3) from one year to the next, ρ is the average oven-dry wood density (tonnes/m^3) α is a dimensionless factor that relates the oven-dry mass of roundwood to the oven-dry mass of the roundwood together with other tree and forest trimmings, k is the fractional component of the carbon content of the forest biomass.

There are other aspects of this evaluation that have to take into account variations due to tree age, and site conditions such as climate and fertility.

The fractional carbon content ranges from 0.47 to 0.53. The value of 0.5 is the value adopted in the estimates of forest carbon storage. This value is similar to the chemical analysis of South African grown fuel woods.

It is important to recognise the contribution of sustained forestry extension in its ability to remove significant amounts of atmospheric carbon dioxide. This should be seen as an important factor in attempting to reduce world wide atmospheric pollution.

2.9 Supply of Wood Biomass in the South African and Zimbabwean Context

The production of wood for industrial processes depends very largely on climatic and land topographical conditions which will allow the growth of the tree species which are required by these industries. The industries are those whose processes produce timber in the form of boards or machined sections of a wide range, together with particle board, dense compressed boards and pulp for paper-making. Timber is also produced in South Africa for use in the mining industry, mainly for mining props in underground mining operations.

The cultivation of timber stands depends on the provision of ample water to sustain the growth of the plant. The typical `green plant' photosynthesis comprises the `initial light reaction' with sunlight and water followed by the `dark reaction' including the absorption of atmospheric CO_2 in the reduction cycle. In simple terms, apart from the land on which to grow trees, the main elements for silviculture are those of water and sunlight. Because of the latitudes within which these lands lie, extending from 15^0S to 35^0S, there is abundant solar radiation. However, in terms of adequate water supply, this is altogether another matter.

The encroachment of the main desert and Karoo type conditions are shown in Figure 2, derived from a report by Acocks[12]. A more recent study presented to the United Nations Conference on Desertification-UNCOD in Nairobi, September 1977,[28] largely confirms Acock's predictions, illustrated in Figure 3.

The view expressed in the UNCOD report is to the effect that ecosystems of southern Africa can, in wet periods, recover areas lost to desertification during dry spells. However, as "man is one of the main agents" of this condition of desertification due to mis-applied technology, bad management or other human controls, it is considered that it is unlikely that the desertification trends will ameliorate unless improved land reclamation, soil conservation and farm management practices are maintained.

FIG. 2 KAROO ENCROACHMENT OVER SOUTH AFRICA[12]

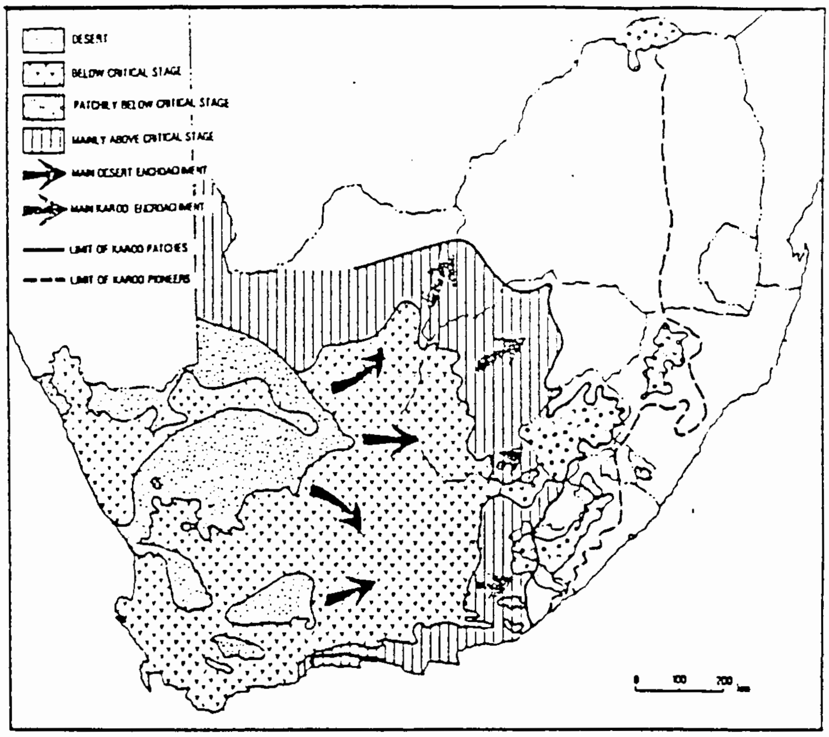
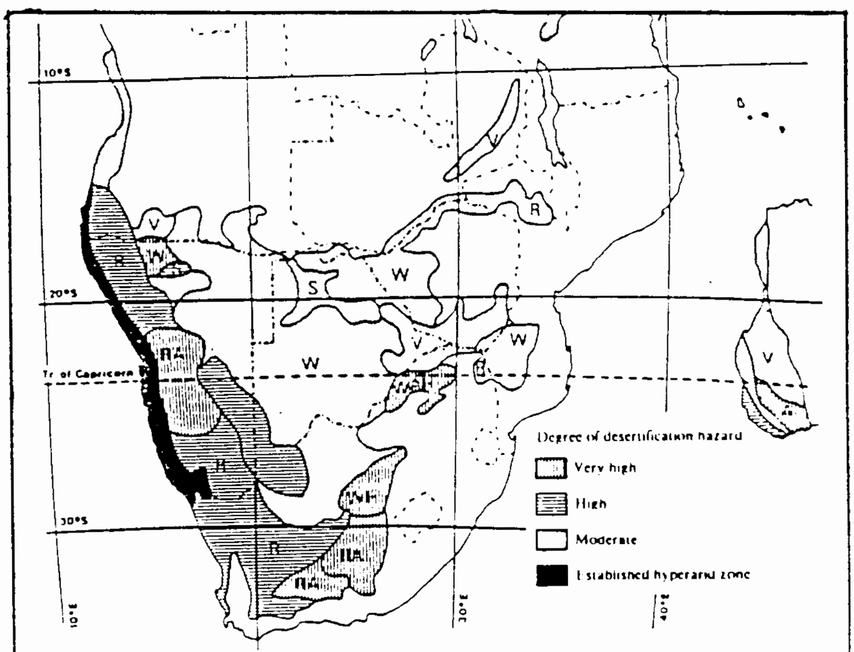


FIG. 3 DEGREES OF DESERTIFICATION HAZARD FOR SOUTHERN AFRICA.[28]

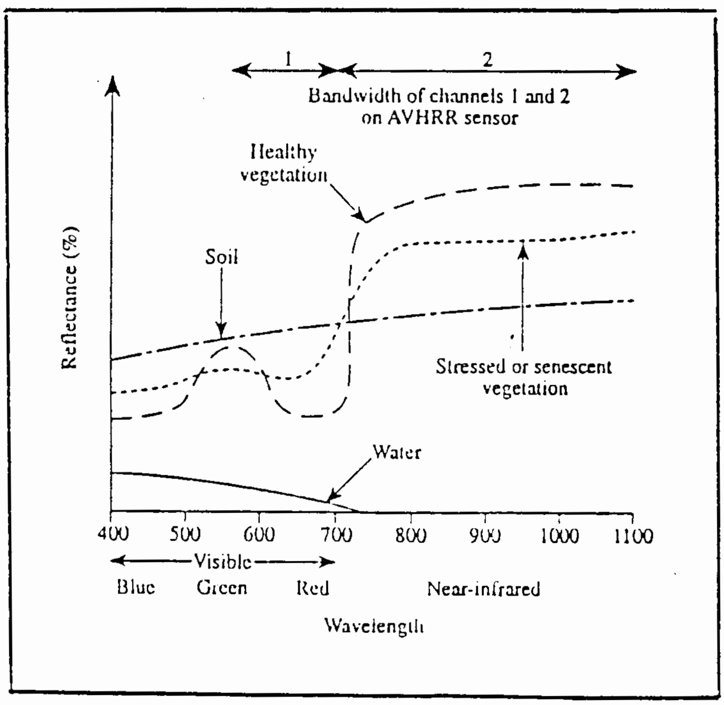


Desertification map for Southern Africa prepared for UNCOD. Desertification is here defined as 'the intensification or extension of desert conditions; it is a process leading to reduced biological activity, with consequent reduction in plant biomass, in the land's carrying capacity for livestock, in crop yields and human well-being.' Legend: W, surfaces subject to sand movement; R, stony or rocky surfaces subject to aerial stripping by deflation or sheet wash; V, alluvial or residual surfaces subject to stripping of topsoil and accelerated runoff, gully erosion on slopes and/or sheet erosion or deposition on flat lands; S, surfaces subject to salinization or alkalinization; H, subject to human pressure; A, subject to animal pressure.

In a recent survey by Millington et al[13] March 1994 - a satellite computer normalised difference vegetation index imaging (NDVI) system was developed. Biomass resource assessment using remotely sensed data is mainly concerned with the interaction of electromagnetic radiation with the vegetable canopy. Radiation of all wave lengths interact with this biomass cover. If the vegetation does not completely cover the ground, there is interaction between the radiation and the ground.

The proportion of radiation that is reflected at a particular wave length makes it possible to derive a characteristic curve for green vegetation as shown in Fig. 4.

FIGURE 4. CHARACTERISTIC LAND COVER REFLECTANCE CURVES AND RELATION TO AVHRR SENSOR BANDWIDTHS



However the actual vegetation or land cover curve will vary depending on the type of vegetation, seasonal growth, whether the plant is heat or water stressed and the effective canopy cover relative to the land.

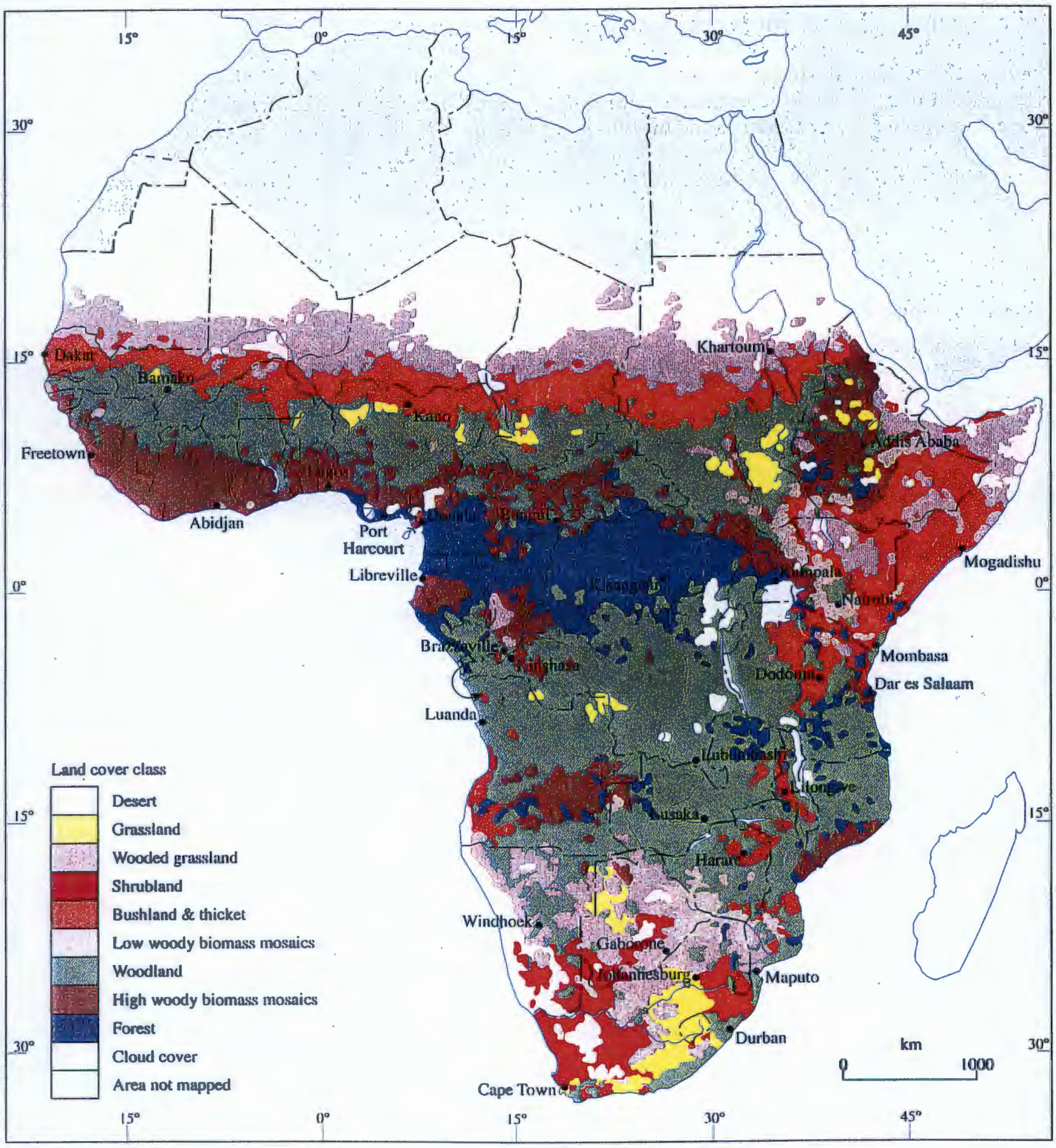
Detailed studies which are concerned with the physiology and biochemistry of plants in relation to their special characteristic have been undertaken. These studies conclude that spectral reflectance of vegetation is related to the physiological process that drives plant growth, namely photosynthesis and respiration.[13]

Figure 5 illustrates the satellite depiction of the woody biomass coverage of Sub-Saharan Africa. This figure largely confirms the predictions of Acock and the UNCOD studies and reports.

The issue that arises from the review of some of the climatic conditions affecting silviculture in South Africa and the adjoining regions is that rainfall is crucial to the sustained production of timber. The indications are that timber stands or wood lots will have to compete for water in marginal areas. In areas where there is adequate rainfall and limited agriculture, the growing of timber for commercial purposes will continue to increase in area and in yield.

Whilst fuel wood and wood residue are certainly renewable fuel sources, their production is finite - limited by the availability of water in this Southern African region.

FIGURE 5 REGIONAL SUMMARY LAND COVER CLASSES



2.10 The Economics of Energy at Saw-mills

'The Economics of Energy at Saw-mills' report[14] was prepared to meet the request of the South African Lumber Millers Association to examine the use of energy at saw-mills.

The aim was to consider in detail the types, quantities and sources of all fuels in South African saw-mills. Furthermore, the report was to discuss what opportunities there were available to the industry so that it might be self-sufficient in electrical power generation, using its own wood resources.

The eight saw-mills considered in the report are all wet mills, which means that there is no dry milling after kilning or re-manufacturing of the kiln-dried timber.

A standard wet saw-mill comprises the following elements: a weigh-bridge, log yard, log deck, sorting and stacking bays, de-barking plant, the wetmill with green deck, kiln stacking bays, kiln traverse car, kilns, de-stacking bays, dried timber grading, sorting and bundling facilities.

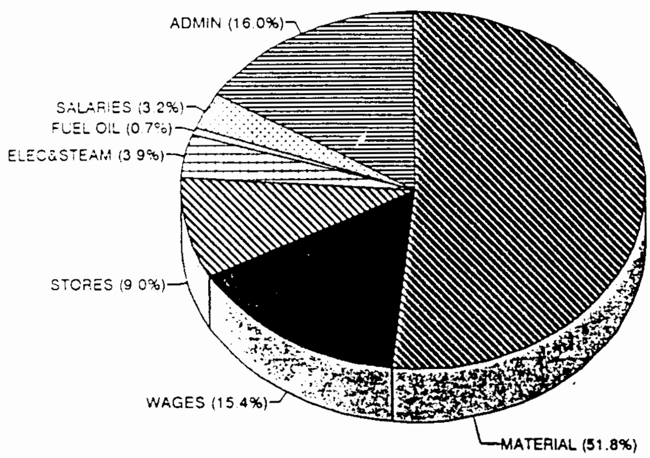
The eight saw-mills surveyed ranged from 100m^3 per day to 400m^3 per day of wood intake. These mills varied in degrees of mechanisation from those with little mechanical log handling, necessitating intensive labour utilisation, to the highly mechanised plants which used powered rollers, de-barkers, fully automatic green chains and PLC controlled kiln drying cycles. Generally the smallest mills have the lowest mechanisation.

The allocation of budgeted costs in 1981 is shown in Table 5.

TABLE 5

ALLOCATION OF TOTAL BUDGETED COSTS 1981[14b]

TOTAL BUDGETED COSTS 1981
COST CENTRES PERCENT OF TOTAL



	Range Max. %	Range Min. %
Material	62.6	39.7
Wages	22.2	5.6
Stores	12.1	4.1
Elec.&Steam	12.0	0.0
Fuel Oil	1.2	0.2
Salaries	5.6	1.5
Admin.	24.0	6.8
	100	100

The cost of electricity and steam varies from zero to 12 percent of budget. Of the eight saw-mills surveyed, only three generated their own power supply. In all the plants, steam was generated for drying and timber conditioning kilns. The boilers for this steam supply were wood-fired. The wood was in the form of slabs, sawdust and hogged or chipped wood. The boiler grates were either flat or inclined stepped grates. Whilst imported electric power and fuel oil for power generation purposes are significant elements in the consumption of energy by saw-mills, they only amount to 3.8% and 3.0% respectively. Hence the bulk of energy used for production is generated by boilers burning the wood residues. Table 6 illustrates the annual energy consumption of the saw-mill operations or production centres in which the kiln consumption of energy is 94% of the total energy used by the saw-mills reviewed.

TABLE 6[14b]

AVERAGE ESTIMATED ANNUAL ENERGY CONSUMPTION PER PRODUCTION CENTRE

Production	Electricity		Steam		Fuel Oil		Total	
centre	GWh	GJ	GWh	GJ	GWh	GJ	GWh	GJ
Log deck	0.061	220	-	-	0.245	882	0.306	1102
%	0.20	(5.24)			0.80	(26.53)	1.00	
Wetmill 0.594	2138			0.404	1454	0.998	3592	
%	1.94	(50.94)			1.32	(43.73)	3.26	
Kilns	0.318	1145	28.52	102665	0.079	284	28.915	104094
%	1.04	(27.30)	93.17	(100)	0.26	(8.54)	94.47	
Boiler	0.089	320			0.040	144	0.129	464
%	0.29	(7.62)			0.13	(4.33)	0.42	
Drymill 0.049	176			0.089	320	0.138	496	
%	0.16	(4.20)			0.29	(9.62)	0.45	
D.T. Store	0.012	43			0.052	187	0.064	230
%	0.04	(1.02)			0.17	(5.62)	0.21	
Conveyors	0.043	155			0.015	54	0.058	209
%	0.14	(3.69)			0.05	(1.62)	0.19	
Total	1.166	4197	28.52	102665	0.924	3325	30.608	110187
%	3.81	(100)	93.17	(100)	3.02	(100)	100	

Note: Fuel oils include saw-mills using diesel generators.

The inference is that depending on the size of the saw-mill, if it were possible to generate steam at higher pressure and provide appropriate superheat conditions, a greater degree of self-sufficiency in power generation could be achieved with very little additional wood fuel consumption.

The level of mechanisation of a saw-mill has a substantial effect on the ratio of power utilised per m^3 of roundwood intake. This feature is reflected in Tables 7 and 8.

TABLE 7

WEIGHTED AVERAGE ELECTRICAL CONSUMPTION PER CUBIC METRE[14c]

Mill size m^3 / day	Average installed kW	Average Consumption kWh / week	kWh / day	Base Load factor %	Average Consumption per kWh/m^3
100	661	12 150	2430	25	26.11
200	1 120	17 345	3469	23	19.02
300	1 855	29 811	5962	27	20.95
400	1 802	55 340	11 068	50	28.23
Average	-	-	-	31	24.03

TABLE 8

ELECTRICITY CONSUMPTION VERSUS MECHANIZATION [14d]

Degree of mechanization	Average installed power kW	Average power consumption kWh / week	Average ratio kWh / m^3	Average base load factor %
Low to medium mechanized	760	17 078	22	28
Highly mechanized	1 422	34 197	32	27
Very highly mechanized	2 823	40 000	29	33

Table 7 shows the performance of the mills based on intake of roundwood ranging from 100 to 400m^3 /day. The 300m^3 /day mill was the most highly mechanized with a 27% base load and a power consumption of 20.95 kWh /m^3 of roundwood intake.

In Table 8 the effect of mechanization is reflected in the statistic that the very highly mechanized mill required 29 kWh/m^3 compared with 32 kWh/m^3 for the so-called highly mechanized saw-mill.

The base loads referred to are those due to the kilns and boiler facilities. These vary from 12 to 50% of total load with an average of 25% or about 10 kWh/m^3 of roundwood intake.

Whilst consideration is given in the report to the effect of moisture content in the fuel wood on the output of steam from a boiler, the matter of fuel management is dealt with only briefly. Larger fuel storage capacity would also increase the time available for waste to dry which would improve the combustion efficiency.[14]

An important point made in the above study was that there was a lack of energy consumption statistics or data recorded by the saw-mills. This omission made it very difficult to determine the operating efficiency of saw-mills in order to compare the cost of self-generated power with that of imported electric power.

There is one exception and that is in regard to steam heating of the kilns. In this respect as referred to earlier, 94% of the total energy used in a wet mill is consumed by the kilning process. The reason for this is that the finished timber volume from the kilns can be related to the steam energy input per m^3 of product, and a cost of kilning can generally be evaluated from this.

The accurate cost of steam for either process heating or combined heating and power (CHP) is seen as a crucial element in assessing the viability or self-sufficiency in respect of heat only or combined heat and power for a saw-mill.

The cost of steam however is one of the many elements derived from the energy cost analysis as determined in the Appendix D.

One of the most important costs that affect viability of a project is that of plant capital cost. Another factor that significantly impacts on viability is that of power output. In the case of South African saw-mills, plants less than 1000 kW would be difficult to justify economically.

The plant size constraint in the Zimbabwean saw-milling scene is not so severe, due largely to the higher price of electrical power from the national generator ZESA.

CHAPTER 3

3.0 The Wood Fuel Resources

It is essential to establish the quantity of the wood residue that is generated by the South African and Zimbabwean saw milling industries so that the potential energy that could be generated can be viewed in the context of:

a) the saw-milling industry;

b) the contribution to the national electrical power generation system and,

c) the utilisation of a renewable resource in the most beneficial manner.

3.1 Typical waste to finished product ratios in South Africa

The recovery of finished board timber against round wood intake is assessed at 48% of the saw-mill input on a volumetric basis. Of the balance 41% of this is wet waste, a further 11% is lost through shrinkage and oversize. The shrinkage refers to the volumetric change in the sawn timber after kiln drying. The oversize is that fraction of the board of timber which is cut off to bring the board to standard length. The shrinkage as referred to above amounts to about 9% of the sawn timber with oversize amounting to a further 4%.

In most instances the oversize product is returned to the residue circuit and is of the order of 2 to 3%. Thus the total recoverable wood residue resource would be approximately 43 - 44% with kiln shrinkage losses of 8 to 9%.

The wet residue will vary from 50% to 30% moisture. The lower moisture condition occurs through natural air drying.

Figure 6 reflects the total wood waste and sawn timber output against the assessment of:

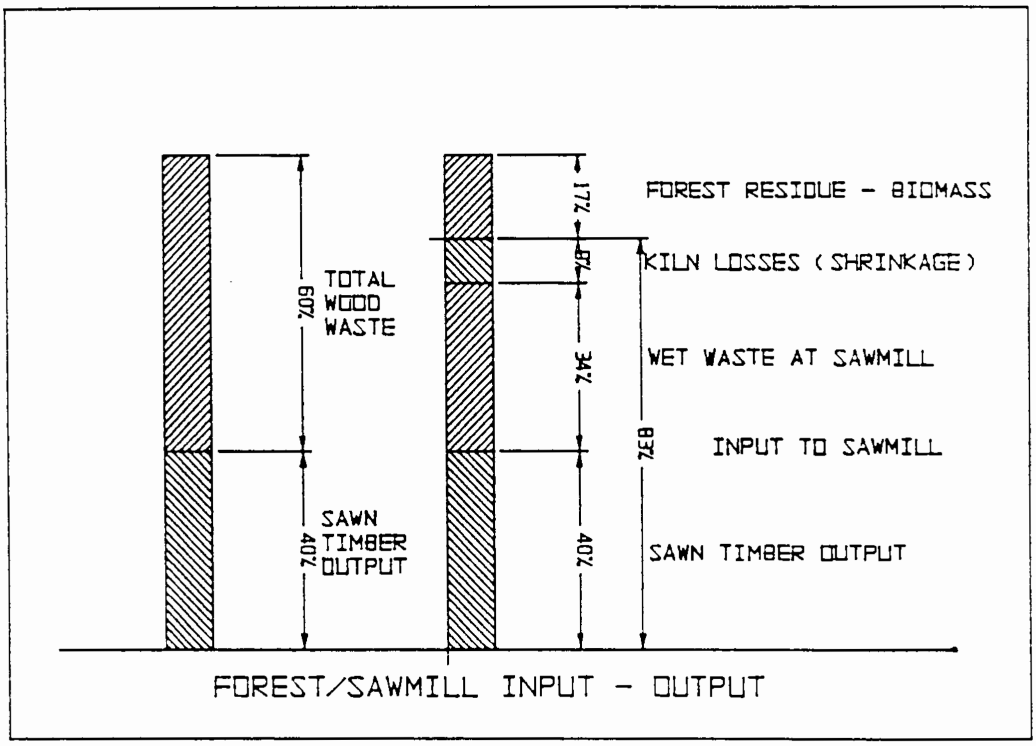
a) forest residue at 17%

b) kiln volumetric loss of 9%.

c) wet waste at saw-mill of 34% and,

d) the actual timber output of the mill at 40%.

FIGURE 6



The analysis of South African data from the Ministry of Water Affairs and Forestry[15] (WA&F) and the Forest Owners Association[16] (FOA) provides the following information for the years 1993 - 1994 and 1994 - 1995 as shown in Table 9.

TABLE 9

THE SUPPLY OF TIMBER PRODUCTS FROM SOUTH AFRICAN FOREST INDUSTRIES

	1993 - 1994		1994 - 1995	
Type	Mm^3	%	Mm^3	%
Saw logs	3.27	21.2	5.1	30.0
Veneer logs	0.13	0.8		
Poles	0.25	1.6	0.62	3.6
Mining timber	1.65	10.7	2.07	12.2
Pulpwood	10.00	64.8	9.02	53.1
Matchwood	0.03	0.2	0.02	0.1
Charcoal	0.10	0.7	0.17	1.0
	$15.43m^3 \times 10^6$		$17.00m^3 \times 10^6$	

As the saw logs and veneer logs often produce waste at the same site, there is the opportunity of using this waste in a common CHP plant. These two values should be added together. The percentage contribution will then be 22% for the saw logs and veneer logs combined in the 1994-1995 statistics.

Whilst mining timber constitutes between 10 and 12 per cent of the timber purchased, the species used by this industtry is nearly all hardwood and is not seen as a viable source of wood fuel in the context of a saw-mill operation.

If the recoverable wood residue is expressed as a percentage of the softwood saw log and veneer intake, the waste is 43 - 44% and the merchantable timber is approximately 48% with a 3% allowance for shrinkage. On the basis of these ratios the amount of waste produced in 1993-1994 would have been 1.47 million m^3 and for 1994-1995 the waste produced would have been 2.26 million m^3.

