Öko-Institut

Draft Final Report

Wood Waste Power Plants in Zimbabwe as options for CDM

Part II
Assessment of financial and technical feasibility studies

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List of acronyms and abbreviations

BDT	Bone dry tons
CC	Combined-Cycle
CDM	Clean Development Mechanism
CER	Certified emission reductions
DNR	Department of Natural Resources
EM	Environmental Manual for Power Development
FC	Forestry Commission
FSC	Forest Stewardship Council
GoZ	Government of Zimbabwe
GT	gas turbine
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit GmbH
HP	High Pressure
IEA	International Energy Agency
IRR	Internal Rate of Return
LP	Low Pressure
MET	Ministry of Environment and Tourism
NPV	Net Present Value
O&M	Operating and Maintenance
ZESA	Zimbabwe Electricity Supply Authority
ZPC	Zimbabwe Power Company

1 Introduction

In the framework of the German technical assistance for Zimbabwe, GTZ supports Zimbabwe Power Company, ZPC, a private company and wholly owned subsidiary of the Zimbabwe Electricity Supply Authority, ZESA. ZPC is developing new power generation projects in Zimbabwe and identified wood waste power generation plants in cooperation with the timber industries as options for the development of technically, economically and environmentally viable power generation.

GTZ contracted Öko-Institut to conduct a study with the following objectives:

- To assess the technical and financial feasibility studies of the project;
- To evaluate whether the project would be eligible as a CDM project;
- To analyse the environmental, social and economic impacts of the project;
- To estimate the potential greenhouse gas emissions reductions that could be achieved by the project;
- To analyse the baseline of the project, i.e. the situation that would have occurred without the project;
- The analyse the CDM possible benefits with regard to financing wood waste power generation plants in Zimbabwe.

This part of the report covers the analysis of the technical and financial feasibility of the project based on the feasibility studies prepared by ZPC. The evaluation of the wood waste power generation project as a CDM project is contained in a separate report.

2 Project description

In the Eastern Highlands of Zimbabwe Plantation timber production is an important sector of Zimbabwe's economy. Three large companies (Border Timbers, Forestry Commission, Wattle Company) are operating plantations and sawmills. In total these companies produce about 87 % of the national output of sawn timber. The operation sawmills produce considerable amounts of wood waste (sawmill dust, wood chips at the sawmills and off-cuts and bark left in the field). In total, wood waste residues are estimated to be about 750,000m^3 annually. At present, less than 10 % of this waste volume is to generate heat for the timber-drying kilns. The residues at the sawmills are burnt, the residues in the plantations are left at the forest floor.

The timber companies in co-operation with Zimbabwe Power Company (ZPC) are considering the installation of wood waste power cogeneration plants. No such plant has yet been installed in Zimbabwe. In other regions cogeneration biomass plants in conjunction with sawmills are already a widespread application. This practice ensures the steam supply for the kilns of the sawmill with the secondary benefit of power generation while using the residues of the mill and the supporting machines. In these cases, fuel transport does not need to be considered in the economic and ecological calculations.

In Zimbabwe's Eastern Highlands two cogeneration power plant projects using wood residues from sawmills are planned. These projects - Nyanga and Chimanimani wood waste power plant - are analysed as possible options for CDM projects in this study.

The main objectives of the projects are (ZPC and Wattle Company 1999, ZPC and FC 1999):

- Disposal of wood residues in an environmental friendly manner,
- Electricity generation for sale to the grid to ZESA and contribution to internal power deficit in Zimbabwe,
- Provision of steam for the sawmill operations,
- Provisions of adequate revenues to ensure adequate returns on investment,
- Ensure continuity and stability of power supply to the sawmill.

At present, electricity for the sawmill is purchased from the national utility (ZESA) and the steam for the kilns is produced in boilers, in which wood residues are burnt. Power supply to the sawmills experience occasional voltage drips. The cogeneration plants would contribute to system stability, would improve reliability for the sawmills and would prevent damages to motors and installations at the sawmills.