The potential supply and demand for softwood saw logs is assessed in the Forest Owners Association report[16]. This report considers three supply and demand scenarios in the context of growth for the South African saw-milling industry.

In Figure 7 the demand for saw-logs is shown rising at 1.5%/ year to 5.05 million cubic metres in 2025, at 2.5%/ year to 5.80 million cubic metres in 2025, at 4.0%/ year to 7.4 million cubic metres in 2025. The Figure 8 shows the residue arising from softwood saw-milling operations to the same time horizon of 2025 and for the same cumulative growth rates. The wood waste generated for the three rates are as follows:

a) at 1.5% per year : 2.17 million cubic metres
b) at 2.5% per year : 2.51 million cubic metres
c) at 4.0% per year : 3.18 million cubic metres

FIG. 7
THE ESTIMATED DEMAND FOR SAWLOGS IN SOUTH AFRICA[16]
1997 - 2025

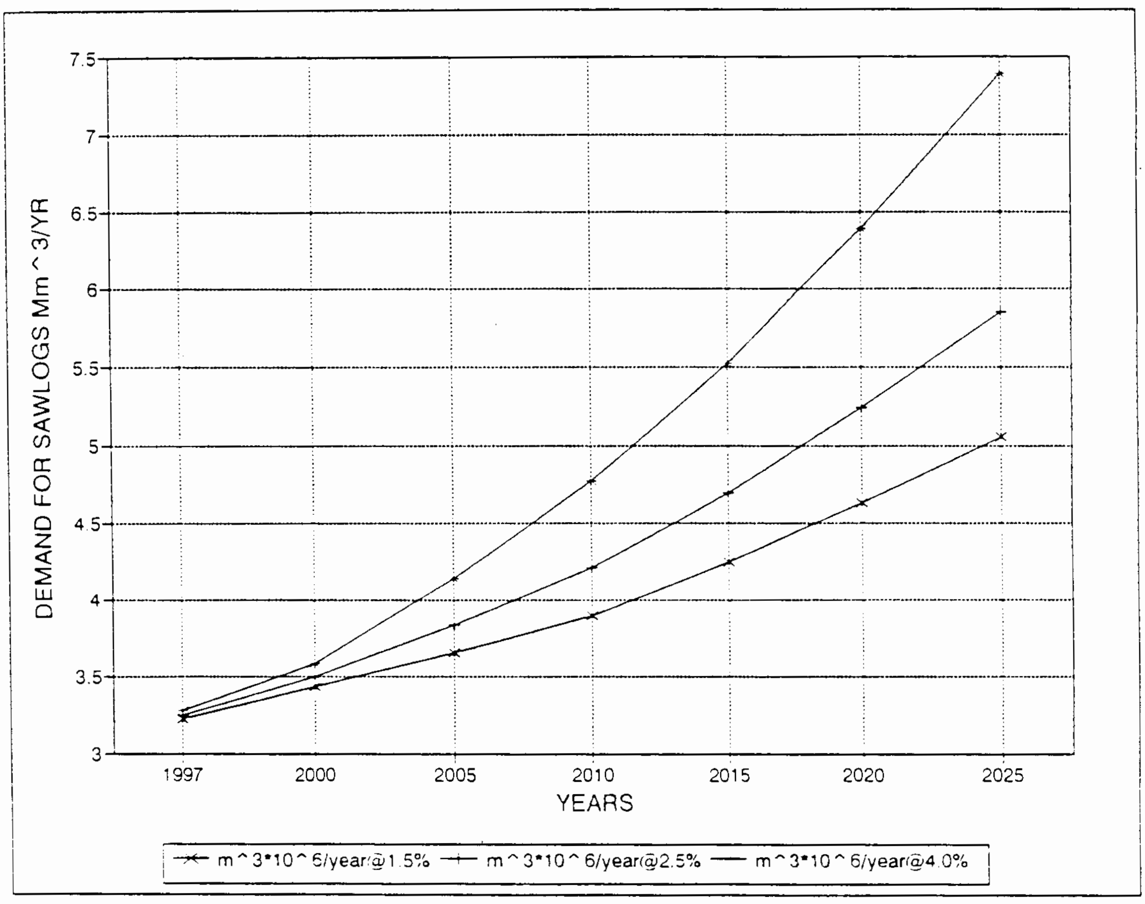
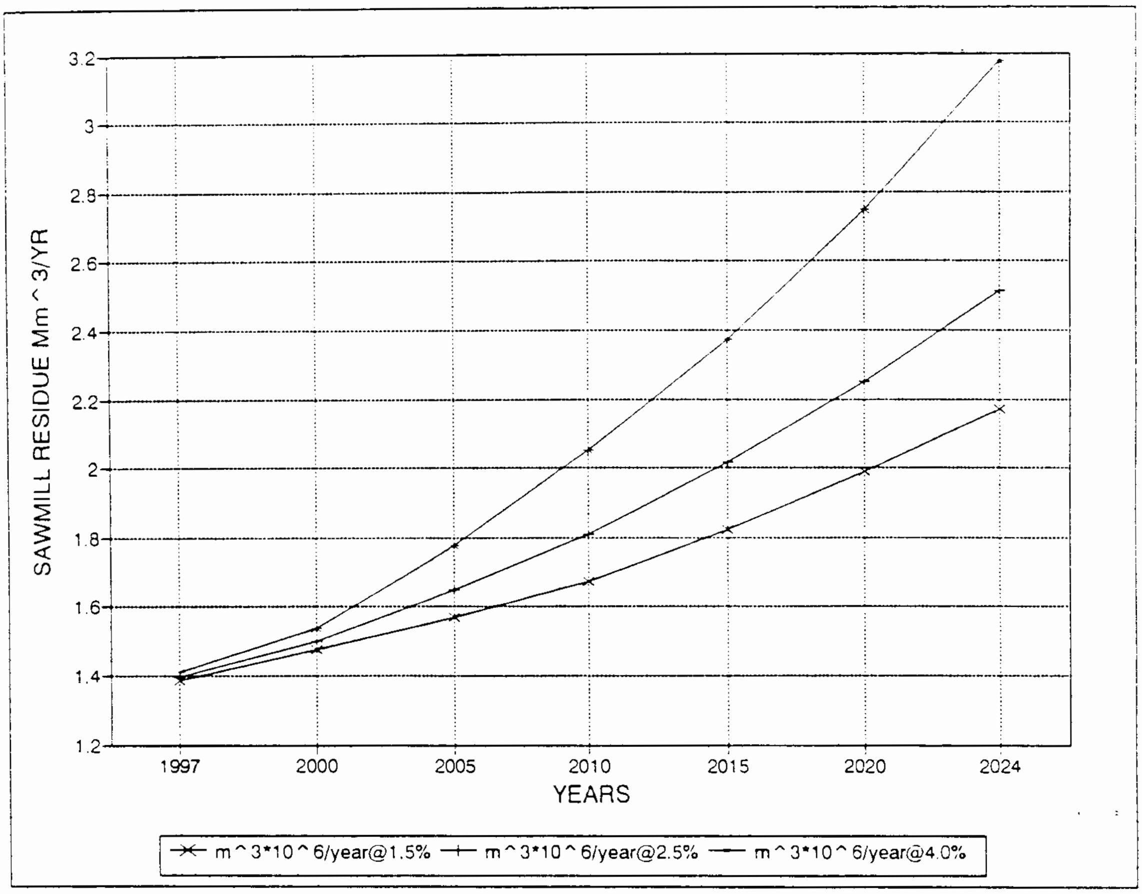


FIG. 8
ESTIMATED SOUTH AFRICAN SAW-MILL WOOD RESIDUE ARISINGS 1996 - 2025



Converting these volumetric wood waste outputs to tonnes on the basis of 1 tonne of wet wood = $0.94m^3$, the wet wood waste generated in tonnes in 2025 for the same growth ratios are as follows:

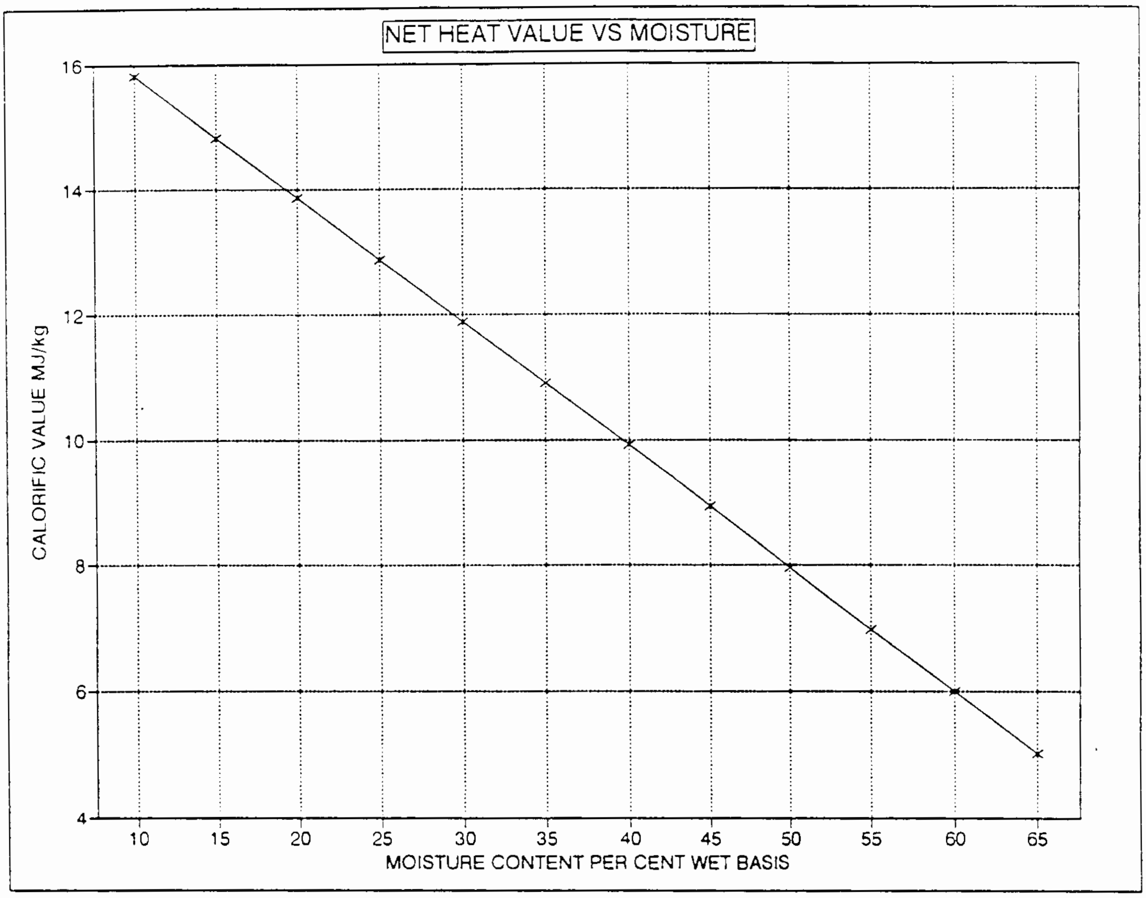
d) at 1.5% per year : 2.3 million tonnes

e) at 2.5% per year : 2.7 million tonnes

f) at 4.0% per year : 3.4 million tonnes

Depending on the management of the wood waste in terms of air drying, the moisture content of the waste wood fired in saw-mill steam plant varies from 30 to 60% in wet mills. In dry mills the moisture content is usually that of the equilibrium value for site conditions and varies from 10% to 15%. Figure 9 illustrates the relationship between moisture content and calorific value for Pine species.

FIG. 9
NET HEAT VALUE vs MOISTURE CONTENT OF WOOD FUEL



The estimated present energy potential of the wood waste based on:

a) 50% moisture content is 11.74 peta Joules or 3261 GWh

b) 40% moisture content is 14.624 peta Joules or 4062 GWh

c) 30% moisture content is 17.51 peta Joules or 4864 GWh

The forecast minimum energy potential available from wood waste based on 50% moisture content and the 1.5% growth rate at the 2025 time horizon is 27 peta Joules or 7500 GWh.

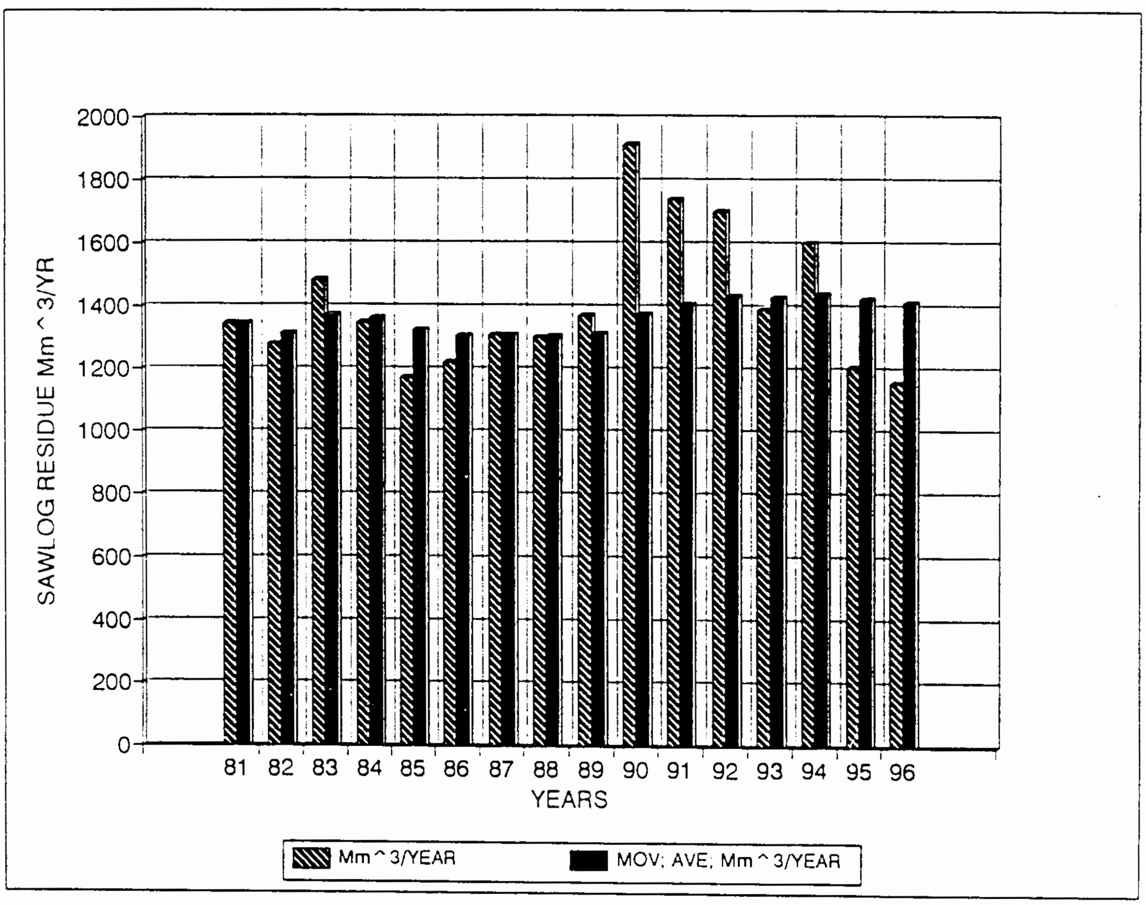
The forecast maximum energy potential from wood waste based on 30% moisture content and 4.0% growth is 40 peta Joules or 11200 GWh. These values will however have to be modified in terms of plant energy conversion efficiency.

In the case of direct steam heated kilns these have a relatively high efficiency in insulated kilns, usually in the order of 60 - 70% in terms of water driven off the timber to be dried.

Historical data[17] for the period 1981 to 1996 shows the cyclical nature of the production of saw-mill wastes; this is illustrated in Fig. 10.

A moving average evaluation of this data indicates that there has been little or no increase in the amount of the saw-mill residue produced by the South African saw-milling industry over the last fifteen years.

FIG. 10
SAWLOG RESIDUES FROM RSA MILLS



3.2 Zimbabwe Saw-mill Waste Resources and Ratios

The quantities of sawlogs supplied to the Zimbabwe saw-milling industry have been determined from the annual reports of the Zimbabwe Forestry Commission[29] (ZFC) and the Timber Producers Federation (TPF)[30] of that country. The production of sawlogs from the Forestry Commission is shown in Figure 11 for the period 1992 to 1995. There was no published data available for 1991 - 1992.

The annual increase of production is assessed at 13.6%. The 1994 - 1995 report goes on to state that this rate of growth is unlikely to be sustained beyond 1996 - 1997.

The Timber Producers Federation (TFP) data is drawn from their 1997 Forestry Plantation and Roundwood Processing Statistics. The volume of roundwood produced is shown in Figure 12. This data covers the period 1991 to 1997 and reflects a growth of 9.35% per year.

The company Border Timbers Ltd.(BTL) is the largest timber producer after ZFC. In their report, `Budget Proposals 1995', their production of roundwood shows a growth of 4.69% for the period 1981 - 1995. The average growth for the saw-milling industry in Zimbabwe is estimated to be in the order of 5 to 6% per annum.

Assuming an average industry growth of 5.5%, the production of roundwood or sawlogs will rise from approximately 450 000 tonnes in 1997 to 2.0 million tonnes of wet wood in 2025.

FIG 11
ZIMBABWE FORESTRY COMMISSION PRODUCTION OF SAWLOGS FOR THE PERIOD 1993 - 1995

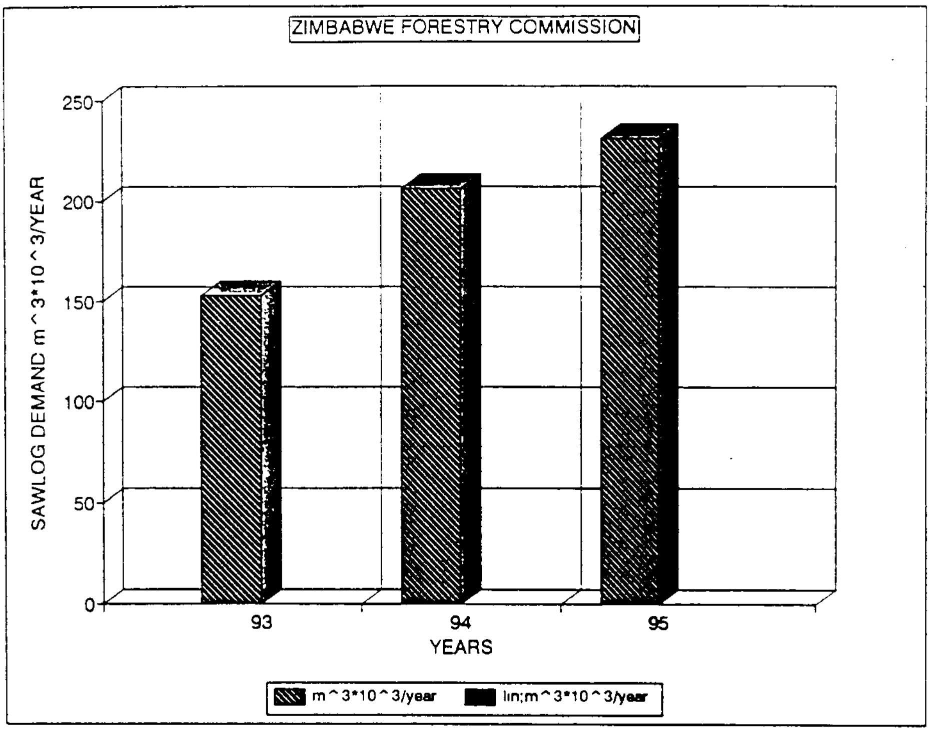
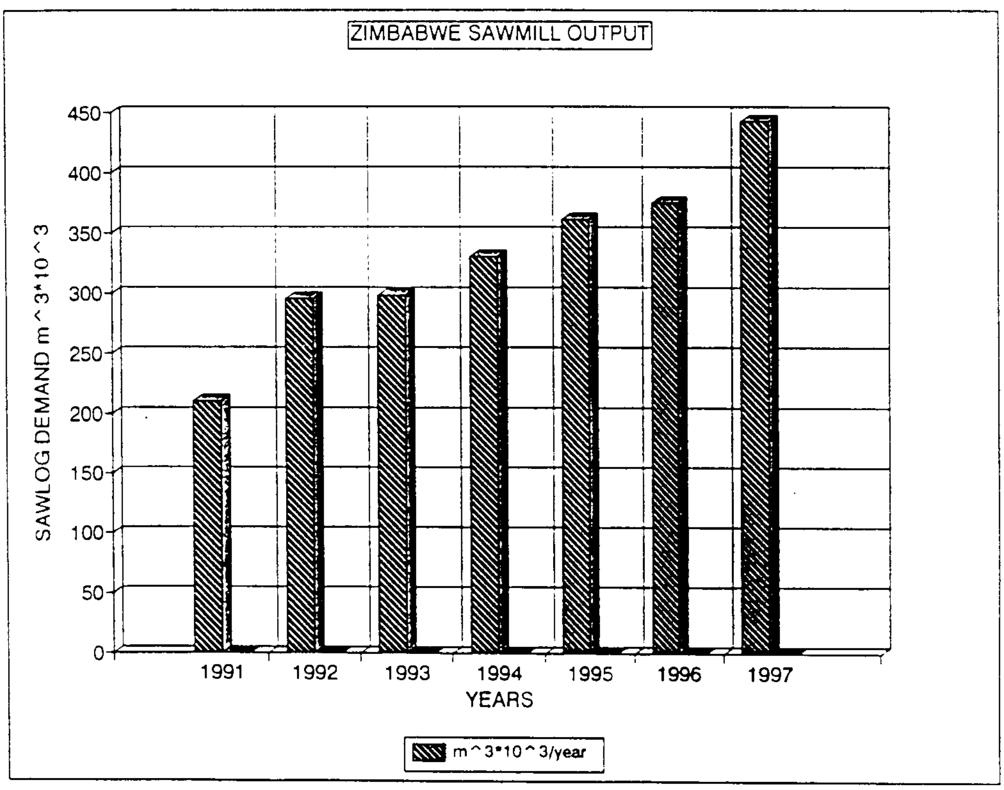


FIG 12
ZIMBABWE SAW-MILL OUTPUT



CHAPTER 4

4.0 Saw-mill Energy and Power

4.1 Power Requirements of a Saw-mill

To gain a perspective of the energy and power requirements of a saw-mill it is necessary to examine in some detail the main plant elements in a typical wet and alternatively dry saw-mill.

Figure 13 illustrates the routes by which wood waste is generated. In the main this residue has a moisture content of 50 - 55% on a wet basis with a small amount of kiln-dried oversize being fed into the waste system. This residue is usually subject to some in-transit drying and arrives at the saw-mill boiler plant with a typical moisture content of 44-48%.[19]

Figure 14 shows the waste generated from processing wood in a dry mill. Quite often both wet mills and dry mills operate at the same site. However, for clarity, the depiction of the dry mill shows the kilned or dry timber at the equilibrium moisture content being processed into finished products. The amount of wood waste generated by this further processing of the kiln-dried timber amounts to 50 - 55% of the input. The target for finished timber products is 50% of the input; however the industry norm is 40 to 48% of the input.

The waste wood quality arising from the dry mill processes is of a much greater energy content. This wood fuel is equivalent to 50 - 55% of the heating value of coal on a mass basis.

In the dry mill there is little need for steam unless it is involved in special processes such as veneer production wherein re-saturation of the roundwood is required together with the final drying of the veneer lamina. In most dry mills up to 90% of the energy input is electrical power for rotary machines. This power is usually provided by induction type electric motors for the wood processing machines.

The major energy input to the wet mills is that required for kiln-heating, which is of the order of 93-95% of the total energy required by the saw-mill.

It is seldom the case that the steam heating load of a wet saw-mill can be matched precisely with the steam requirement of a turbine or steam engine that has sufficient capacity to supply the electric power requirements of the saw-mill.

FIG. 13

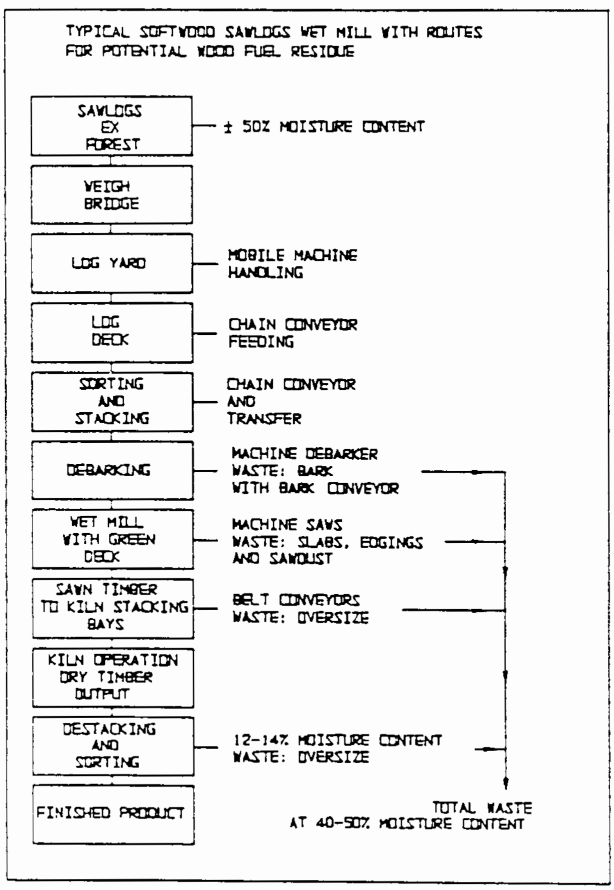
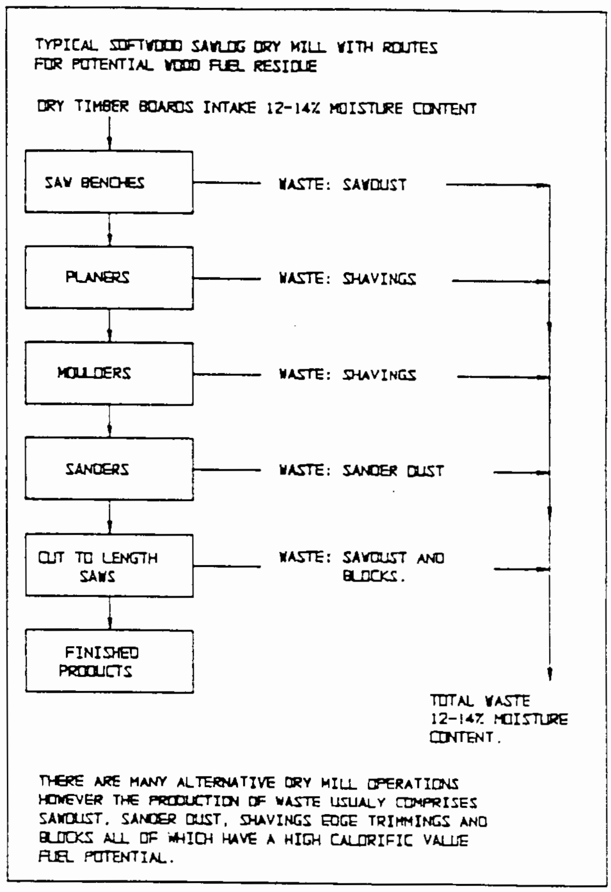


FIG. 14

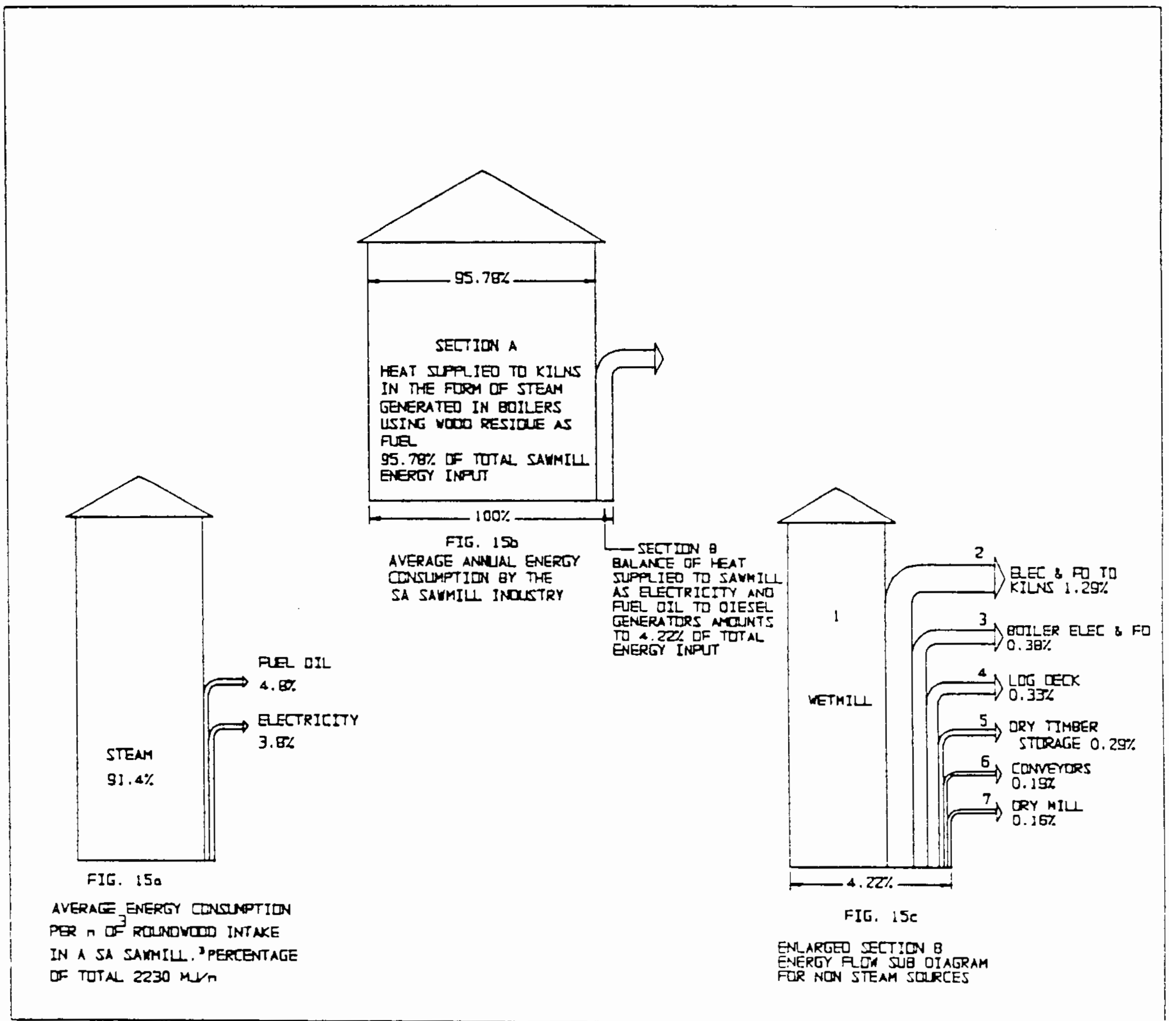


The most important feature in the CHP plant operation is the matter of quality of wood waste in terms of energy potential. The wet mill moisture content will vary from 47% to 62%.[14] In a dry mill the moisture content is between 12 and 14% and depends largely on the site moisture equilibrium of the particular timber species.

4.2 Energy Utilisation in a Saw-mill[14]

The average annual energy utilisation by the various elements of the timber processign route in a wet saw-mill is shown in Figures 15a, 15b and 15c.

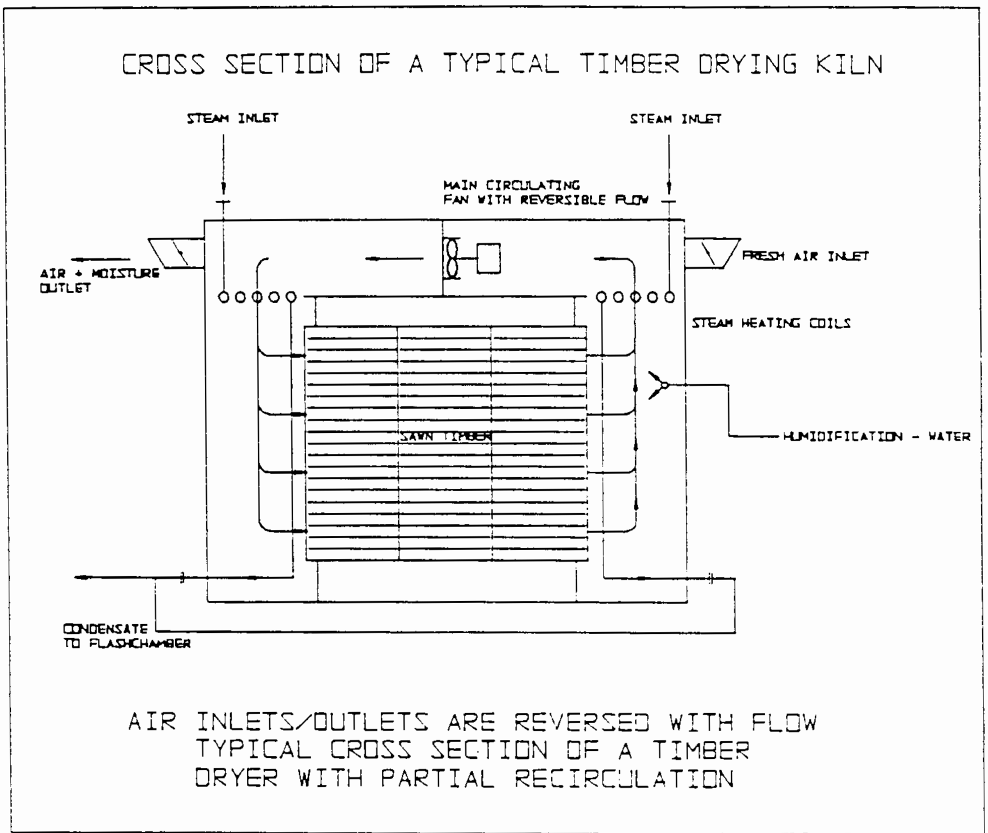
FIG. 15 ENERGY FLOW DIAGRAM FOR A TYPICAL SA SAW-MILL



The most conspicuous energy user of the kiln complex in a wet mill is the timber drying process which accounts for 94 - 97% of the total energy demand of a wet saw-mill.

In order to examine the process of timber drying with a view to assessing the opportunity for improving the thermal efficiency of this process, an appropriately detailed study is made of the psychometry involved in drying the product. Figure 16 illustrates a cross-section of a typical timber drying kiln using a partial re-circulation of the air flow. This partial re-circulation substantially reduces the heat required to drive off the free and bound water inherent in the cellular structure of the timber.

FIG. 16 CROSS SECTION OF A TYPICAL TIMBER DRYING KILN



There are in the main, two power plant options for saw-mills contemplating the installation of power generating plant using steam.

The first option is a condensing steam turbine in which the exhaust steam is condensed to boiler feed condition, using an external source of cooling medium such as water or air cooling. The condensing steam turbine does not permit any significant downstream heat extraction for supply to the saw-mill kilning as the condensed water from a condenser would have a temperature of 50 - 55 °C. The modern timber drying kiln operates in the range of 80 - 95 °C which means that the approach temperature of the steam would have to be 120 - 130 °C, which is equivalent to a team pressure of 2-3 bar.

In numerous cases in the South African saw-milling industry where power is self-generated, the plant that has been installed is of the condensing type. The reason for this situation is that nearly all the generating plant is seldom purchased as new plant and has often been acquired from small de-commissioned municipal power utilities in which all these power plants were of the condensing type.

The alternative power plant option is that of a back pressure or pass out type turbine or steam engine, the latter being of the back pressure type only. The design of this type power plant is usually application-specific and is therefore not often available in the used power plant market. However, this type of plant allows the highest overall thermal efficiency to be achieved with the best utilisation of the wood fuel resource.

In order to relate the effect of using either a condensing turbine / engine sets and alternatively, a back pressure power plant, the wood consumption and energy flow diagrams are shown against the assessed consumption of energy per cubic metre of roundwood intake.[18]

The consumption of energy per m^3 of timber input for a saw-mill fully dependent on imported electrical power has been assessed as follows:-[14b]

Electricity	85 MJ/m^3	3.8 per cent
Steam	2037 MJ/m^3	91.4 per cent
Fuel oil	107 MJ/m^3	4.8 per cent

Some of the fuel oil consumed at a saw-mill is used in diesel electric generators.

A condensing steam turbine considered typical of existing 1.0 to 1.5 MW power plants operation in the SA saw-milling industry would operate on an inlet steam condition of 14.8 bar 307 °C superheat condensing to 0.1688 bar. The specific steam consumption is 8.32 kg/kW or 8320 kg/h to generate 1.0 MW of electric power. The estimated Rankine efficiency is 15.8%.

Assuming a boiler efficiency of approximately 69% when burning fuel with a moisture content of 45%, the amount of wood fuel required to generate 8.32 tonnes of steam per hour would be 3.0 tonnes/h. The overall thermal efficiency of the boiler and turbine plant is 10.1%.

The wood fuel consumption, steam demand and overall efficiencies for the various saw-mill energy options are shown in Table 10. Energy flow diagrams for the condensing and back pressure turbine options are depicted in Figures 17, 18 and 19. These figures show the overall energy flows within the boiler and turbine thermal boundaries which include the condensate return from the timber drying kilns.

Table 10

South African Sawmill Biomass Energy Utilisation Options – Mill Size: 500m³ per day Roundwood intake

	1 Sawmill fully dependent On imported electric power		2 Sawmill condensing Turbine output 1000kW		3 Sawmill with back pressure Turbine output 500kW		4 Sawmill with back pressure Turbine output 1718kW	
Consumption of Energy Per m^3 of round woood[18]	MJ/m^3	Percent	MJ/m^3	Percent	MJ/m^3	Percent	MJ/m^3	Percent
Electricity	85 actual	3.8	864 equivalent	28.7	594 equivalent	27.7	3338 equivalent	95.6
Steam direct to Kilns	2037	91.4	2037	67.7	1446	67.3	0	0
Fuel Oil	107	4.8	107	3.6	107	5.0	107	4.4
Totals	2229	100.0	3008	100.00	2147	100.00	3445	100.0
Steam demand tonnes Per hour (TPH)	19.6 TPH		27.9 TPH		19.6 TPH		22.5 TPH	
Boiler / CHP Plant overall efficiency percent	69%		50%		64%		68%	
Wood fuel consumption Tonnes per hour	7.0		10.0		7.0		8.0	
Tonnes per day	168		216		168		192	
Unused residue per Day - tonnes based on the production of 276 tonnes of waste wood per day	108		60		108		84	

The energy flow diagrams shown in Figures 17, 18 and 19 refer to the following plant types:

Figure 17 - a condensing turbine with boiler capacity to meet the requirements of both the turbine and kiln energy demands. The gross electrical power output is 1.0 MW.

Figure 18 - A back pressure turbine of 500 kW gross output which fulfills the average hourly power requirement of a 500m^3 per day roundwood timber input. The boiler also supplies the additional steam requirement for the kilns.

Figure 19 - A back pressure turbine which has the steam flow capacity to handle the total steam requirement of the kilns in respect of the 500m^3 per day timber input. The power output of this turbine is 1718 kW.

FIG. 17 POWER PLANT FOR SAW-MILL - CONDENSING TURBINE 1.0 MW OUTPUT

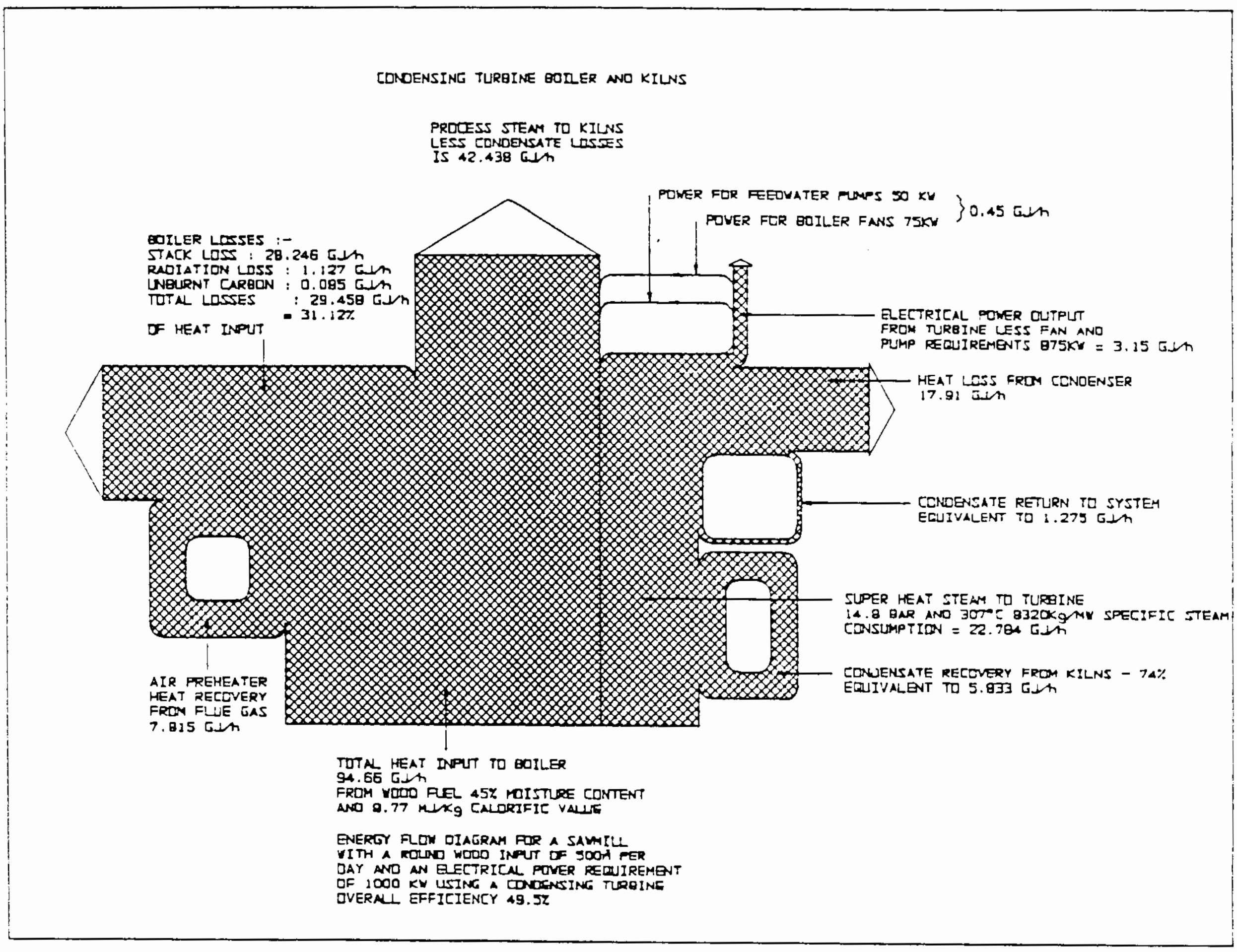


FIG. 18 CHP - PLANT FOR SAW-MILL - BACK PRESSURE, 500 kW OUTPUT

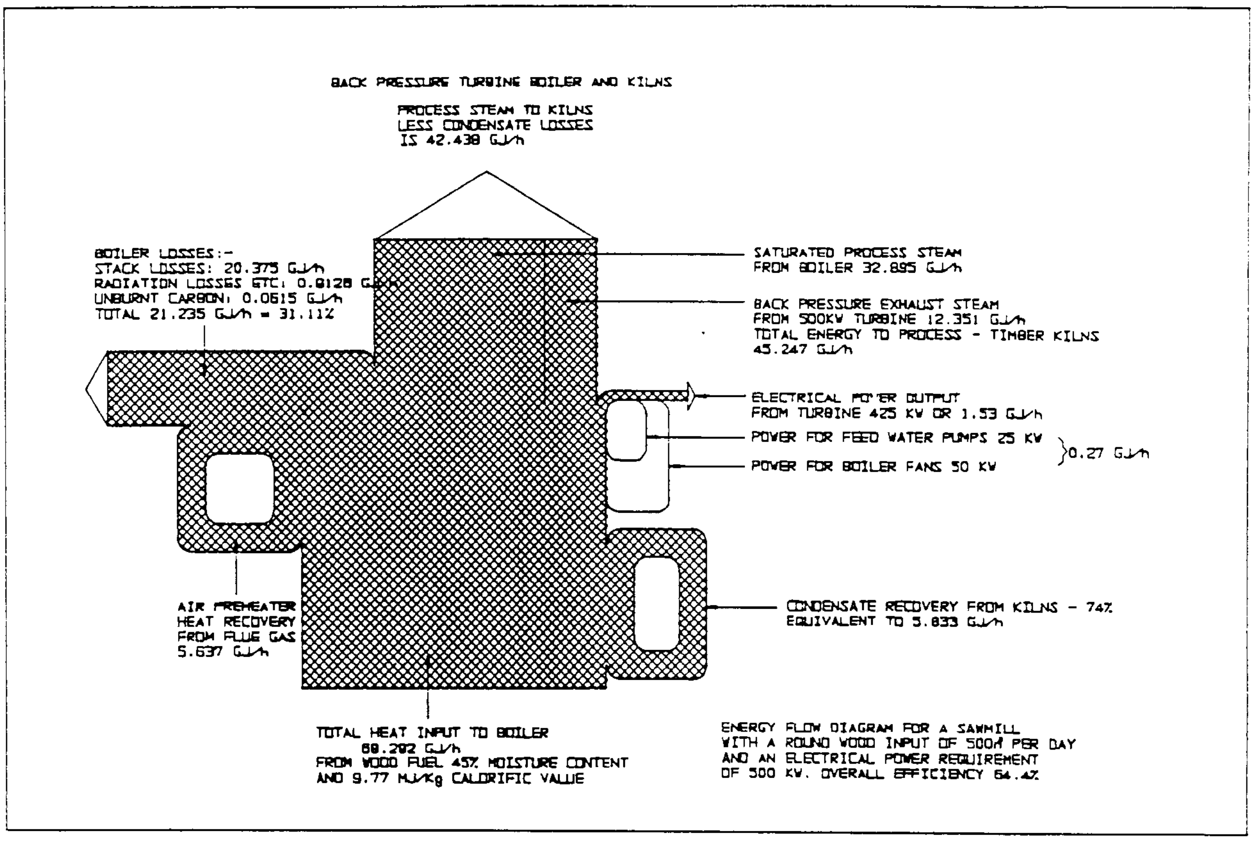
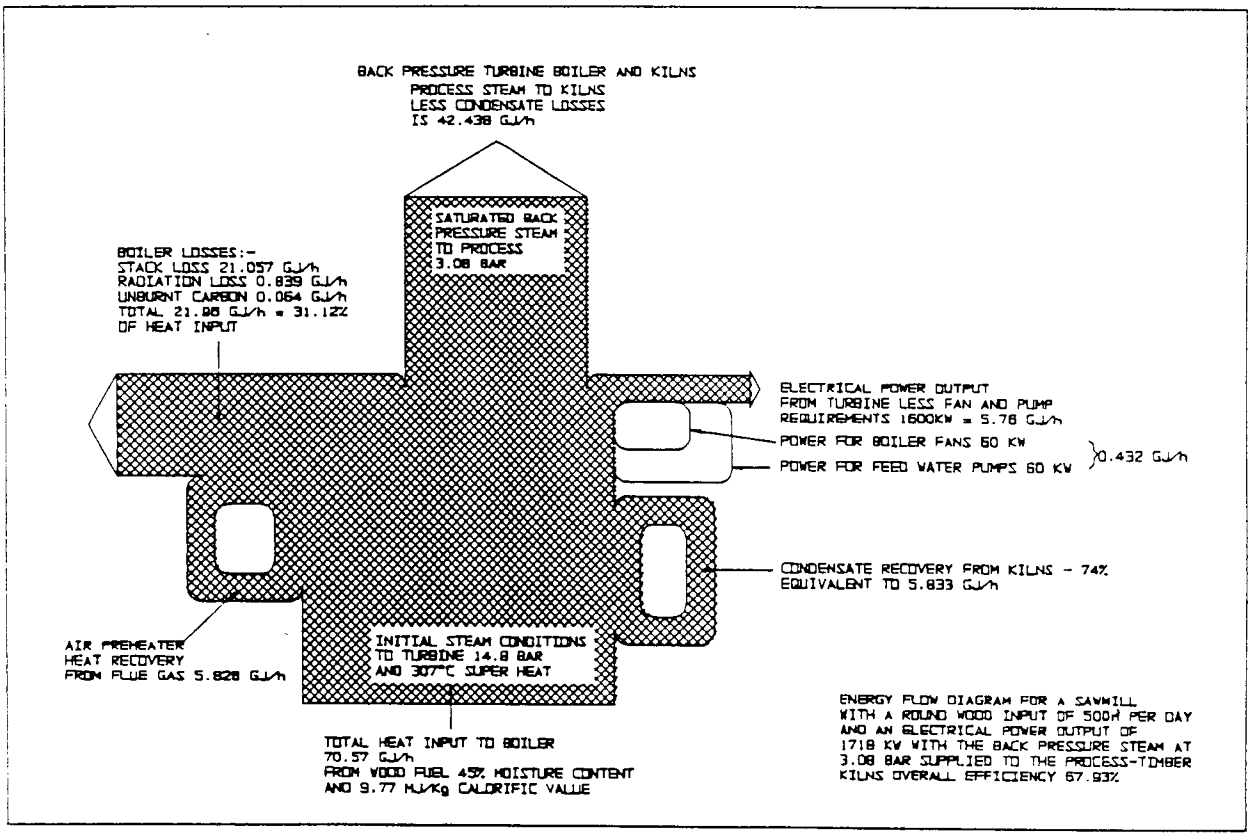


FIG 19 CHP - PLANT FOR SAW-MILL - BACK PRESSURE 1.7 MW OUTPUT



CHAPTER 5

5.0 Combined Heat and Power - Viability and Economics

5.1 Saw-mill Energy Demand

In chapter 4 it was shown that all saw-mill operations other than `bushmills' generate steam for kiln heating and that of the total energy used by a saw-mill some 93-95% of the energy input is used for this purpose. The fuel for operating the steam boilers is the wood waste or residue from the saw-mill operation. The average quantity of fuel produced by a saw-mill substantially exceeds the energy requirements of the kiln heating system.

In the case of a saw-mill with a $500m^3$ per day roundwood intake, the potential energy available from the wood residue is approximately 113 GJ/h. The average heat energy demand by the kiln complex to handle this quantity of sawn timber is about 42 to 45 GJ/h. These values are based on wood residue with 45% moisture content with a net calorific value of 9.77 MJ/kg.

The excess waste wood is usually incinerated, often in low temperature conical furnaces where this has been permitted. It should be noted that current South African air pollution control legislation[24] prohibits this type of incineration. High temperature incineration is however permitted, in which case the emission from such furnaces must meet the requirements of the pollution control regulations.

An alternative disposal method is to transport the waste to a permitted landfill site. Both these options involve costs arising from capital equipment, operation and maintenance.

It is apparent that if the surplus wood waste was burnt in a steam generating plant with either a condensing or back pressure turbine, electric power could be produced. This arrangement would allow two options that could provide sufficient electrical power for the saw-mill's own requirements and furthermore, any surplus power could be sold into the grid system.

However the decision to invest in the capital plant to convert this wood fuel resource into electrical power will depend on the economic justification of the project. In order to justify such expenditure it will be necessary to examine the various elements that affect the cost of power so generated.

5.2 Fuel Costs

In the case that all or part of the wood waste arising from the saw-milling operation is used to generate power there is zero intra mill cost. If additional wood fuel is required for the generation of electrical fuel cost, this marginal fuel cost (MFC) is the cost to extract the additional cubic metres of wood for the increased demand for power generation only.

In the South African context it is unlikely that any substantial effort would be made at this stage to extract additional wood from the forests for purely fuel purposes unless it was part of a sawlog recovery policy to increase the utilisation efficiency of the felled timber.

5.3 Current Regional Electrical Power Costs

5.3.1 South African Power Costs for Sawmills

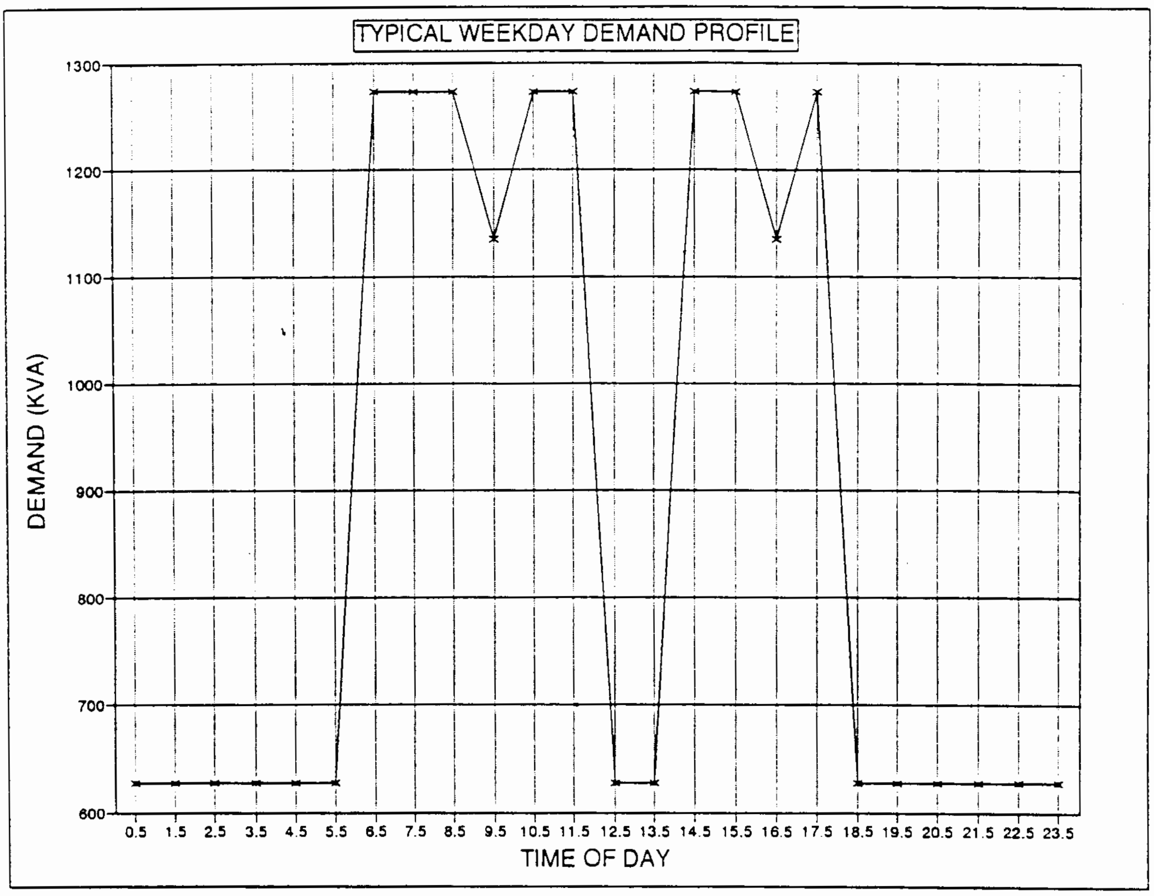
The ESKOM Ruraflex 2 or the Standard Rural rates for power would be those charged to saw-mills in rural areas. The assumptions made are that the power is supplied to a saw-mill with a 500m^3 per day roundwood intake. The notified maximum demand (NMD) would be 2000 kVA. The main power consumers at such a saw-mill are:

a) Kilns and boiler plant ancillaries assessed at 33% of the NMD and is equivalent to 627 kVA based on a 0.95 power factor. This plant will operate 24 hours per day throughout the year.

b) The main saw-mill power demand is assessed at 64% of the NMD at 1280 kVA. This portion of the plant would operate for about 10 hours per day, weekdays only.