2.1 Nyanga wood waste power plant

Nyanga plant shall use wood residues from Nyanga Sawmill owned by the Wattle Company, one of the largest sawmills in Zimbabwe. According to the feasibility study, the wood waste residues shall fuel a power generation plant with a capacity of 3.5 MW_{el}. At the same time the co-generation plant shall supply steam to the sawmill that is needed in the kilns to dry the rough sawn timber.

The Nyanga Wood Waste Power Plant will be owned and developed by a company that is planned to be formed by the Wattle Company, Zimbabwe Power Company (ZPC) and a third investor. ZPC is a private company that has been set up by the national utility, Zimbabwe Electricity Supply Authority (ZESA) to develop and invest in commercially viable power generation projects that began operation in 1999.

The wood processed in the sawmill originates from Wattle company plantations surrounding the sawmill. The pine and Eucalyptus plantations are managed in a 25-year rotation. Certification process of plantations by Forest Stewardship Council (FSC) is currently under way and will be completed in 2000. In the neighbourhood a second sawmill, Erin Sawmill, owned by the FC, could provide additional wood waste and could possibly be included in a larger project.

2.2 Chimanimani wood waste power plant

Chimanimani plant – located in the South Eastern Highlands of Zimbabwe - shall use wood residues from a sawmill owned by the Forestry Commission (FC). According to the feasibility study, the wood waste residues shall fuel a power generation plant with a capacity of 3 MW_{el}. At the same time the co-generation plant shall supply steam to the sawmill that is needed in the kilns to dry the rough sawn timber.

The Chimanimani Wood Waste Power Plant will be owned and developed by the Forestry Commission, ZPC and a third investor. FC is a parastatal under the MET that is active in commercial forestry, timber processing and manufacture of timber products.

The wood processed in the sawmill originates from three plantations surrounding the sawmill. Planted species are different pine species (P. patula, P. elliotti, P. taeda), gum and other hardwood. Certification process of plantations by Forest Stewardship Council (FSC) has almost been completed. In about 12 kilometres distance from Chimanimani sawmill, there is located another sawmill that could provide additional wood waste and could possibly be included in a larger power plant project.

3 Technological analysis

3.1 Nyanga power plant

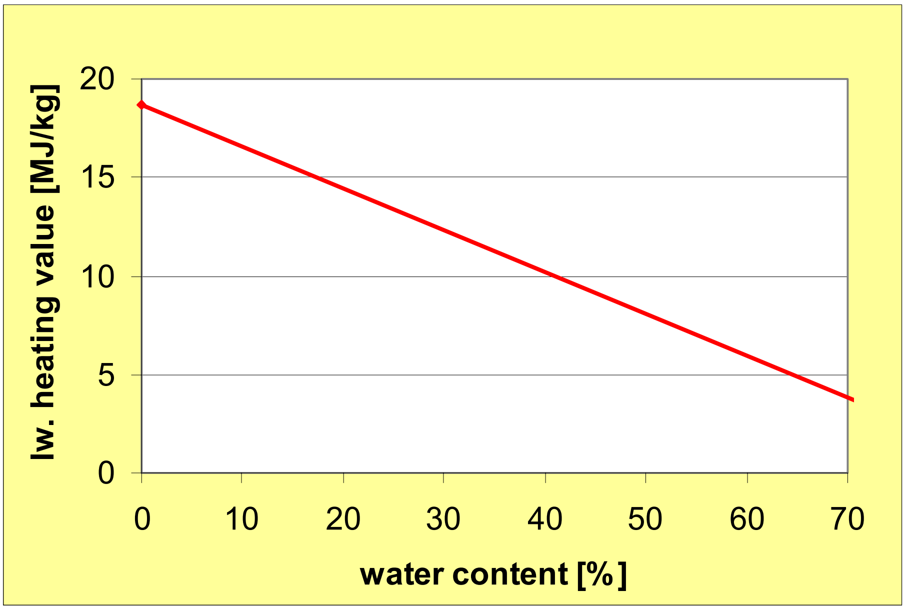
3.1.1 Availability of fuel and power plant dimension

With the additional information of the flow chart of raw material we got in December from the partners in Zimbabwe, for the Nyanga site about 49,084 BDT[1] of wood residues are available annually, 4,200 BDT more than stated in the feasibility study. For the plant design, the project developers assumed that only 80 % of the total residue amount will be available to take into account uncertainties in fuel supply and difficulties in recovering the estimated available wood residues, that means 39,000 BDT following the new information. From December to March fuel availability is reduced by a third according to the information from the partners in Zimbabwe.