Figure 20 represents an idealised form of a typical saw-mill demand profile conforming to the above example.

FIG. 20



The cost of electrical energy for the two types of supply that could be used by a saw-mill would range between 15 and 16 cents per kWh (July 1997).

Figure 21 shows the relationship between the average rate of increase in the cost of electric power in respect of the current and predicted rates of inflation for South Africa.

exceeding 300 kVA is estimated to be Z$0.52 per KVA based on the July 1997 ZESA standard prices for the supply of electricity.

The average annual increase of the cost of electrical power has been 35% per annum over the last 7 years. Figure 22 shows the relationships of cost and inflation for the period 1993 to 1997. The power cost has been smoothed using the moving average to indicate cost trend.

FIG. 22

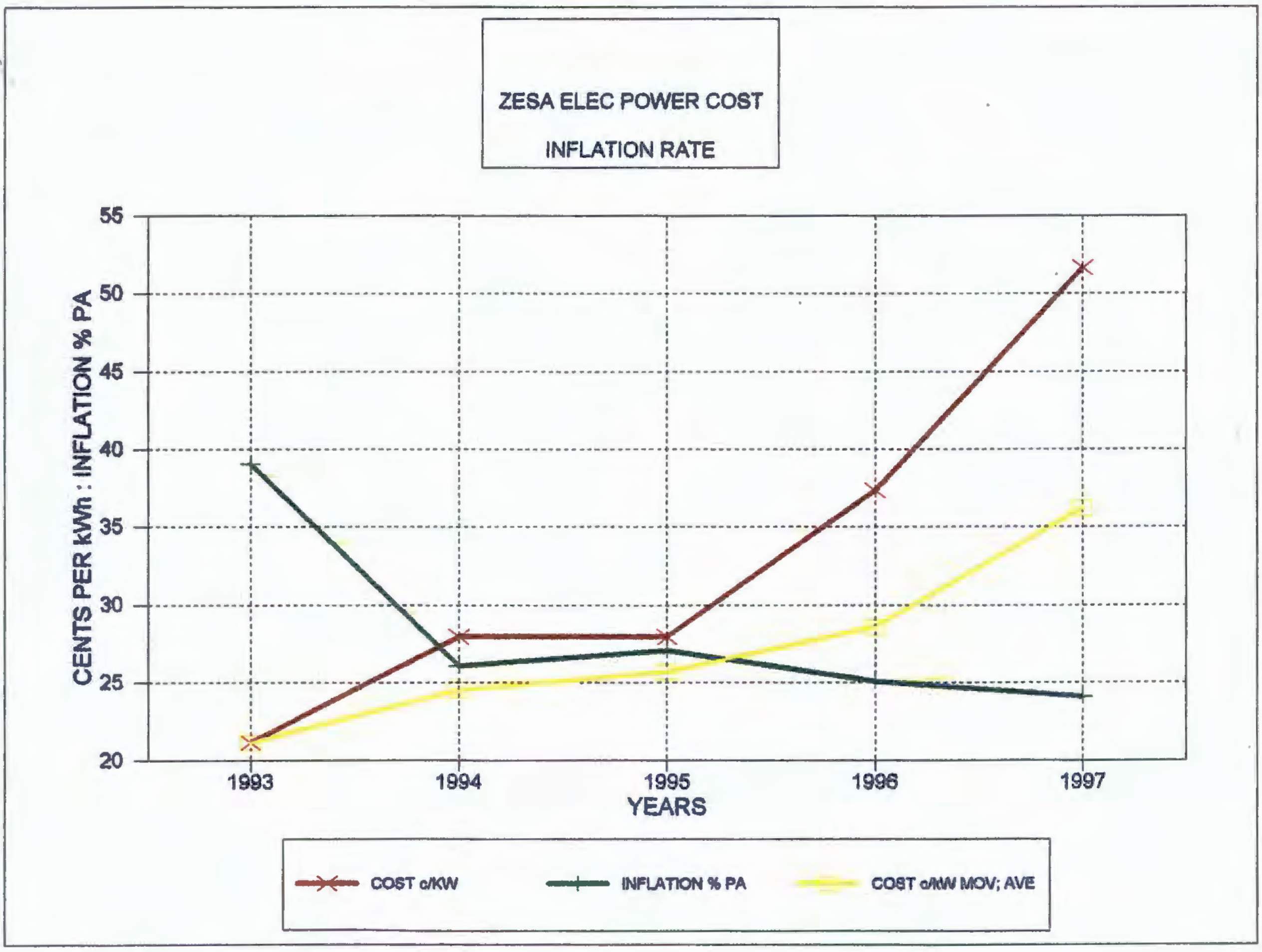
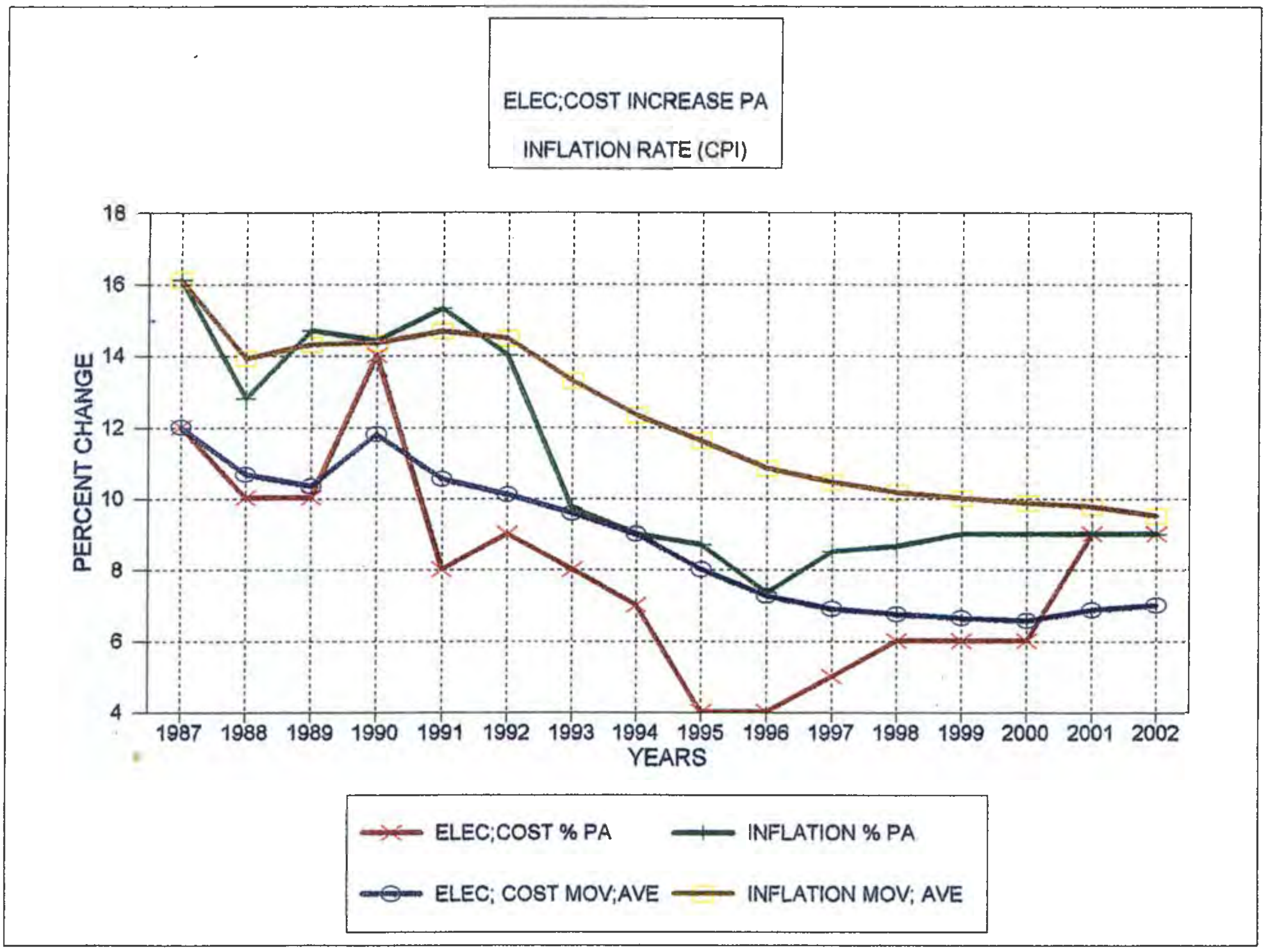


FIG. 21



The values shown for the years 1998 to 2002 are based on the ESKOM estimated future price increases. The average electric power cost will be below the consumer price index (CPI) by 3 per cent for the years 1998 to 2002, thereafter the rate of power cost increase will equal the rate of inflation.

5.4. **Zimbabwe Power Costs for Saw-Mills**

5.4.1 The energy level of a saw-mill is made on the assumption of a mill capacity of 250m^3/ day round wood intake. This size of mill would have a total connected power requirement of 800 to 1000 kW. The average power demand for a saw-mill of this size would be about 650 kVA. The current cost of energy for an industrial consumer with a demand capacity

5.5. Power Cost

5.5.1 The three main elements that affect the costs of constructing and operating a wood-fired power plant are:-

1) The availability of the fuel required.

2) The cost of the fuel delivered.

3) The financial cost to construct and operate the power plant.

In respect of the matter concerned with the availability of fuel, it was shown in Chapter 4 that there is adequate residue wood fuel even in the case of the condensing turbine power plant i.e., the plant would require 84% of the residue generated by the saw-milling operation. In the case of back pressure turbines, these plants would use 60 to 63% of the wood fuel residue delivered to the power plant. The cost of the fuel would be zero at source. It will be seen that the capital cost of the steam and power generating plant will have the greatest impact on the cost of the power produced by a saw-mill.

5.5.2 The Determination of Combined Heat and Power Opportunities at a Saw-mill

In order to commit capital resources to any project of this type it is important to determine that the investment is economically feasible. The decisions are influenced by factors such as cash flow, risk, return on investment, energy conservation and environmental effects amongst others.

Certain preliminary calculations can be carried out to determine at the outset as to whether such an investment warrants further detailed analysis.

There are several simple methods to assess energy conservation options. One method if the payback period (PB) and another is the return on investment (ROI). These methods ignore the time value of money and are considered appropriate for the first level of assessment. The analysis can be taken further using the benefit cost ratio (B/C), and the net present value (NPV).

The following assumptions are made in respect of a typical SA saw-mill:

1. Electrical power for saw-mill is estimated to R0.1556 / kWh. (Current ESKOM tariff).

2. Boiler efficiency 69%   Fuel cost is zero.   3 shifts / day 329 days / yr.

3. Capital cost for a new CHP plant is assessed at R5 000 per kW installed[38] based on a power output of 1000 kW.

4. Capital cost for a refurbished CHP plant is estimated at R1400 per kW installed. In two cases in which local saw-mills have installed power plant, the costs range from R1400 per kW (Mondi Saw-mills - Mpumalanga) down to R1200 per kW (A.C. Whitcher - Western Cape). The cost of R1400 per kW is used as the benchmark value for the installed refurbished plant.

The capital cost of refurbished CHP plant has been adjusted exponentially to account for plant sizes other than 1000 kW output.[41] These capital values have been used in Appendix D for the evaluation of the operating costs of a saw-mill generating its own power.

From the Appendix C-1) Figures 3 and 4 it will be seen that the cost of power produced by a saw-mill with new CHP plant varies from R0.310 / kWh in the case of a 500 kW generator to R0.181 / kWh for a 2000 kW unit.

This range of power costs substantially exceed the present ESKOM supplied power cost to a South African saw-mill. The cost of power from ESKOM was assessed at R0.15 to R0.16 per kWh for rural saw-mills.

Where refurbished CHP plant can be installed in a saw-mill, a case for such investment can be examined on the basis of six levels of power output. The evaluation takes into account minimum manning levels, depreciation, current interest rates, insurance rates, management overheads, maintenance and operational costs together with basic fuel costs. In the case of a 500 kW output CHP plant having a capital cost of R862 500 the estimated power cost is R0.18 / kWh with a nil profit return.

Table 11: The economic performance and output data for power generation capacities ranging from 500 kW to 2000 kW of refurbished power plant for South African saw-mills.

OUTPUT kW	CAPITAL COST R	TONNES STEAM/ HR	STEAM COST R/ TONNE	PROFIT MARGIN %	ROI %	PB YEARS	B/C RATIO	NPV MILLIONS R
500	862500	5.9	13.75	-2	-	-	-	1.01
1000	1400000	11.8	9.45	28.0	19.5	4.1	2.31	0.44
1250	1637500	14.75	8.52	35.1	27.8	3.0	1.76	1.24
1500	1860000	17.7	7.88	40.0	34.5	2.5	2.11	2.07
1750	2073750	20.65	7.4	43.7	40.1	2.2	2.41	2.93
2000	2280000	23.6	7.03	46.5	44.9	2.0	2.67	3.81

The main points of investment criteria are:

a) That the pay back period (PB) should be less than half of the estimated life of the plant which in this case is assessed at 10 years.

b) If the return on investment ROI is less than 20% per year the second level of measurement should be considered and that is the benefit / cost analysis (B/C). If the B/C is greater than 1.0 the investment is considered to be viable.

Figures 23a and 23b depicts these factors for a range of power outputs in 250 kW increments from 1000 kW to 2000 kW. The economic investment appears to be between 1000 and 1250 kW output based on the various assumed conditions that have been applied in the Appendix D.

FIG. 23a

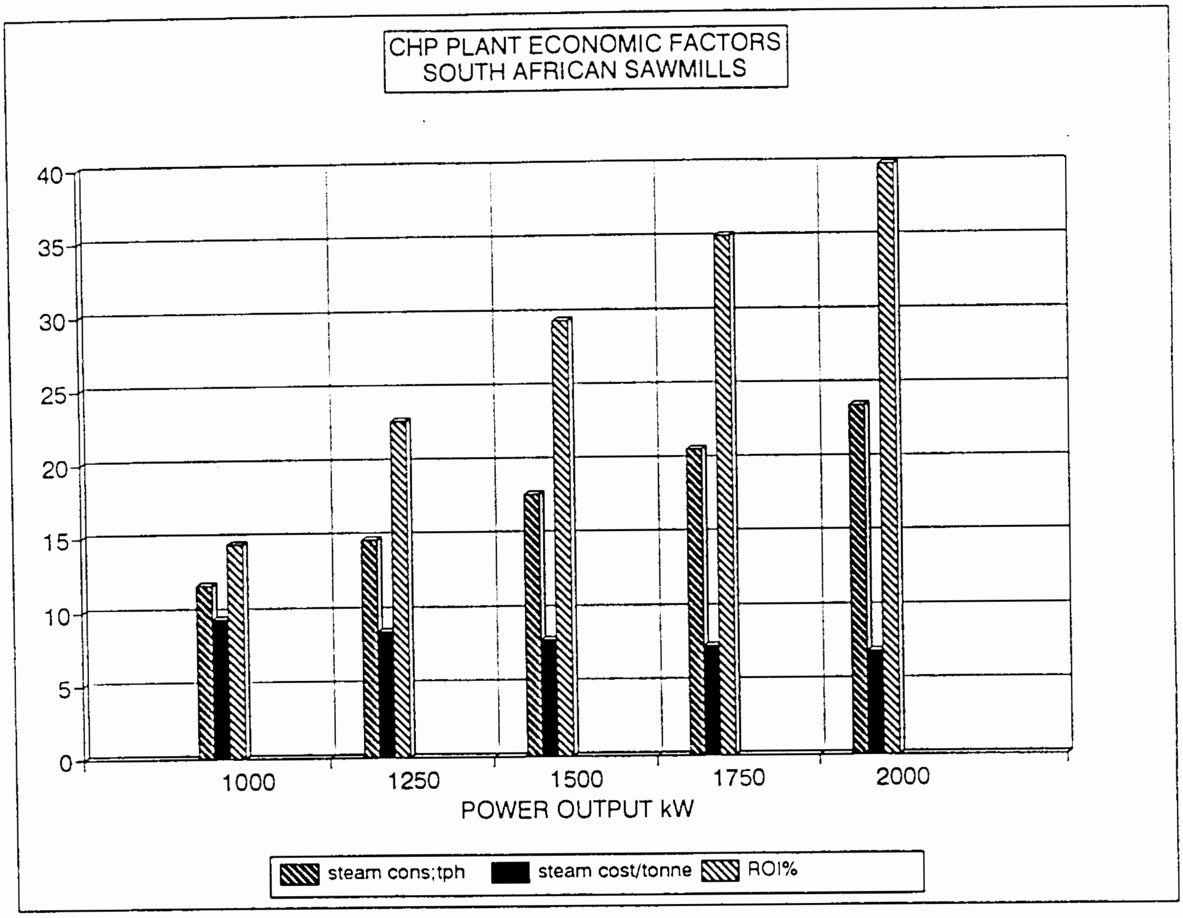


FIG 23 b

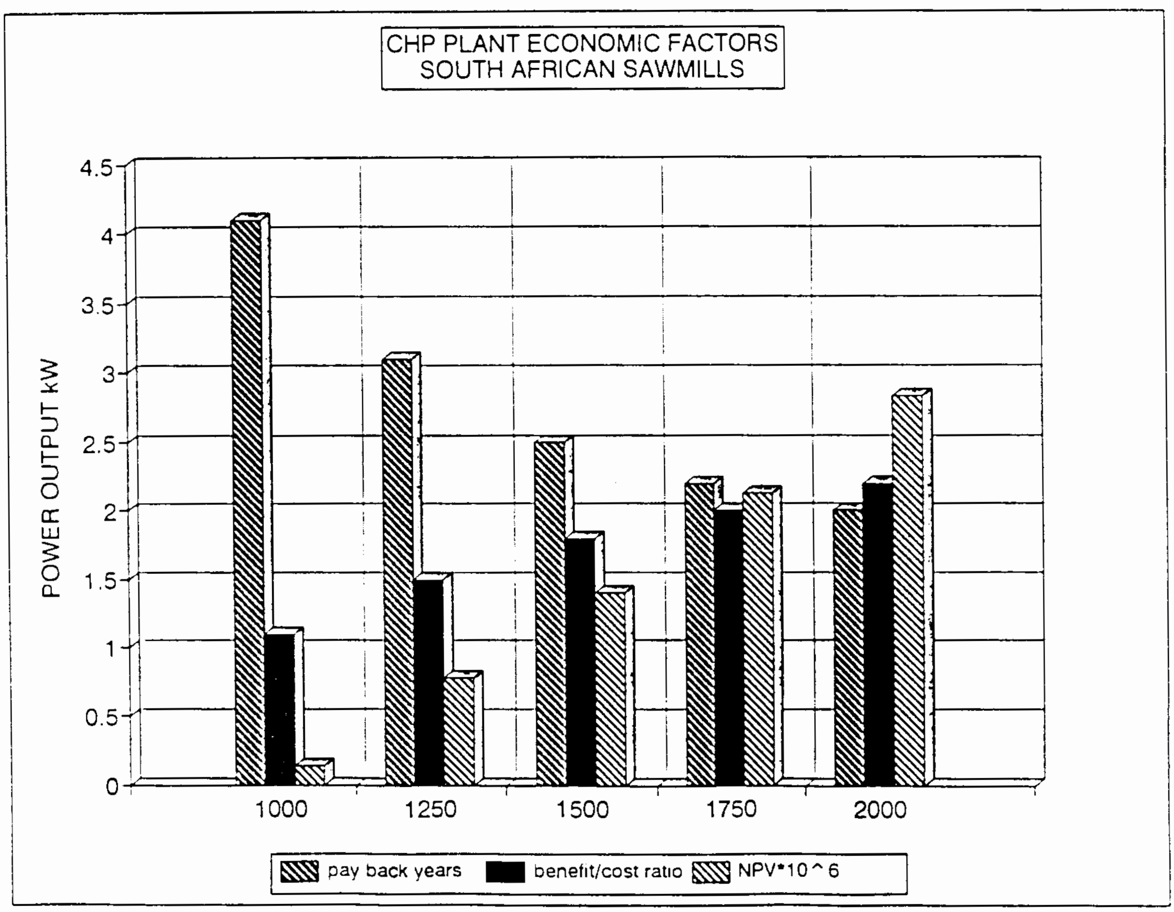


Table 12: The economic performance and output data for power generation capacities ranging from 500 kW to 2000 kW for refurbished power plant in Zimbabwe saw-mills.

OUTPUT kW	CAPITAL COST Z$	TONNES STEAM/ HR	STEAM COST Z$/ TONNE	PROFIT MARGIN %	ROI %	PB YEARS	B/C RATIO	NPV MILLIONS Z$
500	2155000	5.9	31.57	28.37	22.0	3.7	1.2	0.44
1000	3500000	11.8	23.66	46.3	49.3	1.84	2.42	4.98
1250	4087500	14.75	21.86	50.39	58.3	1.58	2.8	7.45
1500	4650000	17.7	20.61	53.2	65.5	1.92	3.15	9.97
1750	5180000	20.65	19.65	55.4	71.85	1.3	3.98	12.58
2000	5690000	23.6	18.90	57.1	77.41	1.21	3.68	15.79

FIG 24a

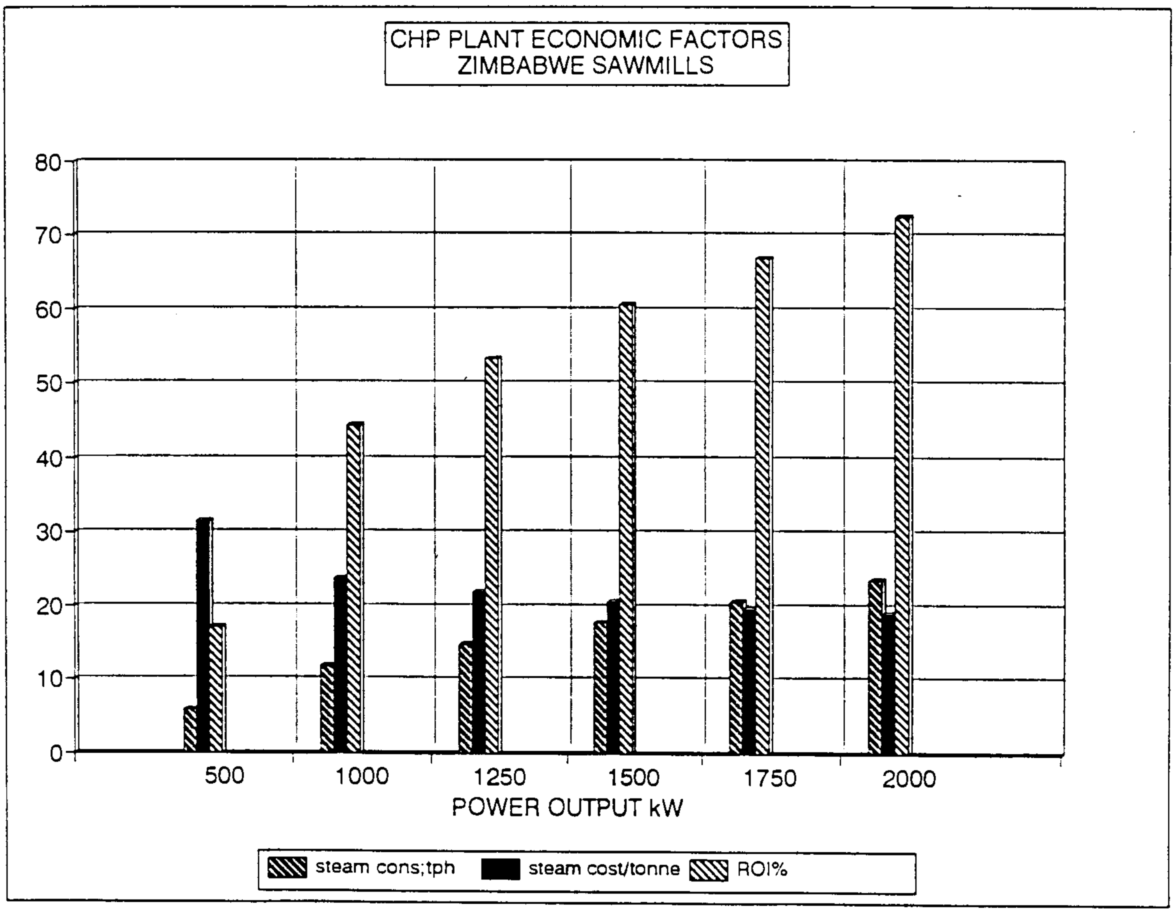
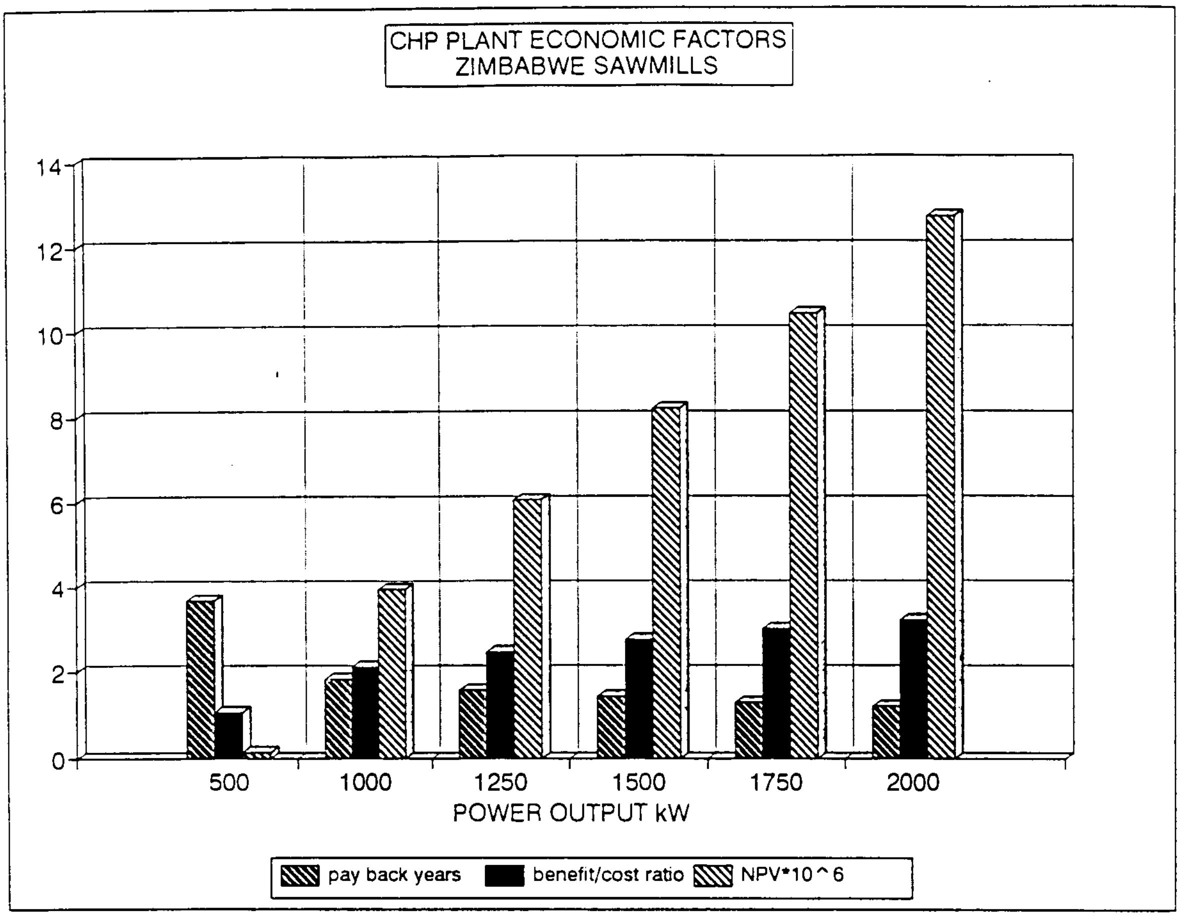


FIG 24b



In comparing the economic performance of similar power plant, the main issue is that of the difference in cost of the utility supplied power in South Africa and Zimbabwe.

The power cost comparison related to the Rand at the present time, the Zimbabwe power cost per kWh is some 34-35% higher than the South African equivalent tariff.

The conclusion that can be drawn from the foregoing analysis is that in South Africa it will be difficult to justify on purely economic terms the installation of power generating plant where the average output is less than 1000 kW. Furthermore this statement is qualified to the extent that the installed cost should not exceed R1400 kW and the notional cost of the fuel is set at zero cost per tonne.

In the Zimbabwe case, because of the higher utility price for power, there appears to be greater scope for the utilisation of wood waste in the economic generation of electric power.

The data used in Tables 11 and 12 are based on the results of the computation of the capital cost, tonnes of steam per hour, and profit margin for the range of power outputs for both the South African and Zimbabwean saw-milling industries as evaluated in Appendices D figures 1 to 12.

The evaluation of return on investment (ROI), benefit/cost ratio and net present value were determined by means of a computer programme outlined in Appendix D-13 to 24. The programme uses accounting formulae to determine the following:

a) depreciation charge per year;
b) pay back period;
c) return on investment;
d) benefit cost ratio;
e) present worth factor;
f) net present value.

The examples illustrated are for 1) a South African saw-mill with power output of 500 to 2000 kW and 2) a Zimbabwean saw-mill with the same range of power outputs.

The economic factors for this range of power outputs are shown in Tables 11 and 12. The interpretation of the data set out in Tables 11 and 12 together with the use of the computer programme used for evaluation of the operating costs of a saw-mill in either South Africa or Zimbabwe will enable economic decisions to be made in respect of the availability of self-generated power options.

5.6 Questionnaire to the South African and Zimbabwean Saw-milling Industry.

The pilot study[18] carried out by the South African National Timber Research Institute (NTRI) in 1982 was concerned with three coniferous saw-mills which were chosen subjectively on the basis of size in terms of daily roundwood throughput. The mill capacities were 105, 293 and 392m^3 per day input.

A second study[14] was initiated at the request of the South African Lumber Millers Association. The purpose of this second study was to assess the utilisation of energy at saw-mills. In particular the study was to examine the types, quantities, sources of fuels and their costs.

A further objective was to determine what opportunities there might be for the saw-milling industry to be energy self-sufficient. To this end data from a further five more saw-mills was collected. Whilst the statistical ratios could be viewed as remaining much the same as reported above, it was felt that a questionnaire to a number of saw-mills and to certain associations affiliated to the saw-milling industries both in South Africa and Zimbabwe would provide current data on the industry in these countries.

To this end two types of questionnaire were drawn up, one of which was sent to the affiliated saw-milling associations: Appendix E: Table E-1. The other type of questionnaire was sent to four selected saw-mills, three in South Africa and one in Zimbabwe. This questionnaire is shown in Appendix E Table E-2.

In response to the questionnaire E-1, the South African Lumber Millers Association reported that of the 75 saw-mills, all but three saw-mills in South Africa are partially or wholly dependent on their electrical power supply from Eskom. However all these saw-mills kiln-dry most of their sawn timber production. The heating medium is steam which in turn is generated from refuse wood-fired boilers.

There are some 300 `bush mills' which use diesel engines or tractors with mechanically driven saw benches. The timber produced is usually air dried which obviates the necessity to generate steam using wood residues.

It was apparent from the replies to this questionnaire that the data called for was not readily available from the Saw-Milling Associations of South Africa and Zimbabwe. This paucity of information makes it difficult to draw a general picture of the saw-milling industry in these two countries.

The response to Questionnaire E-2 sent to selected saw-mills provided specific information on which to base a number of important issues discussed in this paper.

The analysis of the current data when compared with that of 1982 - 1983 shows that the factors and ratios affecting the operation of South African saw-mills have not changed in any significant respect.

The species that predominates is that of pine. The saw-mill waste is mainly saw-dust, bark with hogged material from log edgings and sawn timber off-cuts. The moisture content remains at 50 - 55% (wet basis).

The ratio of waste to sawn timber varies from 47% to 51% with an average yield of waste 49% of the roundwood received at the mill. The 1983 report[18] on the matter of wood waste or residue from the saw-milling operation is of the order of 48%.

The questionnaire calls for more detail in respect of the timber drying kilns as these represent 95 - 97% of the total energy consumed by a saw-mill.

Those saw-mills which produced their own electric power were asked to provide detailed information of the characteristics of their generating plant. The two issues, namely kiln performance and steam demand together with performance data on power generation has allowed the evaluation of viability of the combined heat and power or power only options to be determined. The collated information provided by the responses to the questionnaire E-2 are shown in Table E-1a and E-1b.

In the case of the A.C. Whitcher saw-mill, data on the performance of their steam turbines and generator sets were recorded over a period of 10 days, 24 hours per day. The analysis of this data has allowed average values to be determined for the steam turbine operating conditions and the specific steam consumption.

As there are only three saw-mills in South Africa that generate their own power using saw-mill waste, it is difficult to generalise on what constitutes typical power plant conditions. In view of this, the A.C. Whitcher data has been used as a benchmark for the evaluation of plant performance in Appendix D.

CHAPTER 6 - DISCUSSION, SUMMARY AND CONCLUSIONS

6.1 The South African and Zimbabwean Potential for Cogeneration

In the South African context the saw-milling industry is aware that there is an inherent potential to cogenerate electric power for use in the saw-mill. However the fulfillment of that opportunity of self-generated power is beset by two major constraints. The first is the relatively low cost of electric power supplied by the utility generator - ESKOM. The second is the capital cost of appropriate steam-powered generating plant. By appropriate plant is meant the use of back pressure or pass out type steam turbines or engines.

This type of steam plant would allow the entire steam generating capacity to pass through the power generating unit to the kilns for timber drying and conditioning. This arrangement would condense the steam flow and allow the return of the condensate to the CHP thermal boundary. This arrangement would avoid the cost and operation of the conventional condenser and cooling water system as is the case with a condensing power plant.

A difficulty that arises from the back pressure / passout is that of load balancing. During the same time that the wet mill is operating, a large portion of the power output can be utilised in the mill and the kilns. However when the mill is not operating the kiln electrical load is only about 30 - 50% of the potential power output of the CHP plant. A solution to this problem of load balancing would be to sell the spare electrical capacity to the utility generator. At the present time however, this option would be priced at ESKOM's assessment of avoided cost. This avoided cost would be equivalent to the average cost of coal fuel delivered to the ESKOM power stations.

The view of the Zimbabwean scene is different in that the cost of electric power is 30-35% higher than the equivalent ESKOM cost. Furthermore there is at present a lack of generating capacity in that country to meet current demand.

6.2 Resources

The current production of waste wood by South African saw-mills that process roundwood into sawn timber is about 1.45 million tonnes. This output is expected to rise to 2.25 million tonnes in 2025 on the basis of a 1.5% annual increment[16].

In terms of electrical energy potential this is estimated at 40 MW at the 1997 rate of residue production. Whilst this value of power output is about 0.1% of the ESKOM capacity it is nevertheless a significant amount of electrical energy that could be generated while at the same time supplying the downstream heat plant requirements namely the timber drying kilns.

The production of waste wood in Zimbabwe is presently estimated at 300 000 tonnes rising at the rate of 5 to 6 per cent per annum. The present potential electrical energy equivalent of saw-mill residue is 8 MW.

These estimated power outputs are based on wood fuel with 40 - 45% moisture content and thermal efficiencies for boiler plant and turbine as set out in Chapter 4. The electrical outputs represent the maximum power that could be generated from the fuel resources to the saw-milling industry.

Currently the installed self-generated power capacity of the South African saw-mills is approximately 10 MW. There are no saw-mills in Zimbabwe that generate electric power from saw-mill residue. This under-utilisation of the fuel resource is due largely to lack of economic motive due to the relatively low cost of electric power from the utility generators.

6.3 Saw-mill Energy and Power

The main energy consumer in a wet saw-mill is the timber drying kiln complex. This energy user accounts for about 95% of the total energy input to the mill. However the electrical power requirement of the saw-mill through a Rankine type steam cycle can use 60 to 85% of the energy in the wood residue in order to provide the electrical capacity required by the saw-mill.

In the case of back pressure or passout turbines or engines, the exhaust steam can be almost entirely used for kiln heating, thereby significantly improving the overall plant thermal efficiencies which would be of the order of 60 to 65%.

6.4 Economics of Cogeneration of Electric Power

In the South African context, the cost of power from the utility generator - ESKOM is such that even with the installation of refurbished plant, there is little prospect at present for self-generation of electric power being considered as a viable option in South African saw-mills. If the cost of power increased significantly, the case for cogeneration would become more attractive from an investment point of view.

The situation in Zimbabwe is markedly different. This is due to the higher power tariffs and there is in addition, a capacity shortage on the part of ZESA at the present time. There are several cases in Zimbabwe where cogeneration plants operating in the sugar industry sell surplus power to the grid system. This regional under-capacity may change in the long term; however the utilisation of a substantial quantity of wood residue in a more economically efficient manner is an important objective for the regional saw-milling industry to consider and implement where appropriate.

6.5 Environmental Issues

6.5.1 NO_x Emissions

In an efficient combustion system using wood residue from a saw-mill operation the emissions in terms of NO_x are below the limits imposed by the EU authorities. The United Kingdom current limits on NO_x as gNO_2 GJ^{-1} for solid fuel range from 175 for stoker firing to 228 for other methods of firing. From tests by Tariq and Purvis[7] the average fuel wood

NO_X as gNO^2 GJ^{-1} was 47. These low values confirm the results of the tests by the US Department of Energy.[11]

The overall view is that with the correctly applied combustion air to wet or dry wood fuel the emission of particulates and the oxides of nitrogen are significantly lower than those produced by the combustion of fossil fuels except in such cases where the latter fuels are burnt in large power plants that use either pulverised fuel or fluidised bed combustion systems.

6.5.2 CO_2 Emissions

In assessing the carbon - carbon dioxide balance, it is apparent that whilst the carbon budget of sinks and generation should produce a nil balance, it is estimated that some 40-43% of the plantation volume of timber is not harvested and hence retains the captured carbon dioxide for some considerable time after felling.

6.6 Conclusions

The opportunity for the South African saw-milling industry to self-generate electrical power is clearly apparent in terms of the wood fuel resource available coupled with an internal power demand. This demand arises from the operation of the saw-mill and the timber drying kilns.

The fact that there are only three saw-mills in South Africa generating power is largely due to the low cost of Eskom supplied power. By using the main utility generator power supply in saw-mills, this energy option does not resolve a number of important issues. One of the principle problems is the accumulation of wood residue at the saw-mill site. One of the options for disposal of this residue is high temperature incineration resulting in a net increase in CO_2 and NO_x without any environmental benefit. Another option is that of landfill. The landfill using wood waste may affect ground water quality. Furthermore, as the surface of the wood residue in a landfill dries there is concern that uncontrolled and possibly spontaneous combustion of a substantial body of fuel can occur.

The situation in Zimbabwe is different in that there is an economic incentive to consider CHP plants in the context of the larger saw-mills. In order to simplify the assessment of the economic feasibility of a combined heat and power project, a simple computer programme has been developed for use in this dissertation to evaluate a wide range of variables such as cost per kW of installed generating plant, fuel costs and power plant efficiency for both turbine and boilers. The data generated in these evaluations may then be used to determine the economic factors which may then be judged against prevailing financial and environmental criteria.

APPENDICES

Appendix A-1

The Psychrometric Analysis of a Typical Timber Drying Kiln using Steam Heating in Extended Surface Tubes

The kiln is of brick construction in respect of the main walls with concrete roof and floor. The duty of the kiln is dry sawn timber having a moisture content of 55% on the wet basis to 12% maximum over a period of 75 hrs. The batch of timber has a volume of $70m^3$.

A cubic metre of P-Patula has a wet mass of 1062 kg at 55% moisture. The amount of water associated with this mass of wood is 583.9kg.

If this wood is to be dried to 12% moisture content the remaining mass of moisture is 127.4 kg/m^3.

Hence the mass of moisture to be driven off the wood is 456.5 kg/m^3.

The amount of moisture to be removed in 75 hours is thus 31955 kg. The average rate per hour is 427 kg. Water sprays are used to maintain kiln humidity; this adds to the amount of water to be evaporated.

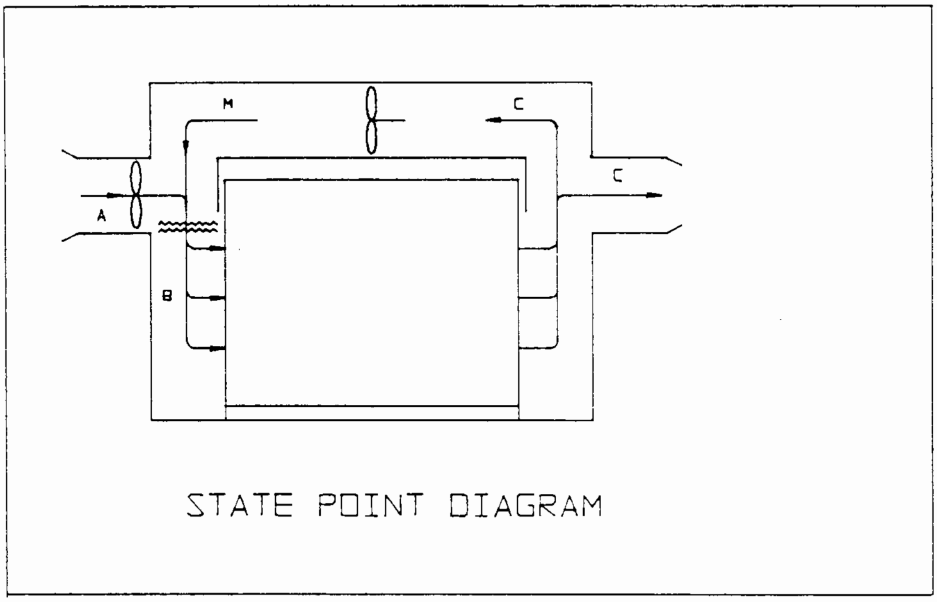
The measured and computed data for the four state points of an actual timber drying kiln are set down as follows:

STATE POINT	DRY BULB °C	WET BULB °C	Rh %	ENTHALPY kJ/kg	KG WATER/KG OF DRY AIR	AIR MASS kg/s
A	20	15.8	65.2	62.03	0.00947	5.6
M	47.71	39.2	64.5	186	0.0464	19.467
B	70	39.2	22.9	210.4	0.0464	19.467
C/recirc	58.89	45.56	48.3	236	0.06085	13.867
C/exhaust	58.89	45.56	48.3	236	0.06085	5.6

Water pick up (0.06085 - 0.00947) x 5.6 x 3600 = 1035.8kg/h

The state points above are shown in figure App.-A-1.

Fig App -A -1



The heat input is (236 - 186) x 19.467 x 3600 = 3.5041 GJ/h which is equivalent to 1662 kg of steam per hour for saturated steam at 4 bar gauge and sea level conditions.

In addition to this heat requirement for the removal of moisture from the timber and the spray water there is the heat loss through the walls, roof and floor of the kiln. In the case of a brick-walled kiln with concrete roof and floor the heat loss is estimated at 247 MJ/h and is equivalent to 117 kg of steam per hour.

The total steam input is thus 1779 kg/h. The reported steam consumption for masonry built timber kilns in South Africa is 1.8 to 2.0 tonnes/h.

The evaporative efficiency is $\frac{(h_2 - hm)}{(hs - hm)}$

Where h_s = moisture at 100% Rh corresponding with the enthalpy at state point C = 0.0666 kg water per kg of dry air.

h_m = moisture at state point M = 0.0464

h_2 = moisture at state point C = 0.06085

Evaporative efficiency $\frac{(0.06085 - 0.0464)}{(0.0666 - 0.0464)} = 71.55\%$

Appendix B -1

1. **Condensing and Back Pressure Turbine Power Plant Operating in Conjunction with the Steam Requirements of a Wet Sawmill**

1.1 A typical saw-mill is considered. This saw-mill has a capacity of $500m^3$ per day of roundwood. The residue arising from this input will amount to 52% of the input i.e. $260m^2/$ day which is equivalent to 276 tonnes of wood per day with an average moisture content of 45%. The calorific value of wood residue with this moisture content is 9.77 MJ/kg for the pine species. Thus the energy available from this wood residue is 113 GJ/h.

1.2 The average energy consumption rates per cubic metre of roundwood intake are as follows:[18]

Electricity	85 MJ / m^3 or 24 kWh / m^3
Steam	2037 MJ m^3
Fuel Oil	107 MJ / m^3

The electrical power requirement for the above mill at 24 kWh / m^3 is 500 kW based on the average electrical energy requirement over 24 hours. It should be noted however that the wet mill and its associated plant will generally only operate for 10 - 11 hours per day.[20] The timber drying kilns will operate for the full 24 hours each day.

The installed power capacity of a sawmill of 500 $m^3/$ day through-put would be approximately 1000 kW. About 85 percent of this installed capacity would be utilised during the time that the saw-mill and associated plant is operating.

The electrical load would fall to 25 - 35 per cent of the installed capacity when only the kilns and boiler plant are operating. This aspect of the imbalance in regard to the power generated to steam demand, is one of the most difficult energy problems facing the saw-milling industry in southern Africa.

A solution to the problem could be found in that the surplus power available during the time that only the drying kilns operate, could be sold into the regional or national grid system at a viable cost.

1.3 The assessment of Boiler Performance[23]

The boiler would be fitted superheaters and an off-take for saturated steam. The design or working pressure is taken as 14.8 bar and superheat temperature of 307 °C [23]. The wood fuel has a moisture content of 45% and a calorific value of 9.77 MJ / kg. An air preheater is fitted and the feed water temperature is 94 °C. The combustion system operates with 80% excess air.

The boiler heat balance is shown as follows:

1.	Dry gas loss	9.07 percent
2.	Moisture air in fuel and combustion air	20.377 percent
3.	Unburnt carbon in refuse	0.09 percent
4.	Radiation and unaccounted losses	1.19 percent
5.	Net output of boiler	68.88 percent
		100.00 percent

To achieve this efficiency on fuel with a moisture content of 45% or higher the combustion air would have to be preheated[21]. In this particular case the temperature of the preheated air is estimated at 145 °C.

1.4. Case I - A condensing turbine supplied with superheated steam from the boiler plant.

As there is no bypass or back pressure steam from the turbine, the entire saturated process steam supply must be provided by the boilers at 3 bar to the timber drying kilns at the rate of 2037 MJ per m^3 of timber intake.

The mass of saturated steam required is

$$\frac{2037 \times 500}{24 \times 2161.17} = 19636 \text{ kg steam / h}$$

which is equivalent to 42.4375 GJ/ h.

The turbine requirement is for steam at 14.8 bar and 307°C superheat exhausting to a condenser at 0.1688 bar and 56.44°C condensate temperature. The estimated specific steam consumption will be 8320 kg / MW or 22.784 GJ / h. Ref. Fig. App.-B-1a.

The total output of the boiler plant will be 65.22 GJ / h. The recovery by the air preheater is 7.44 GJ/h.

The equivalent energy input to the boiler based on 68.9% thermal efficiency will be 94.66 GJ / h or 27180 kg of steam per hour.

The heat in the exhaust steam from the turbine given up to the cooling medium is 2366.9 kJ / kg of steam. Thus the heat to the cooling water is

$$2366.9 \times 8320 = 19.692 \text{ GJ / h.}$$

Turbine efficiency from computation - fig. App. -B-1b is 15.8%. The net output is 1000 kW less the power for fans and feedwater pumps which is estimated at 125 kW, hence the output is 875 kW or 3.15 GJ / h.

Energy in the condensate return from the condenser is equivalent to 1.275 GJ / h.
Energy in the condensate return from the kilns is equivalent to 5.833 GJ/h.

$$\text{Efficiency} = \frac{42.4375 + 3.15 + 1.275}{94.66} = 0.495 \text{ or } 49.5\%$$

1.5 Case II - A back pressure turbine supplied with superheat steam exhausting to timber drying kilns.

Power output 500 kW less boiler feed water pumps and boiler fan power at 75 kW. This results in a net output of 425 kW which is equivalent to 1.53 GJ/h. Ref. Fig. App. -B-2a.

The turbine inlet conditions are as for Case I. The specific steam consumption is 11430 kg steam per hour per MW. Ref. Fig. App. -B-2b.

The back pressure turbine steam demand for 500 kW output of the turbine is 5715 kg steam/h.

The kiln steam requirement based on 2037 MJ/m^3 of timber intake over 24 hours:-

$$\frac{2037 \times 500 \times 100}{24 \times 2161.17} = 19636 \text{ kg steam/h or } 42.4375 \text{ GJ/h.}$$

Of this amount of steam, 5715 kg/h is provided by the turbine back pressure steam. Hence the amount of saturated steam from the boiler is 13921 kg/h. However the total demand of steam from the boiler plant will be 68.282 GJ/h.

The heat recovery by the air preheater is 5.637 GJ/h.

The heat in the kiln condensate returned:-
7.8694 - 2.036 = 5.8334 GJ/h.

Both these heat recoveries are accounted for in the boiler inputs.
Total heat equivalent output to kilns from the boiler and the electrical output of the turbine:- 42.4375 + 1.53 = 43.968 GJ/h.

$$\text{Overall efficiency} \quad \frac{43.968}{68.282} = 0.644 \text{ or } 64.4\%$$

1.6 Case III - A back pressure turbine supplied with superheat steam exhausting to timber drying kilns.

Power output 1718 kW less boiler feedwater pumps and boiler fan power at 125 kW. Net output 1593 kW.

The turbine inlet and outlet conditions are as for Case II with the exception that the entire turbine exhaust back pressure steam at 3.08 bar is supplied to the kilns and the heat energy therein satisfies the kiln operating requirement for the 500m^3 per day timber input, equivalent to 42.4375 GJ/h.

The total heat output of the boiler is 19637 (3053.7 - 565.33) x 10^{-6} = 48.864 GJ/h.

The equivalent energy input to the boiler based on 68.9% thermal efficiency is 70.92 GJ/h.
The heat recovery from the preheated air and the kiln condensate return is accounted for in the boiler thermal boundary.

$$\text{Overall efficiency} \qquad \frac{42.4375 + 5.735}{70.92} = 0.6793 \text{ or } 67.93\%$$

The conclusion that can be drawn from the examination of these estimates of energy input and plant thermal efficiency is that the back pressure turbines supplying part or all the electrical power to a saw-mill are significantly more efficient than a saw-mill using a condensing steam turbine.

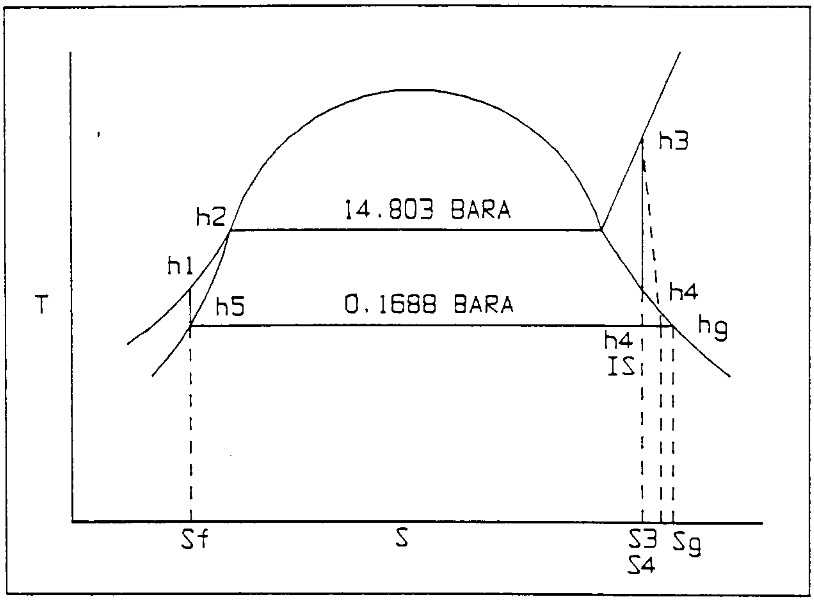
The other consideration is that for approximately 4% extra energy input to the plant the electrical output of the back pressure turbine system can be raised from a gross output of 500 kW to 1718 kW.

In terms of fuel available, the condensing power plant will require approximately 84% of the wood waste arising from the saw-milling operation, whereas the back pressure turbine plants will use between 60 and 63% of this fuel resource.

With these amounts of wood fuel available for power generation, high plant efficiency is not a real consideration. However in terms of plant capital cost and simplicity, the back pressure turbine exhausting directly to the timber kiln complex has a number of advantages, there being no need to have conventional steam condensing plant, no cooling water make up required and a significant reduction in the power, such as that required to pump the cooling water to ponds or to operate fans in a mechanical draught cooling tower.

App. -B -Fig. 1a

CEA2

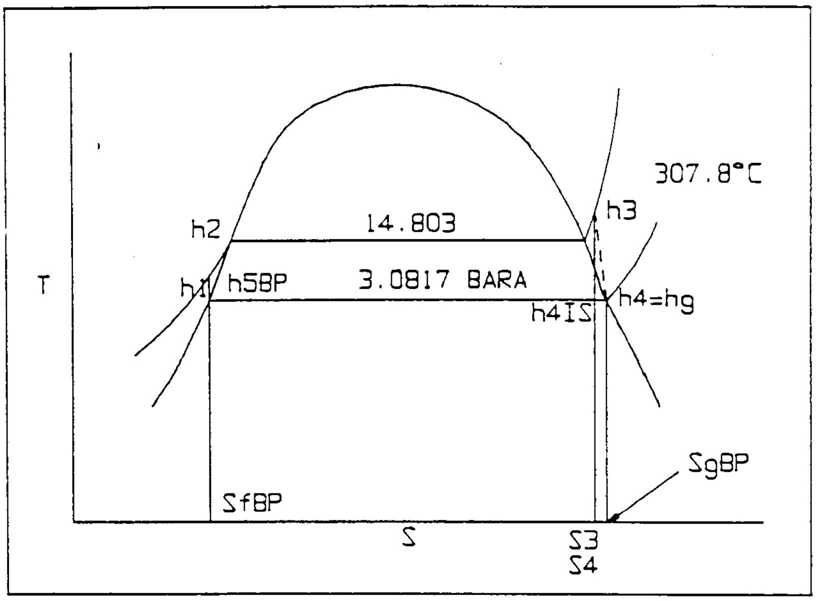


CONDENSING TURBINE
TS - DIAGRAM

ST	INPUT	NAME	OUTPUT	UNIT	COMMENT
					FIG APP-B-1b
					STEAM TURBINES CONDENSING TYPE
		h1	315.57688	kJ/kg	heat state point h1
	300.65	h5		kJ/kg	heat state point h5
	.00102	Vf		m^3/kg	specific vol ; at P2 m^3/kg
	14.803	P1		bar	inlet press; bara
	.1688	P2		bar	exhaust press; bara
	6.9524	S3		S	entropy state point h3
		S4	6.9524	S	entropy state point h3
		x	.85865675		factor
	.7863	Sf		S	entropy state point hf
	7.9674	Sg		S	entropy state point hg
		h4is	2280.5837	kJ/kg	heat state point h4is isentropic
	2606.5	hg		kJ/kg	heat state point hg
		hf	300.65	kJ/kg	heat state point hf
		Eis	57.865617		isentropic efficiency
	3054.1	h3		kJ/kg	heat state point h3
	2606.5	h4		kJ/kg	heat state point h4
		Wt	447.6	kJ/kg	total work kJ/kg
		Wp	14.926884	kJ/kg	pump work kJ/kg
		Wn	432.67312	kJ/kg	net work kJ/kg
		HS	2738.5231	kJ/kg	heat supplied kJ/kg
		Er	15.799506		Rankine efficiency per cent
		SSCs	2.3112136	kg/s/kW	specific steam cons; kg/s/kW
	1	M		MW	MW power output
		SSCh	8320.369	kg/h/MW	specific steam cons; kg/h/MW

App. -B -Fig. 2a

CEA3



BACK PRESSURE TURBINE
TS - DIAGRAM

ST	INPUT	NAME	OUTPUT	UNIT	COMMENT
					FIG APP-B-2b
					STEAM TURBINES BACK-PRESSURE TYPE
		h1	577.95179	kJ/kg	heat state point h1
	565.41	h5		kJ/kg	heat state point h5
	.00107	Vf		m^3/kg	specific vol ; at P2 m^3/kg
	14.803	P1		bar	inlet press; bara
	3.0817	P2		bar	exhaust press; bara
	6.9524	S3		S	entropy state point h3
		S4	6.9524	S	entropy state point h3
		x	.99424691		factor
	1.6814	Sf		S	entropy state point hf
	6.9829	Sg		S	entropy state point hg
		h4is	2714.1665	kJ/kg	heat state point h4is isentropic
	2726.6	hg		kJ/kg	heat state point hg
		hf	565.41	kJ/kg	heat state point hf
		Eis	96.342368		isentropic efficiency
	3054.1	h3		kJ/kg	heat state point h3
	2726.6	h4		kJ/kg	heat state point h4
		Wt	327.5	kJ/kg	total work kJ/kg
		Wp	12.541791	kJ/kg	pump work kJ/kg
		Wn	314.95821	kJ/kg	net work kJ/kg
		HS	2476.1482	kJ/kg	heat supplied kJ/kg
		Er	12.719683		Rankine efficiency per cent
		SSCs	3.1750244	kg/s/kW	specific steam cons; kg/s/kW
	1	M		MW	MW power output
		SSCh	11430.088	kg/h/MW	specific steam cons; kg/h/MW

Appendix C-1

1. The assessment of electrical energy costs at a South African saw-mill.

1.1 The assumptions that are made are as follows:
The saw-mill input of roundwood is 500 m^3/day.
The notified maximum demand (NMD) would be 2000 kVA against which the following main loads apply.

a) The kilns and boiler plant ancillaries assessed power requirement is 33% of NMD and is equivalent to 627 kVA at 0.95 power factor.

This plant would operate 24 hours per day continuously.

b) The main saw-mill plant is considered to use 67% of the NMD hence the power requirement is 1273 kVA.

This plant would operate for 10 hours per day weekdays only.

Considering a 30-day month, the breakdown for potential working days and time are as follows:

Weekdays	22
Saturdays	4
Sundays	4

Total hours per month 720.

The estimated cost of the imported power to such a saw-mill would be 15.6 cents per kWh at 0.95 power factor. Reference Figure App. -C -1.

Fig. App. -C -1.

St	Input	Name	Output	Unit	Comment
					ELECTRICAL POWER COSTS - SAWMIL
					ESKOM RURAL TARIFFS
					INPUT 500m^3 PER DAY ROUNDWOOD
		K	627	kW	kiln and boiler power demand kW
	.33	Klf			kiln/boiler load factor decimal
	.95	PF		PF	power factor
		Kth	720	h/M	kiln/boiler operational hours/month
	24	Kh		h/D	kiln/boiler op; hours/day
	30	Kd		D/M	kiln/boiler op; days/month
		M	1273	kW	sawmill power demand kW
		Mlf	.67		sawmill load factor decimal
		Mth	200	h/M	sawmill operational hours/month
	10	Mh		h/D	sawmill op; hours/day
	20	Md		D/M	sawmill op; days/month
		MDr	1		recorded maximum demand decimal
		Ek	27357.264	R	kiln energy cost
	.0606	Ec		R/kWh	energy charge/kWh
		Em	15428.76	R	sawmill energy cost
		Dtc	63680	R	demand charge cost
	31.84	Dc		R	demand charge/kVA
	2000	NMD		kW	notified maximum demand
		Tsub	106608.95	R	sub total cost
	142.93	Bc		R	basic charge
		Tot	109807.22	R	total cost of energy consumed
	.03	ts		R	transmission surcharge decimal
		Tunit	706040	kWh	total units consumed kWhrs
		Totcos	.1555255	R	cost per kWh

Similar inputs are applied to Zimbabwe saw-mills, the roundwood input per day is assessed at $250m^3$ per day.

The current cost of power based on the July 1997 ZESA standard price for electrical power is estimated at 52.7 cents per kWh at 0.95 power factor as shown in Figure App. -C -2.

Fig. App. -C -2.

St	Input	Name	Output	Unit	Comment
					ELECTRICAL POWER COSTS ZESA
					LOADS GREATER THAN 300 kVA
		kWm	832291.2	kW	energy consumed per month kW
	.95	Lf			load factor
	30.42	Dm		D/M	days per month 365/12=30.42
	1200	MD		kVA	maximum demand kVA
		MDcos	223716	Z$	max demand cost
	186.43	MDc		Z$	max demand charge per kVA
		kWcos	214760.26	Z$	kWh charge per month
	.2888	HPc		Z$	on peak energy charge
	.2009	LPc		Z$	off peak energy charge
		Tot	439026.26	Z$	total monthly cost of energy
		Tucos	.52749117	Z$	energy cost per kWh
	550	Fc		Z$	monthly fixed charge

Fig. App -C -3

St	Input	Name	Output	Unit	Comment
					POWER COST- CHP PLANT
					2000 kW
		Afc	2684795.2	R	annual fixed cost
		Ia	1800000	R	interest amount
		Dep	500000	R	depreciation per year
		OH	118102.15	R	overhead per year
		Mc	87733.027	R	management employment cost per year
		Ac	78960	R	artisan cost per year
		Inc	100000	R	insurance cost per year
		Avc	689552	R	annual variable cost
		Bma	0	R	fuel cost per year
		Ep	252672	R	electric power cost plant operation/y
		Oc	236880	R	operator cost per year
		Tpc	3374347.2	R	total cost of production
		Cp	.21367447	R	unit cost kWh
		Po	15792000	kW/y	kilowatt output per year
		Ps	200000	R	plant spares cost per year
	2	sr		%	spares as percentage of capital cost
		Tcc	1E7	R	total capital cost
	18	r		%	rate of interest percentage
	329	Dyr		D/y	days per year
	20	Ar		R/h	artisan rate per hour
	12	Ahr		h/D	artisan hours per day
	1	Inr		%	insurance rate per cent
		Bm	0	R/kWh	net fuel cost per kWh
		Opy	7896	h/y	plant operational hours per year
		Kw	200	kW	boiler and power plant demand per hour
	.16	Pwc		R	electric power unit cost decimal
	24	Hd		h/D	hours per day
	10	Or		R/h	operator rate per hour
	3	No			number of operators per shift
	5	dr		%	depreciation rate per cent
	2000	Phr		kW	plant kilowatt output per hour
		To	3374347.2	R	turnover
		Sp	.21367447	R	selling price per unit of prod; (G1)
		Opc	3374347.2	R	operational cost per year
		Pm	0	R	profit margin per year
	0	Pr		%	profit ratio Pm/To(input with G2)
					alt;set Pr=0 or n and G1 for Sp value
	3.5	OHpc		%	overhead per cent of turnover
	2.6	Mcpc		%	management per cent of turnover

Fig. App. -C-3 cont...

St	Input	Name	Output	Unit	Comment
		Bo	6.7413	MJ/kg	boiler heat input to steam MJ/kg fuel
	9.77	Ef		MJ/kg	calorific value of fuel as fired MJ/kg
	.69	Bfy			boiler efficiency decimal
		Bos	2.8066848	kg/kg	boiler steam output kg steam/kg fuel based on latent heat, feed water and comb air enthalpy accounted for in boiler overall efficiency
		Bosft	0	R/t	boiler steam cost per tonne
	0	Cosft		R/t	cost of fuel per tonne
		Bop	23.6	t/h	turbine specific steam cons; tonnes/h
		LHsi	2401.8729	kJ/kg	enthalpy of steam kJ/kg above tfsi
		Pasi	16.013793	bara	pressure bar abs
	15	Pgsi		barg	pressure bar gauge
		kPa	1601.019	kPa	pressure kilo pascal abs
		tsi	201.41826	C	steam temperature deg C
	11.8	Sfcon		t/MW	specific steam cons; tonnes/MW
	5000	Coskw		R/kW	capital cost per kW installed (G2)
		Tsty	186345.6	t/y	steam demand by turbine tonnes/year
		Tfy	66393.491	t/y	fuel consumption tonnes/year
		Stcos	18.108006	R/t	steam cost per tonne (overall cost)
	93	tfsi		C	feed water temp to boiler deg C
		kWtf	237.85464	kW/t	kW output per tonne of fuel fired

Fig. App -C -4

t Input	Name	Output	Unit	Comment
				POWER COST- CHP PLANT
				500 kW OUTPUT
	Afc	745807.17	R	annual fixed cost
	Ia	450000	R	interest amount
	Dep	125000	R	depreciation per year
	OH	38354.931	R	overhead per year
	Mc	28492.234	R	management employment cost per year
	Ac	78960	R	artisan cost per year
	Inc	25000	R	insurance cost per year
	Avc	350048	R	annual variable cost
	Bma	0	R	fuel cost per year
	Ep	63168	R	electric power cost plant operation/y
	Oc	236880	R	operator cost per year
	Tpc	1095855.2	R	total cost of production
	Cp	.27757223	R	unit cost kWh
	Po	3948000	kW/y	kilowatt output per year
	Ps	50000	R	plant spares cost per year
2	sr		%	spares as percentage of capital cost
	Tcc	2500000	R	total capital cost
18	r		%	rate of interest percentage
329	Dyr		D/y	days per year
20	Ar		R/h	artisan rate per hour
12	Ahr		h/D	artisan hours per day
1	Inr		%	insurance rate per cent
	Bm	0	R/kWh	net fuel cost per kWh
	Opy	7896	h/y	plant operational hours per year
	Kw	50	kW	boiler and power plant demand per hour
.16	Pwc		R	electric power unit cost decimal
24	Hd		h/D	hours per day
10	Or		R/h	operator rate per hour
3	No			number of operators per shift
5	dr		%	depreciation rate per cent
500	Phr		kW	plant kilowatt output per hour
	To	1095855.2	R	turnover
	Sp	.27757223	R	selling price per unit of prod: (G1)
	Opc	1095855.2	R	operational cost per year
	Pm	0	R	profit margin per year
0	Pr		%	profit ratio Pm/To(input with G2)
				alt:set Pr=0 or n and G1 for Sp value
3.5	OHpc		%	overhead per cent of turnover
2.6	Mcpc		%	management per cent of turnover

Fig. App. -C -4 cont..

St	Input	Name	Output	Unit	Comment
		Bo	6.7413	MJ/kg	boiler heat input to steam MJ/kg fuel
	9.77	Ef		MJ/kg	calorific value of fuel as fired MJ/kg
	.69	Bfy			boiler efficiency decimal
		Bos	2.8066848	kg/kg	boiler steam output kg steam/kg fuel based on latent heat, feed water and comb air enthalpy accounted for in boiler overall efficiency
		Bosft	0	R/t	boiler steam cost per tonne
	0	Cosft		R/t	cost of fuel per tonne
		Bop	5.9	t/h	turbine specific steam cons; tonnes/h
		LHsi	2401.8729	kJ/kg	enthalpy of steam kJ/kg above tfsi
		Pasi	16.013793	bara	pressure bar abs
	15	Pgsi		barg	pressure bar gauge
		kPa	1601.019	kPa	pressure kilo pascal abs
		tsi	201.41826	C	steam temperature deg C
	11.8	Sfcon		t/MW	specific steam cons; tonnes/MW
	5000	Coskw		R/kW	capital cost per kW installed (G2)
		Tsty	46586.4	t/y	steam demand by turbine tonnes/year
		Tfy	16598.373	t/y	fuel consumption tonnes/year
		Stcos	23.52307	R/t	steam cost per tonne (overall cost)
	93	tfsi		C	feed water temp to boiler deg C
		kWtf	237.85464	kW/t	kW output per tonne of fuel fired

Appendix D

This appendix deals with the evaluation of the operating costs of a saw-mill operating a combined heat and power plant. The boiler performance and power plant specific steam consumption has been dealt with in Appendix B. The data from Appendix B has been used where applicable.

The benchmark cost of refurbished steam/turbine plant for South African saw-mills has been set at R1400 per kW installed for 1000 kW output. The same plant size in the Zimbabwean saw-milling industry is assessed at Z$3500 per kW installed.

The exponential equation[41] used is as follows:

$$C = Cr. (S/Sr)^n$$

Where Cr is the cost of the reference plant
C is the cost of the plant at required size
S is the size at C
Sr is the size at Cr
n is the scale exponent which has a value of 0.7 in terms of the capital plant under consideration.

As the programme allows iterative analysis, it is possible to set a projected profit margin with a unit power cost per kWh and thence determine the maximum installed cost per kW of the capital plant.

In the following print-outs a selection of CHP plant capacities have been evaluated. These evaluations have been carried out for South African and Zimbabwean saw-mills. Currency terms have not been used but are appropriate to each country.

App -D -Fig. 1: South African Sawmill Power Cost - CHP Plant

St	Input	Name	Output	Unit	Comment
					POWER COST- CHP PLANT
					500 kW OUTPUT
		Afc	323288.34	R	annual fixed cost
		Ia	155250	R	interest amount
		Dep	43125	R	depreciation per year
		OH	21417.9	R	overhead per year
		Mc	15910.44	R	management employment cost per year
		Ac	78960	R	artisan cost per year
		Inc	8625	R	insurance cost per year
		Avc	317298	R	annual variable cost
		Bma	0	R	fuel cost per year
		Ep	63168	R	electric power cost plant operation/y
		Oc	236880	R	operator cost per year
		Tpc	640586.34	R	total cost of production
		Cp	.16225591	R	unit cost kWh
		Po	3948000	kW/y	kilowatt output per year
		Ps	17250	R	plant spares cost per year
	2	sr		%	spares as percentage of capital cost
		Tcc	862500	R	total capital cost
	18	r		%	rate of interest percentage
	329	Dyr		D/y	days per year
	20	Ar		R/h	artisan rate per hour
	12	Ahr		h/D	artisan hours per day
	1	Inr		%	insurance rate per cent
		Bm	0	R/kWh	net fuel cost per kWh
		Opy	7896	h/y	plant operational hours per year
		Kw	50	kW	boiler and power plant demand per hour
	.16	Pwc		R	electric power unit cost decimal
	24	Hd		h/D	hours per day
	10	Or		R/h	operator rate per hour
	3	No			number of operators per shift
	5	dr		%	depreciation rate per cent
	500	Phr		kW	plant kilowatt output per hour
		To	611940	R	turnover
	.155	Sp		R	selling price per unit of prod; (G1)
		Opc	640586.34	R	operational cost per year
		Pm	-28646.34	R	profit margin per year
		Pr	-4.681233	%	profit ratio Pm/To(input with G2)
					alt;set Pr=0 or n and G1 for Sp value
	3.5	OHpc		%	overhead per cent of turnover
	2.6	Mcpc		%	management per cent of turnover

App.-D -Fig. 1 SA (cont.)

St	Input	Name	Output	Unit	Comment
		Bo	6.7413	MJ/kg	boiler heat input to steam MJ/kg fuel
	9.77	Ef		MJ/kg	calorific value of fuel as fired MJ/kg
	.69	Bfy			boiler efficiency decimal
		Bos	2.8066848	kg/kg	boiler steam output kg steam/kg fuel based on latent heat, feed water and comb air enthalpy accounted for in boiler overall efficiency
		Bosft	0	R/t	boiler steam cost per tonne
	0	Cosft		R/t	cost of fuel per tonne
		Bop	5.9	t/h	turbine specific steam cons; tonnes/h
		LHsi	2401.8729	kJ/kg	enthalpy of steam kJ/kg above tfsi
		Pasi	16.013793	bara	pressure bar abs
	15	Pgsi		barg	pressure bar gauge
		kPa	1601.019	kPa	pressure kilo pascal abs
		tsi	201.41826	C	steam temperature deg C
	11.8	Sfcon		t/MW	specific steam cons; tonnes/MW
	1725	Coskw		R/kW	capital cost per kW installed (G2)
		Tsty	46586.4	t/y	steam demand by turbine tonnes/year
		Tfy	16598.373	t/y	fuel consumption tonnes/year
		Stcos	13.750501	R/t	steam cost per tonne (overall cost)
	93	tfsi		C	feed water temp to boiler deg C
		kWtf	237.85464	kW/t	kW output per tonne of fuel fired

App -D -Fig. 2: South African Sawmill Power Cost - CHP Plant

St	Input	Name	Output	Unit	Comment
					POWER COST- CHP PLANT
					1000 kW
		Afc	489616.68	R	annual fixed cost
		Ia	252000	R	interest amount
		Dep	70000	R	depreciation per year
		OH	42835.8	R	overhead per year
		Mc	31820.88	R	management employment cost per year
		Ac	78960	R	artisan cost per year
		Inc	14000	R	insurance cost per year
		Avc	391216	R	annual variable cost
		Bma	0	R	fuel cost per year
		Ep	126336	R	electric power cost plant operation/y
		Oc	236880	R	operator cost per year
		Tpc	880832.68	R	total cost of production
		Cp	.11155429	R	unit cost kWh
		Po	7896000	kW/y	kilowatt output per year
		Ps	28000	R	plant spares cost per year
	2	sr		%	spares as percentage of capital cost
		Tcc	1400000	R	total capital cost
	18	r		%	rate of interest percentage
	329	Dyr		D/y	days per year
	20	Ar		R/h	artisan rate per hour
	12	Ahr		h/D	artisan hours per day
	1	Inr		%	insurance rate per cent
		Bm	0	R/kWh	net fuel cost per kWh
		Opy	7896	h/y	plant operational hours per year
		Kw	100	kW	boiler and power plant demand per hour
	.16	Pwc		R	electric power unit cost decimal
	24	Hd		h/D	hours per day
	10	Or		R/h	operator rate per hour
	3	No			number of operators per shift
	5	dr		%	depreciation rate per cent
	1000	Phr		kW	plant kilowatt output per hour
		To	1223880	R	turnover
	.155	Sp		R	selling price per unit of prod; (G1)
		Opc	880832.68	R	operational cost per year
		Pm	343047.32	R	profit margin per year
		Pr	28.02949	%	profit ratio Pm/To(input with G2)
					alt;set Pr=0 or n and G1 for Sp value
	3.5	OHpc		%	overhead per cent of turnover
	2.6	Mcpc		%	management per cent of turnover

App. -D -Fig. 2. SA (cont.)

St	Input	Name	Output	Unit	Comment
		Bo	6.7413	MJ/kg	boiler heat input to steam MJ/kg fuel
	9.77	Ef		MJ/kg	calorific value of fuel as fired MJ/kg
	.69	Bfy			boiler efficiency decimal
		Bos	2.8066848	kg/kg	boiler steam output kg steam/kg fuel based on latent heat, feed water and comb air enthalpy accounted for in boiler overall efficiency
		Bosft	0	R/t	boiler steam cost per tonne
	0	Cosft		R/t	cost of fuel per tonne
		Bop	11.8	t/h	turbine specific steam cons; tonnes/h
		LHsi	2401.8729	kJ/kg	enthalpy of steam kJ/kg above tfsi
		Pasi	16.013793	bara	pressure bar abs
	15	Pgsi		barg	pressure bar gauge
		kPa	1601.019	kPa	pressure kilo pascal abs
		tsi	201.41826	C	steam temperature deg C
	11.8	Sfcon		t/MW	specific steam cons; tonnes/MW
	1400	Coskw		R/kW	capital cost per kW installed (G2)
		Tsty	93172.8	t/y	steam demand by turbine tonnes/year
		Tfy	33196.746	t/y	fuel consumption tonnes/year
		Stcos	9.4537535	R/t	steam cost per tonne (overall cost)
	93	tfsi		C	feed water temp to boiler deg C
		kWtf	237.85464	kW/t	kW output per tonne of fuel fired

App. -D -Fig. 3: South African Sawmill Power Cost - CHP Plant

St	Input	Name	Output	Unit	Comment
					POWER COST- CHP PLANT
					1250 kW
		Afc	565280.85	R	annual fixed cost
		Ia	294750	R	interest amount
		Dep	81875	R	depreciation per year
		OH	53544.75	R	overhead per year
		Mc	39776.1	R	management employment cost per year
		Ac	78960	R	artisan cost per year
		Inc	16375	R	insurance cost per year
		Avc	427550	R	annual variable cost
		Bma	0	R	fuel cost per year
		Ep	157920	R	electric power cost plant operation/y
		Oc	236880	R	operator cost per year
		Tpc	992830.85	R	total cost of production
		Cp	.10059076	R	unit cost kWh
		Po	9870000	kW/y	kilowatt output per year
		Ps	32750	R	plant spares cost per year
	2	sr		%	spares as percentage of capital cost
		Tcc	1637500	R	total capital cost
	18	r		%	rate of interest percentage
	329	Dyr		D/y	days per year
	20	Ar		R/h	artisan rate per hour
	12	Ahr		h/D	artisan hours per day
	1	Inr		%	insurance rate per cent
		Bm	0	R/kWh	net fuel cost per kWh
		Opy	7896	h/y	plant operational hours per year
		Kw	125	kW	boiler and power plant demand per hour
	.16	Pwc		R	electric power unit cost decimal
	24	Hd		h/D	hours per day
	10	Or		R/h	operator rate per hour
	3	No			number of operators per shift
	5	dr		%	depreciation rate per cent
	1250	Phr		kW	plant kilowatt output per hour
		To	1529850	R	turnover
	.155	Sp		R	selling price per unit of prod; (G1)
		Opc	992830.85	R	operational cost per year
		Pm	537019.15	R	profit margin per year
		Pr	35.102732	%	profit ratio Pm/To(input with G2)
					alt;set Pr=0 or n and G1 for Sp value
	3.5	OHpc		%	overhead per cent of turnover
	2.6	Mcpc'		%	management per cent of turnover

App. -D -Fig. 3. SA (cont.)

St	Input	Name	Output	Unit	Comment
		Bo	6.7413	MJ/kg	boiler heat input to steam MJ/kg fuel
	9.77	Ef		MJ/kg	calorific value of fuel as fired MJ/kg
	.69	Bfy			boiler efficiency decimal
		Bos	2.8066848	kg/kg	boiler steam output kg steam/kg fuel based on latent heat, feed water and comb air enthalpy accounted for in boiler overall efficiency
		Bosft	0	R/t	boiler steam cost per tonne
	0	Cosft		R/t	cost of fuel per tonne
		Bop	14.75	t/h	turbine specific steam cons; tonnes/h
		LHsi	2401.8729	kJ/kg	enthalpy of steam kJ/kg above tfsi
		Pasi	16.013793	bara	pressure bar abs
	15	Pgsi		barg	pressure bar gauge
		kPa	1601.019	kPa	pressure kilo pascal abs
		tsi	201.41826	C	steam temperature deg C
	11.8	Sfcon		t/MW	specific steam cons; tonnes/MW
	1310	Coskw		R/kW	capital cost per kW installed (G2)
		Tsty	116466	t/y	steam demand by turbine tonnes/year
		Tfy	41495.932	t/y	fuel consumption tonnes/year
		Stcos	8.5246411	R/t	steam cost per tonne (overall cost)
	93	tfsi		C	feed water temp to boiler deg C
		kWtf	237.85464	kW/t	kW output per tonne of fuel fired

App. -D -Fig. 4: South African Sawmill Power Cost - CHP Plant

St	Input	Name	Output	Unit	Comment
					POWER COST- CHP PLANT
					1500 kW
		Afc	637345.02	R	annual fixed cost
		Ia	334800	R	interest amount
		Dep	93000	R	depreciation per year
		OH	64253.7	R	overhead per year
		Mc	47731.32	R	management employment cost per year
		Ac	78960	R	artisan cost per year
		Inc	18600	R	insurance cost per year
		Avc	463584	R	annual variable cost
		Bma	0	R	fuel cost per year
		Ep	189504	R	electric power cost plant operation/y
		Oc	236880	R	operator cost per year
		Tpc	1100929	R	total cost of production
		Cp	.09295247	R	unit cost kWh
		Po	11844000	kW/y	kilowatt output per year
		Ps	37200	R	plant spares cost per year
	2	sr		%	spares as percentage of capital cost
		Tcc	1860000	R	total capital cost
	18	r		%	rate of interest percentage
	329	Dyr		D/y	days per year
	20	Ar		R/h	artisan rate per hour
	12	Ahr		h/D	artisan hours per day
	1	Inr		%	insurance rate per cent
		Bm	0	R/kWh	net fuel cost per kWh
		Opy	7896	h/y	plant operational hours per year
		Kw	150	kW	boiler and power plant demand per hour
	.16	Pwc		R	electric power unit cost decimal
	24	Hd		h/D	hours per day
	10	Or		R/h	operator rate per hour
	3	No			number of operators per shift
	5	dr		%	depreciation rate per cent
	1500	Phr		kW	plant kilowatt output per hour
		To	1835820	R	turnover
	.155	Sp		R	selling price per unit of prod; (G1)
		Opc	1100929	R	operational cost per year
		Pm	734890.98	R	profit margin per year
		Pr	40.030666	%	profit ratio Pm/To(input with G2)
					alt;set Pr=0 or n and G1 for Sp value
	3.5	OHpc		%	overhead per cent of turnover
	2.6	Mcpc		%	management per cent of turnover

App -D -Fig. 4 SA (cont.)

St	Input	Name	Output	Unit	Comment
		Bo	6.7413	MJ/kg	boiler heat input to steam MJ/kg fuel
	9.77	Ef		MJ/kg	calorific value of fuel as fired MJ/kg
	.69	Bfy			boiler efficiency decimal
		Bos	2.8066848	kg/kg	boiler steam output kg steam/kg fuel based on latent heat, feed water and comb air enthalpy accounted for in boiler overall efficiency
		Bosft	0	R/t	boiler steam cost per tonne
	0	Cosft		R/t	cost of fuel per tonne
		Bop	17.7	t/h	turbine specific steam cons; tonnes/h
		LHsi	2401.8729	kJ/kg	enthalpy of steam kJ/kg above tfsi
		Pasi	16.013793	bara	pressure bar abs
	15	Pgsi		barg	pressure bar gauge
		kPa	1601.019	kPa	pressure kilo pascal abs
		tsi	201.41826	C	steam temperature deg C
	11.8	Sfcon		t/MW	specific steam cons; tonnes/MW
	1240	Coskw		R/kW	capital cost per kW installed (G2)
		Tsty	139759.2	t/y	steam demand by turbine tonnes/year
		Tfy	49795.118	t/y	fuel consumption tonnes/year
		Stcos	7.8773277	R/t	steam cost per tonne (overall cost)
	93	tfsi		C	feed water temp to boiler deg C
		kWtf	237.85464	kW/t	kW output per tonne of fuel fired

App. -D -Fig. 5: South African Sawmill Power Cost - CHP Plant

St	Input	Name	Output	Unit	Comment
					POWER.COST- CHP PLANT
					1750 kW
		Afc	707309.19	R	annual fixed cost
		Ia	373275	R	interest amount
		Dep	103687.5	R	depreciation per year
		OH	74962.65	R	overhead per year
		Mc	55686.54	R	management employment cost per year
		Ac	78960	R	artisan cost per year
		Inc	20737.5	R	insurance cost per year
		Avc	499443	R	annual variable cost
		Bma	0	R	fuel cost per year
		Ep	221088	R	electric power cost plant operation/y
		Oc	236880	R	operator cost per year
		Tpc	1206752.2	R	total cost of production
		Cp	.0873319	R	unit cost kWh
		Po	13818000	kW/y	kilowatt output per year
		Ps	41475	R	plant spares cost per year
	2	sr		%	spares as percentage of capital cost
		Tcc	2073750	R	total capital cost
	18	r		%	rate of interest percentage
	329	Dyr		D/y	days per year
	20	Ar		R/h	artisan rate per hour
	12	Ahr		h/D	artisan hours per day
	1	Inr		%	insurance rate per cent
		Bm	0	R/kWh	net fuel cost per kWh
		Opy	7896	h/y	plant operational hours per year
		Kw	175	kW	boiler and power plant demand per hour
	.16	Pwc		R	electric power unit cost decimal
	24	Hd		h/D	hours per day
	10	Or		R/h	operator rate per hour
	3	No			number of operators per shift
	5	dr		%	depreciation rate per cent
	1750	Phr		kW	plant kilowatt output per hour
		To	2141790	R	turnover
	.155	Sp		R	selling price per unit of prod; (G1)
		Opc	1206752.2	R	operational cost per year
		Pm	935037.81	R	profit margin per year
		Pr	43.656839	%	profit ratio Pm/To(input with G2)
					alt;set Pr=0 or n and G1 for Sp value
	3.5	OHpc		%	overhead per cent of turnover
	2.6	Mcpc		%	management per cent of turnover

App. -D -Fig. 5 SA (cont.)

St	Input	Name	Output	Unit	Comment
		Bo	6.7413	MJ/kg	boiler heat input to steam MJ/kg fuel
	9.77	Ef		MJ/kg	calorific value of fuel as fired MJ/kg
	.69	Bfy			boiler efficiency decimal
		Bos	2.8066848	kg/kg	boiler steam output kg steam/kg fuel based on latent heat, feed water and comb air enthalpy accounted for in boiler overall efficiency
		Bosft	0	R/t	boiler steam cost per tonne
	0	Cosft		R/t	cost of fuel per tonne
		Bop	20.65	t/h	turbine specific steam cons; tonnes/h
		LHsi	2401.8729	kJ/kg	enthalpy of steam kJ/kg above tfsi
		Pasi	16.013793	bara	pressure bar abs
	15	Pgsi		barg	pressure bar gauge
		kPa	1601.019	kPa	pressure kilo pascal abs
		tsi	201.41826	C	steam temperature deg C
	11.8	Sfcon		t/MW	specific steam cons; tonnes/MW
	1185	Coskw		R/kW	capital cost per kW installed (G2)
		Tsty	163052.4	t/y	steam demand by turbine tonnes/year
		Tfy	58094.305	t/y	fuel consumption tonnes/year
		Stcos	7.4010084	R/t	steam cost per tonne (overall cost)
	93	tfsi		C	feed water temp to boiler deg C
		kWtf	237.85464	kW/t	kW output per tonne of fuel fired

App. -D -Fig. 6: South African Sawmill Power Cost - CHP Plant

St	Input	Name	Output	Unit	Comment
					POWER COST- CHP PLANT
					2000 kW
		Afc	775473.36	R	annual fixed cost
		Ia	410400	R	interest amount
		Dep	114000	R	depreciation per year
		OH	85671.6	R	overhead per year
		Mc	63641.76	R	management employment cost per year
		Ac	78960	R	artisan cost per year
		Inc	22800	R	insurance cost per year
		Avc	535152	R	annual variable cost .
		Bma	0	R	fuel cost per year
		Ep	252672	R	electric power cost plant operation/y
		Oc	236880	R	operator cost per year
		Tpc	1310625.4	R	total cost of production
		Cp	.08299299	R	unit cost kWh
		Po	15792000	kW/y	kilowatt output per year
		Ps	45600	R	plant spares cost per year
	2	sr		%	spares as percentage of capital cost
		Tcc	2280000	R	total capital cost
	18	r		%	rate of interest percentage
	329	Dyr		D/y	days per year
	20	Ar		R/h	artisan rate per hour
	12	Ahr		h/D	artisan hours per day
	1	Inr		%	insurance rate per cent
		Bm	0	R/kWh	net fuel cost per kWh
		Opy	7896	h/y	plant operational hours per year
		Kw	200	kW	boiler and power plant demand per hour
	.16	Pwc		R	electric power unit cost decimal
	24	Hd		h/D	hours per day
	10	Or		R/h	operator rate per hour
	3	No			number of operators per shift
	5	dr		%	depreciation rate per cent
	2000	Phr		kW	plant kilowatt output per hour
		To	2447760	R	turnover
	.155	Sp		R	selling price per unit of prod; (G1)
		Opc	1310625.4	R	operational cost per year
		Pm	1137134.6	R	profit margin per year
		Pr	46.456133	%	profit ratio Pm/To(input with G2)
					alt;set Pr=0 or n and G1 for Sp value
	3.5	OHpc		%	overhead per cent of turnover
	2.6	Mcpc		%	management per cent of turnover

App. -D -Fig. 6 SA (cont.)

St	Input	Name	Output	Unit	Comment
		Bo	6.7413	MJ/kg	boiler heat input to steam MJ/kg fuel
	9.77	Ef		MJ/kg	calorific value of fuel as fired MJ/kg
	.69	Bfy			boiler efficiency decimal
		Bos	2.8066848	kg/kg	boiler steam output kg steam/kg fuel based on latent heat, feed water and comb air enthalpy accounted for in boiler overall efficiency
		Bosft	0	R/t	boiler steam cost per tonne
	0	Cosft		R/t	cost of fuel per tonne
		Bop	23.6	t/h	turbine specific steam cons; tonnes/h
		LHsi	2401.8729	kJ/kg	enthalpy of steam kJ/kg above tfsi
		Pasi	16.013793	bara	pressure bar abs
	15	Pgsi		barg	pressure bar gauge
		kPa	1601.019	kPa	pressure kilo pascal abs
		tsi	201.41826	C	steam temperature deg C
	11.8	Sfcon		t/MW	specific steam cons; tonnes/MW
	1140	Coskw		R/kW	capital cost per kW installed (G2)
		Tsty	186345.6	t/y	steam demand by turbine tonnes/year
		Tfy	66393.491	t/y	fuel consumption tonnes/year
		Stcos	7.0333046	R/t	steam cost per tonne (overall cost)
	93	tfsi		C	feed water temp to boiler deg C
		kWtf	237.85464	kW/t	kW output per tonne of fuel fired

App. -D -Fig. 7: Zimbabwe Sawmill Power Cost - CHP Plant

St	Input	Name	Output	Unit	Comment
					POWER COST-CHP PLANT
					500 kW
		Afc	866810.56	Z$	annual fixed cost
		Ia	474100	Z$	interest amount
		Dep	107750	Z$	depreciation per year
		OH	71853.6	Z$	overhead costs per year
		Mc	53376.96	Z$	management employment cost per year
		Ac	138180	Z$	artisan cost per year
		Inc	21550	Z$	insurance cost per year
		Avc	603716	Z$	annual variable cost
		Bma	0	Z$	fuel cost per year
		Ep	205296	Z$	electric power plant operating cost/y
		Oc	355320	Z$	operator cost per year
		Ps	43100	Z$	plant spares cost per year
		Tpc	1470526.6	Z$	total cost of production
		Cp	.3724738	Z$	unit power cost kWh
		Po	3948000	kW/y	kilowatt output per year
	2	sr		%	spares as percentage of capital cost
		Tcc	2155000	Z$	total capital cost
	22	r		%	rate of interest percentage
	329	Dyr		D/y	days per year
	35	Ar		Z$	artisan rate per hour
	12	Ahr			artisan hours per day
	1	Inr		%	insurance rate per cent
		Tfy	16598.373	t/y	fuel consumption tonnes/year
		Opy	7896	h/y	plant operational hours per year
		Kw	50	kW	boiler and power plant demand per hour
	.52	Pwc		Z$	electric power unit cost decimal
	24	Hd		h/D	hours per day
	15	Or		Z$	operator rate per hour
	3	No			number of operators per shift
	5	dr		%	depreciation rate per cent
	500	Phr		kW	plant kilowatt output per hour
		To	2052960	Z$	turnover
	.52	Sp		Z$	selling price per unit generated (G)
		Opc	1470526.6	Z$	operational cost per year
		Pm	582433.44	Z$	profit margin per year

App. -D -Fig. 7 ZIM (cont.)

St	Input	Name	Output	Unit	Comment
		Pr	28.370423	%	profit ratio Pm/To per cent
	3.5	OHpc		%	overhead per cent of turnover
	2.6	Mcpc		%	management per cent of turnover
		Bo	6.7413	MJ/kg	boiler heat input to steam MJ/kg fuel
	9.77	Ef		MJ/kg	calorific value of fuel as fired MJ/kg
	.69	Bfy			boiler efficiency decimal
		Bos	2.8066848	kg/kg	boiler steam output kg steam/kg fuel
		LHsi	2401.8729	kj/kg	latent heat of steam kJ/kg
		Bosft	0	Z$/t	boiler steam cost per tonne
	0	Cosft		Z$/t	cost of fuel per tonne
		Bm	0	Z$/kW	net fuel cost per kW
		Bop	5.9	t/h	turbine steam consumption tonnes/h
		Pasi	16.013793	bara	steam pressure bar abs
	15	Pgsi		barg	steam pressure bar gauge
		kPa	1601.019	kPa	steam pressure kilo pascal abs
		tsi	201.41826	C	steam temperature deg C (saturated)
	11.8	Sfcon		t/MW	specific steam cons; tonnes/MW
	4310	Coskw		Z$/kW	capital cost per kW installed
		Tsty	46586.4	t/y	steam demand by turbine tonnes/year
		Stcos	31.565576	Z$/t	steam cost per tonne (overall cost)
	93	tfsi		C	feed water temp to boiler deg C
		kWtf	237.85464	kW/t	kW output per tonne of fuel fired

App. -D -Fig. 8: Zimbabwe Sawmill Power Cost - CHP Plant

St	Input	Name	Output	Unit	Comment
					POWER COST-CHP PLANT
					1000 kW
		Afc	1368641.1	Z$	annual fixed cost
		Ia	770000	Z$	interest amount
		Dep	175000	Z$	depreciation per year
		OH	143707.2	Z$	overhead costs per year
		Mc	106753.92	Z$	management employment cost per year
		Ac	138180	Z$	artisan cost per year
		Inc	35000	Z$	insurance cost per year
		Avc	835912	Z$	annual variable cost
		Bma	0	Z$	fuel cost per year
		Ep	410592	Z$	electric power plant operating cost/y
		Oc	355320	Z$	operator cost per year
		Ps	70000	Z$	plant spares cost per year
		Tpc	2204553.1	Z$	total cost of production
		Cp	.27919872	Z$	unit power cost kWh
		Po	7896000	kW/y	kilowatt output per year
	2	sr		%	spares as percentage of capital cost
		Tcc	3500000	Z$	total capital cost
	22	r		%	rate of interest percentage
	329	Dyr		D/y	days per year
	35	Ar		Z$	artisan rate per hour
	12	Ahr			artisan hours per day
	1	Inr		%	insurance rate per cent
		Tfy	33196.746	t/y	fuel consumption tonnes/year
		Opy	7896	h/y	plant operational hours per year
		Kw	100	kW	boiler and power plant demand per hour
	.52	Pwc		Z$	electric power unit cost decimal
	24	Hd		h/D	hours per day
	15	Or		Z$	operator rate per hour
	3	No			number of operators per shift
	5	dr		%	depreciation rate per cent
	1000	Phr		kW	plant kilowatt output per hour
		To	4105920	Z$	turnover
	.52	Sp		Z$	selling price per unit generated (G)
		Opc	2204553.1	Z$	operational cost per year
		Pm	1901366.9	Z$	profit margin per year

App. -D -Fig. 8 ZIM (cont.)

St	Input	Name	Output	Unit	Comment
		Pr	46.307938	%	profit ratio Pm/To per cent
	3.5	OHpc		%	overhead per cent of turnover
	2.6	Mcpc		%	management per cent of turnover
		Bo	6.7413	MJ/kg	boiler heat input to steam MJ/kg fuel
	9.77	Ef		MJ/kg	calorific value of fuel as fired MJ/kg
	.69	Bfy			boiler efficiency decimal
		Bos	2.8066848	kg/kg	boiler steam output kg steam/kg fuel
		LHsi	2401.8729	kj/kg	latent heat of steam kJ/kg
		Bosft	0	Z$/t	boiler steam cost per tonne
	0	Cosft		Z$/t	cost of fuel per tonne
		Bm	0	Z$/kW	net fuel cost per kW
		Bop	11.8	t/h	turbine steam consumption tonnes/h
		Pasi	16.013793	bara	steam pressure bar abs
	15	Pgsi		barg	steam pressure bar gauge
		kPa	1601.019	kPa	steam pressure kilo pascal abs
		tsi	201.41826	C	steam temperature deg C (saturated)
	11.8	Sfcon		t/MW	specific steam cons; tonnes/MW
	3500	Coskw		Z$/kW	capital cost per kW installed
		Tsty	93172.8	t/y	steam demand by turbine tonnes/year
		Stcos	23.660909	Z$/t	steam cost per tonne (overall cost)
	93	tfsi		C	feed water temp to boiler deg C
		kWtf	237.85464	kW/t	kW output per tonne of fuel fired

App. -D -Fig. 9: Zimbabwe Sawmill Power Cost - CHP Plant

St	Input	Name	Output	Unit	Comment
					POWER COST-CHP PLANT 1250 kW
		Afc	1595756.4	Z$	annual fixed cost
		Ia	899250	Z$	interest amount
		Dep	204375	Z$	depreciation per year
		OH	179634	Z$	overhead costs per year
		Mc	133442.4	Z$	management employment cost per year
		Ac	138180	Z$	artisan cost per year
		Inc	40875	Z$	insurance cost per year
		Avc	950310	Z$	annual variable cost
		Bma	0	Z$	fuel cost per year
		Ep	513240	Z$	electric power plant operating cost/y
		Oc	355320	Z$	operator cost per year
		Ps	81750	Z$	plant spares cost per year
		Tpc	2546066.4	Z$	total cost of production
		Cp	.25796012	Z$	unit power cost kWh
		Po	9870000	kW/y	kilowatt output per year
	2	sr		%	spares as percentage of capital cost
		Tcc	4087500	Z$	total capital cost
	22	r		%	rate of interest percentage
	329	Dyr		D/y	days per year
	35	Ar		Z$	artisan rate per hour
	12	Ahr			artisan hours per day
	1	Inr		%	insurance rate per cent
		Tfy	41495.932	t/y	fuel consumption tonnes/year
		Opy	7896	h/y	plant operational hours per year
		Kw	125	kW	boiler and power plant demand per hour
	.52	Pwc		Z$	electric power unit cost decimal
	24	Hd		h/D	hours per day
	15	Or		Z$	operator rate per hour
	3	No			number of operators per shift
	5	dr		%	depreciation rate per cent
	1250	Phr		kW	plant kilowatt output per hour
		To	5132400	Z$	turnover
	.52	Sp		Z$	selling price per unit generated (G)
		Opc	2546066.4	Z$	operational cost per year
		Pm	2586333.6	Z$	profit margin per year

App. -D -Fig. 9 ZIM (cont.)

St	Input	Name	Output	Unit	Comment
		Pr	50.392284	%	profit ratio Pm/To per cent
	3.5	OHpc		%	overhead per cent of turnover
	2.6	Mcpc		%	management per cent of turnover
		Bo	6.7413	MJ/kg	boiler heat input to steam MJ/kg fuel
	9.77	Ef		MJ/kg	calorific value of fuel as fired MJ/kg
	.69	Bfy			boiler efficiency decimal
		Bos	2.8066848	kg/kg	boiler steam output kg steam/kg fuel
		LHsi	2401.8729	kj/kg	latent heat of steam kJ/kg
		Bosft	0	Z$/t	boiler steam cost per tonne
	0	Cosft		Z$/t	cost of fuel per tonne
		Bm	0	Z$/kW	net fuel cost per kW
		Bop	14.75	t/h	turbine steam consumption tonnes/h
		Pasi	16.013793	bara	steam pressure bar abs
	15	Pgsi		barg	steam pressure bar gauge
		kPa	1601.019	kPa	steam pressure kilo pascal abs
		tsi	201.41826	C	steam temperature deg C (saturated)
	11.8	Sfcon		t/MW	specific steam cons; tonnes/MW
	3270	Coskw		Z$/kW	capital cost per kW installed
		Tsty	116466	t/y	steam demand by turbine tonnes/year
		Stcos	21.861027	Z$/t	steam cost per tonne (overall cost)
	93	tfsi		C	feed water temp to boiler deg C
		kWtf	237.85464	kW/t	kW output per tonne of fuel fired

App. -D -Fig. 10: Zimbabwe Sawmill Power Cost - CHP Plant

St	Input	Name	Output	Unit	Comment
					POWER COST-CHP PLANT
					1500 kW
		Afc	1815871.7	Z$	annual fixed cost
		Ia	1023000	Z$	interest amount
		Dep	232500	Z$	depreciation per year
		OH	215560.8	Z$	overhead costs per year
		Mc	160130.88	Z$	management employment cost per year
		Ac	138180	Z$	artisan cost per year
		Inc	46500	Z$	insurance cost per year
		Avc	1064208	Z$	annual variable cost
		Bma	0	Z$	fuel cost per year
		Ep	615888	Z$	electric power plant operating cost/y
		Oc	355320	Z$	operator cost per year
		Ps	93000	Z$	plant spares cost per year
		Tpc	2880079.7	Z$	total cost of production
		Cp	.24316782	Z$	unit power cost kWh
		Po	11844000	kW/y	kilowatt output per year
	2	sr		%	spares as percentage of capital cost
		Tcc	4650000	Z$	total capital cost
	22	r		%	rate of interest percentage
	329	Dyr		D/y	days per year
	35	Ar		Z$	artisan rate per hour
	12	Ahr			artisan hours per day
	1	Inr		%	insurance rate per cent
		Tfy	49795.118	t/y	fuel consumption tonnes/year
		Opy	7896	h/y	plant operational hours per year
		Kw	150	kW	boiler and power plant demand per hour
	.52	Pwc		Z$	electric power unit cost decimal
	24	Hd		h/D	hours per day
	15	Or		Z$	operator rate per hour
	3	No			number of operators per shift
	5	dr		%	depreciation rate per cent
	1500	Phr		kW	plant kilowatt output per hour
		To	6158880	Z$	turnover
	.52	Sp		Z$	selling price per unit generated (G)
		Opc	2880079.7	Z$	operational cost per year
		Pm	3278800.3	Z$	profit margin per year

App. - D -Fig. 10 ZIM (cont.)

St	Input	Name	Output	Unit	Comment
		Pr	53.236957	%	profit ratio Pm/To per cent
	3.5	OHpc		%	overhead per cent of turnover
	2.6	Mcpc		%	management per cent of turnover
		Bo	6.7413	MJ/kg	boiler heat input to steam MJ/kg fuel
	9.77	Ef		MJ/kg	calorific value of fuel as fired MJ/kg
	.69	Bfy			boiler efficiency decimal
		Bos	2.8066848	kg/kg	boiler steam output kg steam/kg fuel
		LHsi	2401.8729	kj/kg	latent heat of steam kJ/kg
		Bosft	0	Z$/t	boiler steam cost per tonne
	0	Cosft		Z$/t	cost of fuel per tonne
		Bm	0	Z$/kW	net fuel cost per kW
		Bop	17.7	t/h	turbine steam consumption tonnes/h
		Pasi	16.013793	bara	steam pressure bar abs
	15	Pgsi		barg	steam pressure bar gauge
		kPa	1601.019	kPa	steam pressure kilo pascal abs
		tsi	201.41826	C	steam temperature deg C (saturated)
	11.8	Sfcon		t/MW	specific steam cons; tonnes/MW
	3100	Coskw		Z$/kW	capital cost per kW installed
		Tsty	139759.2	t/y	steam demand by turbine tonnes/year
		Stcos	20.607443	Z$/t	steam cost per tonne (overall cost)
	93	tfsi		C	feed water temp to boiler deg C
		kWtf	237.85464	kW/t	kW output per tonne of fuel fired

App. -D -Fig. 11 Zimbabwe Sawmill Power Cost - CHP Plant

St	Input	Name	Output	Unit	Comment
					POWER COST-CHP PLANT
					1750 kW
		Afc	2026887	Z$	annual fixed cost
		Ia	1139600	Z$	interest amount
		Dep	259000	Z$	depreciation per year
		OH	251487.6	Z$	overhead costs per year
		Mc	186819.36	Z$	management employment cost per year
		Ac	138180	Z$	artisan cost per year
		Inc	51800	Z$	insurance cost per year
		Avc	1177456	Z$	annual variable cost
		Bma	0	Z$	fuel cost per year
		Ep	718536	Z$	electric power plant operating cost/y
		Oc	355320	Z$	operator cost per year
		Ps	103600	Z$	plant spares cost per year
		Tpc	3204343	Z$	total cost of production
		Cp	.23189629	Z$	unit power cost kWh
		Po	13818000	kW/y	kilowatt output per year
	2	sr		%	spares as percentage of capital cost
		Tcc	5180000	Z$	total capital cost
	22	r		%	rate of interest percentage
	329	Dyr		D/y	days per year
	35	Ar		Z$	artisan rate per hour
	12	Ahr			artisan hours per day
	1	Inr		%	insurance rate per cent
		Tfy	58094.305	t/y	fuel consumption tonnes/year
		Opy	7896	h/y	plant operational hours per year
		Kw	175	kW	boiler and power plant demand per hour
	.52	Pwc		Z$	electric power unit cost decimal
	24	Hd		h/D	hours per day
	15	Or		Z$	operator rate per hour
	3	No			number of operators per shift
	5	dr		%	depreciation rate per cent
	1750	Phr		kW	plant kilowatt output per hour
		To	7185360	Z$	turnover
	.52	Sp		Z$	selling price per unit generated (G)
		Opc	3204343	Z$	operational cost per year
		Pm	3981017	Z$	profit margin per year

App. -D -Fig. 11 ZIM (cont.)

St	Input	Name	Output	Unit	Comment
		Pr	55.404559	%	profit ratio Pm/To per cent
	3.5	OHpc		%	overhead per cent of turnover
	2.6	Mcpc		%	management per cent of turnover
		Bo	6.7413	MJ/kg	boiler heat input to steam MJ/kg fuel
	9.77	Ef		MJ/kg	calorific value of fuel as fired MJ/kg
	.69	Bfy			boiler efficiency decimal
		Bos	2.8066848	kg/kg	boiler steam output kg steam/kg fuel
		LHsi	2401.8729	kj/kg	latent heat of steam kJ/kg
		Bosft	0	Z$/t	boiler steam cost per tonne
	0	Cosft		Z$/t	cost of fuel per tonne
		Bm	0	Z$/kW	net fuel cost per kW
		Bop	20.65	t/h	turbine steam consumption tonnes/h
		Pasi	16.013793	bara	steam pressure bar abs
	15	Pgsi		barg	steam pressure bar gauge
		kPa	1601.019	kPa	steam pressure kilo pascal abs
		tsi	201.41826	C	steam temperature deg C (saturated)
	11.8	Sfcon		t/MW	specific steam cons; tonnes/MW
	2960	Coskw		Z$/kW	capital cost per kW installed
		Tsty	163052.4	t/y	steam demand by turbine tonnes/year
		Stcos	19.652228	Z$/t	steam cost per tonne (overall cost)
	93	tfsi		C	feed water temp to boiler deg C
		kWtf	237.85464	kW/t	kW output per tonne of fuel fired

App. -D -Fig. 12. Zimbabwe Sawmill Power Cost - CHP Plant

St	Input	Name	Output	Unit	Comment
					POWER COST-CHP PLANT
					2000 kW
		Afc	2232302.2	Z$	annual fixed cost
		Ia	1251800	Z$	interest amount
		Dep	284500	Z$	depreciation per year
		OH	287414.4	Z$	overhead costs per year
		Mc	213507.84	Z$	management employment cost per year
		Ac	138180	Z$	artisan cost per year
		Inc	56900	Z$	insurance cost per year
		Avc	1290304	Z$	annual variable cost
		Bma	0	Z$	fuel cost per year
		Ep	821184	Z$	electric power plant operating cost/y
		Oc	355320	Z$	operator cost per year
		Ps	113800	Z$	plant spares cost per year
		Tpc	3522606.2	Z$	total cost of production
		Cp	.22306271	Z$	unit power cost kWh
		Po	15792000	kW/y	kilowatt output per year
	2	sr		%	spares as percentage of capital cost
		Tcc	5690000	Z$	total capital cost
	22	r		%	rate of interest percentage
	329	Dyr		D/y	days per year
	35	Ar		Z$	artisan rate per hour
	12	Ahr			artisan hours per day
	1	Inr		%	insurance rate per cent
		Tfy	66393.491	t/y	fuel consumption tonnes/year
		Opy	7896	h/y	plant operational hours per year
		Kw	200	kW	boiler and power plant demand per hour
	.52	Pwc		Z$	electric power unit cost decimal
	24	Hd		h/D	hours per day
	15	Or		Z$	operator rate per hour
	3	No			number of operators per shift
	5	dr		%	depreciation rate per cent
	2000	Phr		kW	plant kilowatt output per hour
		To	8211840	Z$	turnover
	.52	Sp		Z$	selling price per unit generated (G)
		Opc	3522606.2	Z$	operational cost per year
		Pm	4689233.8	Z$	profit margin per year

App. -D -Fig. 12 ZIM (cont.)

St	Input	Name	Output	Unit	Comment
		Pr	57.103326	%	profit ratio Pm/To per cent
	3.5	OHpc		%	overhead per cent of turnover
	2.6	Mcpc		%	management per cent of turnover
		Bo	6.7413	MJ/kg	boiler heat input to steam MJ/kg fuel
	9.77	Ef		MJ/kg	calorific value of fuel as fired MJ/kg
	.69	Bfy			boiler efficiency decimal
		Bos	2.8066848	kg/kg	boiler steam output kg steam/kg fuel
		LHsi	2401.8729	kj/kg	latent heat of steam kJ/kg
		Bosft	0	Z$/t	boiler steam cost per tonne
	0	Cosft		Z$/t	cost of fuel per tonne
		Bm	0	Z$/kW	net fuel cost per kW
		Bop	23.6	t/h	turbine steam consumption tonnes/h
		Pasi	16.013793	bara	steam pressure bar abs
	15	Pgsi		barg	steam pressure bar gauge
		kPa	1601.019	kPa	steam pressure kilo pascal abs
		tsi	201.41826	C	steam temperature deg C (saturated)
	11.8	Sfcon		t/MW	specific steam cons; tonnes/MW
	2845	Coskw		Z$/kW	capital cost per kW installed
		Tsty	186345.6	t/y	steam demand by turbine tonnes/year
		Stcos	18.903619	Z$/t	steam cost per tonne (overall cost)
	93	tfsi		C	feed water temp to boiler deg C
		kWtf	237.85464	kW/t	kW output per tonne of fuel fired

App. -D -13 Economic Factors - South African Saw-mills - CHP Plant

St	Input	Name	Output	Unit	Comment
					DETERMINATION OF ECONOMIC FACTORS FOR INVESTMENT IN A CHP PLANT WITH AN OUTPUT OF 500 kW
		DC	43125	R	depreciation charge per year
	862500	FC		R	first cost (capital cost of project)
	20	EL		y	estimated life of plant years
		PP	-30.10892	y	pay back period years
		S	-28646	R	net annual savings
		ROI	-8.321275	%	return on investment per cent
		BC	-.1777795	ratio	benefit/cost analysis
		PWF	5.3527465	factor	present worth factor
		PV	-153334.8	R	present value after n periods
	.18	r			discount rate decimal
		n	20		number of periods = EL
	611940	GAS		R	gross annual savings
	640586	AOC		R	annual operating cost
		NPV	-1015835	R	net present value
		Cp	.16225583	R	unit power cost
		PO	3948000	kWh/y	kilowatt output per year
	329	Dyr		D/y	days per year
	24	Hd		h/D	hours per day
	500	Phr		kW	plant kilowatt output per hour

App. -D -14 Economic Factors - South African Saw-mills - CHP Plant

St	Input	Name	Output	Unit	Comment
					DETERMINATION OF ECONOMIC FACTORS FOR INVESTMENT IN A CHP PLANT WITH AN OUTPUT OF 1000 kW
		DC	70000	R	depreciation charge per year
	1400000	FC		R	first cost (capital cost of project)
	20	EL		y	estimated life of plant years
		PP	4.0810734	y	pay back period years
		S	343047	R	net annual savings
		ROI	19.503357	%	return on investment per cent
		BC	1.3116026	ratio	benefit/cost analysis
		PWF	5.3527465	factor	present worth factor
		PV	1836243.6	R	present value after n periods
	.18	r			discount rate decimal
		n	20		number of periods = EL
	1223880	GAS		R	gross annual savings
	880833	AOC		R	annual operating cost
		NPV	436243.63	R	net present value
		Cp	.11155433	R	unit power cost
		PO	7896000	kWh/y	kilowatt output per year
	329	Dyr		D/y	days per year
	24	Hd		h/D	hours per day
	1000	Phr		kW	plant kilowatt output per hour

App. -D -15 Economic Factors - South African Saw-mills - CHP Plant

St	Input	Name	Output	Unit	Comment
					DETERMINATION OF ECONOMIC FACTORS FOR INVESTMENT IN A CHP PLANT WITH AN OUTPUT OF 1250 kW
		DC	81875	R	depreciation charge per year
	1637500	FC		R	first cost (capital cost of project)
	20	EL		y	estimated life of plant years
		PP	3.0492403	y	pay back period years
		S	537019	R	net annual savings
		ROI	27.795053	%	return on investment per cent
		BC	1.7554361	ratio	benefit/cost analysis
		PWF	5.3527465	factor	present worth factor
		PV	2874526.6	R	present value after n periods
	.18	r			discount rate decimal
		n	20		number of periods = EL
	1529850	GAS		R	gross annual savings
	992831	AOC		R	annual operating cost
		NPV	1237026.6	R	net present value
		Cp	.10059078	R	unit power cost
		PO	9870000	kWh/y	kilowatt output per year
	329	Dyr		D/y	days per year
	24	Hd		h/D	hours per day
	1250	Phr		kW	plant kilowatt output per hour

App. -D -16 Economic Factors - South African Saw-mills - CHP Plant

St	Input	Name	Output	Unit	Comment
					DETERMINATION OF ECONOMIC FACTORS FOR INVESTMENT IN A CHP PLANT WITH AN OUTPUT OF 1500 kW
		DC	93000	R	depreciation charge per year
	1860000	FC		R	first cost (capital cost of project)
	20	EL		y	estimated life of plant years
		PP	2.5309876	y	pay back period years
		S	734891	R	net annual savings
		ROI	34.510269	%	return on investment per cent
		BC	2.1148845	ratio	benefit/cost analysis
		PWF	5.3527465	factor	present worth factor
		PV	3933685.2	R	present value after n periods
	.18	r			discount rate decimal
		n	20		number of periods = EL
	1835820	GAS		R	gross annual savings
	1100929	AOC		R	annual operating cost
		NPV	2073685.2	R	net present value
		Cp	.09295247	R	unit power cost
		PO	11844000	kWh/y	kilowatt output per year
	329	Dyr		D/y	days per year
	24	Hd		h/D	hours per day
	1500	Phr		kW	plant kilowatt output per hour

App. -D -17 Economic Factors - South African Saw-mills - CHP Plant

St	Input	Name	Output	Unit	Comment
					DETERMINATION OF ECONOMIC FACTORS FOR INVESTMENT IN A CHP PLANT WITH AN OUTPUT OF 1750 kW
		DC	103687.5	R	depreciation charge per year
	2073750	FC		R	first cost (capital cost of project)
	20	EL		y	estimated life of plant years
		PP	2.2178243	y	pay back period years
		S	935038	R	net annual savings
		ROI	40.089234	%	return on investment per cent
		BC	2.4135124	ratio	benefit/cost analysis
		PWF	5.3527465	factor	present worth factor
		PV	5005021.4	R	present value after n periods
	.18	r			discount rate decimal
		n	20		number of periods = EL
	2141790	GAS		R	gross annual savings
	1206752	AOC		R	annual operating cost
		NPV	2931271.4	R	net present value
		Cp	.08733189	R	unit power cost
		PO	13818000	kWh/y	kilowatt output per year
	329	Dyr		D/y	days per year
	24	Hd		h/D	hours per day
	1750	Phr		kW	plant kilowatt output per hour

App. -D -18 Economic Factors - South African Saw-mills - CHP Plant

St	Input	Name	Output	Unit	Comment
					DETERMINATION OF ECONOMIC FACTORS FOR INVESTMENT IN A CHP PLANT WITH AN OUTPUT OF 2000 kW
		DC	114000	R	depreciation charge per year
	2280000	FC		R	first cost (capital cost of project)
	20	EL		y	estimated life of plant years
		PP	2.005039	y	pay back period years
		S	1137135	R	net annual savings
		ROI	44.874342	%	return on investment per cent
		BC	2.6696471	ratio	benefit/cost analysis
		PWF	5.3527465	factor	present worth factor
		PV	6086795.4	R	present value after n periods
	.18	r			discount rate decimal
		n	20		number of periods = EL
	2447760	GAS		R	gross annual savings
	1310625	AOC		R	annual operating cost
		NPV	3806795.4	R	net present value
		Cp	.08299297	R	unit power cost
		PO	15792000	kWh/y	kilowatt output per year
	329	Dyr		D/y	days per year
	24	Hd		h/D	hours per day
	2000	Phr		kW	plant kilowatt output per hour

App. -D -19 Economic Factors - Zimbabwean Saw-mills - CHP Plant

St	Input	Name	Output	Unit	Comment
					DETERMINATION OF ECONOMIC FACTORS FOR INVESTMENT IN A CHP PLANT WITH AN OUTPUT OF 500 kW
		DC	107750	Z$	depreciation charge per year
	2155000	FC		Z$	first cost (capital cost of project)
	20	EL		y	estimated life of plant years
		PP	3.6999964	y	pay back period years
		S	582433	Z$	net annual savings
		ROI	22.027053	%	return on investment per cent
		BC	1.2054785	ratio	benefit/cost analysis
		PWF	4.4602661	factor	present worth factor
		PV	2597806.2	Z$	present value after n periods
	.22	r			discount rate decimal
		n	20		number of periods = EL
	2052960	GAS		Z$	gross annual savings
	1470527	AOC		Z$	annual operating cost
		NPV	442806.16	Z$	net present value
		Cp	.37247391	Z$	unit power cost
		PO	3948000	kWh/y	kilowatt output per year
	329	Dyr		D/y	days per year
	24	Hd		h/D	hours per day
	500	Phr		kW	plant kilowatt output per hour

App. -D -20 Economic Factors - Zimbabwean Saw-mills - CHP Plant

St	Input	Name	Output	Unit	Comment
					DETERMINATION OF ECONOMIC FACTORS FOR INVESTMENT IN A CHP PLANT WITH AN OUTPUT OF 1000 kW
		DC	175000	Z$	depreciation charge per year
	3500000	FC		Z$	first cost (capital cost of project)
	20	EL		y	estimated life of plant years
		PP	1.8407809	y	pay back period years
		S	1901367	Z$	net annual savings
		ROI	49.324771	%	return on investment per cent
		BC	2.4230294	ratio	benefit/cost analysis
		PWF	4.4602661	factor	present worth factor
		PV	8480602.8	Z$	present value after n periods
	.22	r			discount rate decimal
		n	20		number of periods = EL
	4105920	GAS		Z$	gross annual savings
	2204553	AOC		Z$	annual operating cost
		NPV	4980602.8	Z$	net present value
		Cp	.27919871	Z$	unit power cost
		PO	7896000	kWh/y	kilowatt output per year
	329	Dyr		D/y	days per year
	24	Hd		h/D	hours per day
	1000	Phr		kW	plant kilowatt output per hour

App. -D -21 Economic Factors - Zimbabwean Saw-mills - CHP Plant

St	Input	Name	Output	Unit	Comment
					DETERMINATION OF ECONOMIC FACTORS FOR INVESTMENT IN A CHP PLANT WITH AN OUTPUT OF 1250 kW
		DC	204375	Z$	depreciation charge per year
	4087500	FC		Z$	first cost (capital cost of project)
	20	EL		y	estimated life of plant years
		PP	1.5804223	y	pay back period years
		S	2586334	Z$	net annual savings
		ROI	58.274226	%	return on investment per cent
		BC	2.8221989	ratio	benefit/cost analysis
		PWF	4.4602661	factor	present worth factor
		PV	11535738	Z$	present value after n periods
	.22	r			discount rate decimal
		n	20		number of periods = EL
	5132400	GAS		Z$	gross annual savings
	2546066	AOC		Z$	annual operating cost
		NPV	7448237.9	Z$	net present value
		Cp	.25796008	Z$	unit power cost
		PO	9870000	kWh/y	kilowatt output per year
	329	Dyr		D/y	days per year
	24	Hd		h/D	hours per day
	1250	Phr		kW	plant kilowatt output per hour

App. -D -22 Economic Factors - Zimbabwean Saw-mills - CHP Plant

St	Input	Name	Output	Unit	Comment
					DETERMINATION OF ECONOMIC FACTORS FOR INVESTMENT IN A CHP PLANT WITH AN OUTPUT OF 1500 kW
		DC	232500	Z$	depreciation charge per year
	4650000	FC		Z$	first cost (capital cost of project)
	20	EL		y	estimated life of plant years
		PP	1.4182018	y	pay back period years
		S	3278800	Z$	net annual savings
		ROI	65.511828	%	return on investment per cent
		BC	3.1450152	ratio	benefit/cost analysis
		PWF	4.4602661	factor	present worth factor
		PV	14624320	Z$	present value after n periods
	.22	r			discount rate decimal
		n	20		number of periods = EL
	6158880	GAS		Z$	gross annual savings
	2880080	AOC		Z$	annual operating cost
		NPV	9974320.5	Z$	net present value
		Cp	.24316785	Z$	unit power cost
		PO	11844000	kWh/y	kilowatt output per year
	329	Dyr		D/y	days per year
	24	Hd		h/D	hours per day
	1500	Phr		kW	plant kilowatt output per hour

App. -D -23 Economic Factors - Zimbabwean Saw-mills - CHP Plant

St	Input	Name	Output	Unit	Comment
					DETERMINATION OF ECONOMIC FACTORS FOR INVESTMENT IN A CHP PLANT WITH AN OUTPUT OF 1750 kW
		DC	259000	Z$	depreciation charge per year
	5180000	FC		Z$	first cost (capital cost of project)
	20	EL		y	estimated life of plant years
		PP	1.3011751	y	pay back period years
		S	3981017	Z$	net annual savings
		ROI	71.85361	%	return on investment per cent
		BC	3.4278755	ratio	benefit/cost analysis
		PWF	4.4602661	factor	present worth factor
		PV	17756395	Z$	present value after n periods
	.22	r			discount rate decimal
		n	20		number of periods = EL
	7185360	GAS		Z$	gross annual savings
	3204343	AOC		Z$	annual operating cost
		NPV	12576395	Z$	net present value
		Cp	.23189629	Z$	unit power cost
		PO	13818000	kWh/y	kilowatt output per year
	329	Dyr		D/y	days per year
	24	Hd		h/D	hours per day
	1750	Phr		kW	plant kilowatt output per hour

App. -D -24 Economic Factors - Zimbabwean Saw-mills - CHP Plant

St	Input	Name	Output	Unit	Comment
					DETERMINATION OF ECONOMIC FACTORS FOR INVESTMENT IN A CHP PLANT WITH AN OUTPUT OF 2000 kW
		DC	284500	Z$	depreciation charge per year
	5690000	FC		Z$	first cost (capital cost of project)
	20	EL		y	estimated life of plant years
		PP	1.2134178	y	pay back period years
		S	4689234	Z$	net annual savings
		ROI	77.411845	%	return on investment per cent
		BC	3.6757876	ratio	benefit/cost analysis
		PWF	4.4602661	factor	present worth factor
		PV	20915231	Z$	present value after n periods
	.22	r			discount rate decimal
		n	20		number of periods = EL
	8211840	GAS		Z$	gross annual savings
	3522606	AOC		Z$	annual operating cost
		NPV	15225231	Z$	net present value
		Cp	.22306269	Z$	unit power cost
		PO	15792000	kWh/y	kilowatt output per year
	329	Dyr		D/y	days per year
	24	Hd		h/D	hours per day
	2000	Phr		kW	plant kilowatt output per hour

QUESTIONNAIRE E-1

These questionnaires were sent to South African and Zimbabwean organisations that were affiliated to their saw-milling industries.

QUESTIONNAIRE E-2

These questionnaires were sent to selected saw-mills in South Africa and Zimbabwe.

QUESTIONNAIRE E-1

1.0 Output quantities in m^3 per annum for the last 3 years :

	SAWLOGS	VENEER LOGS	POLES	MINING TIMBER	MATCH WOOD	CHARCOAL
Species						
Softwood						
Saligna						
Other gun species						
Wattle species						
Other						
TOTALS						

2.0 The estimated intake of timber in the above categories the difference being assessed as waste.

3.0 The average moisture content of timber into the wet mills and for the dry mills and the estimated shrinkage in kilns.

4.0 The average yield per hectare of the various species per annum.

5.0 An estimate if the residue in m^3 left in the forest after clear felling and trimming.

6.0 An estimate of the transport costs per m^3 per kilometer of distance to the sawmill.

7.0 The estimated average cost of the production for m^3.
Can the cost of production be broken down on a percentage basis to various cost centres such as those shown in the following allocation of budget costs.

COST CENTRE	AVERAGE %	RANGE	
		Maximum %	**Minimum %**
Material			
Wages			
Repairs & Maintenance			
Energy electric / steam			
Liquid fuels			
Salaries			
Sub Totals			
Administration			
TOTAL			

Liquid fuels refer to fuel oil (diesel) for internal transport.
Fuel oil used for power generation is usually included with energy costs.
Average is assumed to be unweighted arithmetic average.

8.0 Estimated average consumption of electrical energy per cubic metre of roundwood intake.
Can this average be applied to a range of sawmill sizes? Say 100, 300, 600, 1000 m^3/day intake.

9.0 Self generated energy
How many sawmills generate their own electric power? What size are their plants?
How many sawmills generate steam for Kilning their timber?
Kiln efficiency - Steam consumption : kg steam per kg of timber input / output of kiln.

10.0 Waste wood - residues
The average sawmill recovery from timber input a) wet mills percent
b) dry mills percent

11.0 The estimated total annual residue produced by the industry.
How does the industry deal with this residue?
a) self generated power or steam
b) sold to pulp producers
c) incinerated
d) disposed of in land fills

12.0 Current electricity costs : cents per Kwh (unit) including maximum demand charges.
The historical costs of electrical energy to this sawmilling industry and forecast estimates for electrical energy in the next 5 to 10 years.
Are there available statistics that can show the overall availability of electrical power to sawmills e.g hours per year of outages and estimates of what this may have cost the industry per year?

1. **Quality of the wood residue and mill type**
   a) Wood species bark or wood waste
   b) Moisture content as received
   c) Moisture content when fired in the boiler
   d) Wet or dry mill or both

2. **Quantities**
   a) Amount of timber or sawlogs received per day average in m^3
   b) The amount of sawn timber produced m^3/day
   c) The amount of wood residue produced m^3/day
   d) The amount of oversize returned to the residue circuit m^3/day
   e) The kiln shrinkage per m^3
   f) Number of working days per year and number of working hours per day.
      a) Kilns
      b) Sawmill

3. **Costs**
   a) Cost of transporting timber from forest to mill R/m^3
   b) Is any of the cost from a) applied to the wood waste?
   c) Is it a practical option to recover the wood residue in the forest when clear felling and trimming, if so what distance from the loading point do you consider it is viable to move such residue?

4. **Kilns**
   a) Kiln efficiency kg of steam per m^3 of conditioned (kilned) wood
   b) Timber moisture content at input to kiln and timber moisture content after conditioning in the kiln
   c) Type of kiln and masonary construction or insulated panel walls.
   d) Operating temperatures.
   e) Average drying time - hours.

5. **Boilers**
   a) Type of boiler : water tube or shell boiler
   b) If burning wood residue, the type of grate and furnace e.g. flat grate in a refactory Dutch Oven or stepped grate and integrated boiler furnace
   c) Moisture content of fuels as fired
   d) Boiler thermal efficiency

      Alternatively : combustion data as follows
      Exit gas temperature
      CO_2 and O_2
      Steam flow and pressure
      Feedwater temperature and flow
      Ambient conditions in the boiler house

6. **Combined heat and power (CHP) or power only**
   a) Steam turbines condensing or back pressure / pass out types.
   b) Steam conditions:-
      inlet pressure and temperature and exhaust pressure.
   c) In the case of the back pressure turbine is the exhaust supplied to a process user e.g. timber drying kilns?
   d) Power output and specific steam consumption kg / kW

7. **Electrical power data**

a) Electrical power costs cents/kWh

b) Electric Power consumed per m^3 of round wood intake kW / m^3

Appendix E

Table E-1a

WOOD UTILISATION ANALYSIS

		A.C. Whitcher Western Cape	Mondi Sawmills Mpumalanga	Cape Sawmills Western Cape	Border Timbers Charter-Zimbabwe
Quality of the wood residue and mill type					
a)	Wood species bark or wood waste	P. Patula Hogged	P. Patula + Eliotti	P. Patula + Radiata	P. Patula + Radiata
b)	Moisture content as received	50-55%	50-55%	50%	50-55%
c)	Moisture content when fired in the boiler	42-45%	45%	50%	
d)	Wet or dry mill or both	wet and dry	wet and dry	wetmill	wetmill
Quantities					
a)	Amount of timber or sawlogs received per day average in m^3	200	1020	350 U/B	800
b)	The amount of sawn timber produced m^3/day	80	480	185	390
c)	The amount of wood residue produced m^3/day	70-47% of input	541-52% of input	165-47% of input	410-51% of input
d)	The amount of oversize returned to the residue circuit m^3/day	5			
e)	The kiln shrinkage per m^3	13%	3%	6%	9%
f)	Number of working days per year and number of working hours per day.	246 D/YR	341 D/YR	235 D/YR	330 D/YR
	a) Kilns	24 h/D	24 h/D	24 h/D	24 h/D
	b) Sawmill	10 h/D	18 h/D	10 h/D	10 h/D
Costs					
a)	Cost of transporting timber from forest to mill R/m^3	R18/m^3	R22/m^3	R45/m^3	Z$68/$m^3$
b)	Is any of the cost from a) applied to the wood waste?	NIL	NIL	NIL	NIL
c)	Is it a practical option to recover the wood residue in the forest when clear felling and trimming, I f so what distance from the loading point do you consider it is viable to move such residue?	N/A	N/A	N/A	N/A

Table E-1b

			A.C. Whitcher Western Cape	Mondi Sawmills Mpumalanga	Cape Sawmills Western Cape	Border Timbers Charter-Zimbabwe
4.	**Kilns**					
	a)	Kiln efficiency kg of steam per m^3 of conditioned (kilned) wood				
	b)	Timber moisture content at input to kiln and timber moisture content after conditioning in the kiln	50% - 13%	45-13%	50% - 12%	55% - 12%
	c)	Type of kiln and masonary construction or insulated panel walls.	Masonary Comp.	Masonary+ Clad Alum.	Masonary Comp.	Clad Alum.
	d)	Operating temperatures.	75 - 80°C	60°C 120°C	70 - 75°C	70 - 85°C
	e)	Average drying time - hours.	70 - 80 hours	144 hours 28 hours	75 hours	75 - 80 hours
5.	**Boilers**					
	a)	Type of boiler : water tube or shell boiler	water tube	water tube & shell	water tube	water tube & shell
	b)	If burning wood residue, the type of grate and furnace e.g. flat grate in a refactory	flat grate	flat grate & chain grate	flat grate	stepped grate
		Dutch Oven or stepped grate and integrated boiler furnace	integrated		dutch oven type	
	c)	Moisture content of fuels as fired	42 - 45%	30 – 35%	50%	50- 55%
	d)	Boiler thermal efficiency	69%	80%		65 - 72%
		Alternatively : combustion data as follows				
		Exit gas temperature	285°			
		CO_2 and O_2	9.9 and 8.3			
		Steam flow and pressure	19.6 tph and 14.8 bar	coal 10tph 14 bar wood 43tph 30 bar		
		Feedwater temperature and flow	94°C			
		Ambient conditions in the boiler house	27°C 60% RH			
6.	**Combined heat and power (CHP) or power only**		Power only	Power only		
	a)	Steam turbines condensing or back pressure / pass out types.	condensing turbine	condensing turbines (2)	N/A	N/A
	b)	Steam conditions:- inlet pressure and temperature and exhaust pressure.	14.8 BAR/307°C/0.1688	30 bar		
	c)	In the case of the back pressure turbine is the exhaust supplied to a process user e.g. timber drying kilns?				
	d)	Power output and specific steam consumption kg / kW	950kVA 7.912kg steam/kW	2400 kVA aprox. 5.0kg/kW		
7.	**Electrical power data**					
	a)	Electrical power costs cents/kWh	estimated cost R0.12/kWh	R0.06/kWh		Z$ 0.52/kWh
	b)	Electric Power consumed per m^3 of round wood intake kWh / m^3	114kWh/m^3	56.5kWh/m^3		40kWh/m^3

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23 July 1997

The Faculty Officer
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Dear Sir

In reply to your letter of the 15 June 1998.

I attach my report replying to the matters raised by the Examiners of my dissertation.

An unbound copy of the revised dissertation is also attached.

Yours sincerely

Signed by candidate

Signature Removed

E.D.D. COCHRANE

HEAD OF DEPARTMENT / SUPERVISOR
PROFESSOR R. K. DUTKIEWICZ

The Reply to the Examiners Report from Professor R.K. Dutkiewicz

1.0 Corrections have been made to the text in respect of pages 14, 15 and 49

2.0 In regard to the original page 43 now page 5, the comment refers to table 8 now table 2 in that a derivation of "potential capacity" to "potential energy" is required. This is now described on page 5 as follows:-
The relationship between potential energy capacity and potential energy output is that in which the potential capacity is divided by the number of plant operational hours per year which in turn is a function of the plant efficiency.

The reply to the examiners Report from Dr. G.P.N. Venter

1(2.0) The tables 11 and 12 have been recalculated in terms of the return on investment (RO1) pay back (PB) benefit / cost ratios (B/C) and net present value (NPV).

The need to make these changes arose from the re-evaluation of the capital plant costs. These amended costs were derived from the computation of an exponential equation used for the determination of capital costs of identical or similar plant differing only in size. The effects of the these revised capital costs were to increase the unit power costs of plants with capacities below 1000kW and to decrease the power costs for plants with power outputs above 1000kW. The results of these amendments are shown in tables 11 and 12 which depict the important economic factors and ratios that apply to the South African and Zimbabwean sawmilling industries.

2(3.1) The index has been amended in as much that the numbered paragraphs appear in the index.
Paragraph 5.7 has been renumbered as paragraph 5.6.

3.(3.1) Chapter 2 has been rewritten so as to include the content of paragraph 2.8 in paragraph 2.1.

3(3.3) The Table 4 in paragraph 2.10 "Economics of Energy at Sawmill," has been revised to show in chart and tabular form the average allocation of budgeted costs that applied to South African sawmills in a 1981.

5(3.3) The reference to P. Sorfa's report "Hout 287" [27] in which the actual and predicted softwood residues for South African sawmills are set in table 4 which shows an annual average of 4% growth for this reasource. This data has been amended to exclude the linear growth beyond 1990.

Historical data [17] on the sawmill wood residues from South African sawmills over the period 1981 to 1996 shows a growth of less than one percent per year.

6(3.4) The reference to the statement "The consumption of energy per m^3 has been assessed as follows" this assessment is taken from table 5 on page 32 and is amended to this effect.

7(3.6) The capital cost of the electrical power generation plant has been amended so that the effect of economy of scale can be seen. The revised evaluation is based on the exponential relationship of the cost of a reference plant to that of a similar plant of different capacity.
The tables 11 and 12 have been revised together with the Appendices D-1 to D-12.

8(3.7) Further discussion on tables 11 and 12 has been provided in the text, which deals with the economic implications and opportunities for sawmills to generate their own electric power.

9(3.8) The word "apparent" has been used in place of "available" in paragraph 6.6