Heating value

Feasibility studies for both sites use a lower heating value of 25 MJ/kg. The University of Munich[2] provided a lower heating value of 18,58 MJ/kg for dry pine and assumed that the same value could be applied for Eucalyptus. The effective heating value of the wood residues will strongly depend on the water content of the residues as shown in Figure 1 below.

Figure 1 Relationship between lower heating value and moisture



Source: Holzenergie für Kommunen, 1998

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[1] BDT (Bone dry tons) is a measure to determine fiber volumes at 0% moisture content.

[2] Mr.Ehrlenspiel, Institute for wood research

According to the feasibility study of Nyanga, the wood residues have to be divided in two fractions with different moisture content. The moisture content of 43,500 BDT (89%) of the wood residues is about 60 %, the moisture content of 5,560 BDT (11%) of the wood waste residues is between 11 to 14 %. Regarding these high water contents, the **heating value will be considerably lower than the value of 25 MJ/kg assumed in the feasibility study** (ZPC and Wattle Company 1999, ZPC and FC 1999, Data p.1).

Taking into account the different moistures of the residues, a minimum **average lower heating value** of **about 7 MJ/kg** can be calculated following figure 1 for the project sites. This value is even lower than the value calculated in the draft report because there was a uncertainty in the definition of the moisture. The high moisture values of the residues led to the assumption that the calculation of the moisture was based on the dry wood but it could be corrected by the Nyanga partners that the calculations were based on the weight of the wet wood. This means that the water content of the residues is twice as high and so the heating value is considerably lower.

In an offer for a cogeneration power plant to Wattle Company Spillingwerk GmbH assumed a lower heating value at about 10 MJ/kg (Spillingwerk GmbH 1999). Williams and Larsen (1994) assumed a lower heating value of 10.7 MJ/kg for wood (logs) and wood waste from forestry in tropical countries with 35% water content. All comparisons lead to a considerable lower heating value as assumed in the feasibility studies.

In the following calculations the minimum lower heating value of 7 MJ/kg will be used to meet the worst case because it is based on the assumption that the residues are collected with the maximum moisture content although the residues might be drier in some months.

Enthalpy

Among the total residues, 10,530 BDT (21 %) consist of bark with a humidity of max. 60 %. As data for several tree species indicate, the heating value of bark usually slightly differs from wood values. Literature research did not provide exact values for pine and eucalyptus bark. Comparison of available heating values for several tree species (Institute of Wood Research 1999) did not show clear correlations between heating values for bark and wood. For a more exact estimation of the heating value, measurements for the different fractions have to be performed with the residues from the saw mills.

The enthalpy of the residues can be calculated as seen in the Table 1 below. The water content of the residues has to be added to the weight of the dry residues because the heating value of 7 MJ/kg is related to the moist wood. The water content is calculated as following:

$$water\ content = \frac{dry\ residues \times moisture}{100 - w}$$

Table 1 Energy content of the residues for Nyanga site

	residues BDT	moisture %	water content t	residue weight moist cond. t	lower heating value MJ/kg	enthalpy MWh
wet residues	43,524	60	65,286	108,810	6.0	180,031
dry residues	5,560	11	687	6,247	16.4	28,425
total	49,084			115,057		208,456

Source: calculations of Öko-Institut

To get the enthalpy of the fuel the moist weight of the residues is multiplied with the lower heating value, the result is an enthalpy content of 208.5 GWh per year, 24 GWh less than assumed in the draft report, although the mass of residues rose.

It has to be noticed that the amount of wood residues estimated annually was lower in June 1999 when the manufacturer Spillingwerk GmbH (Hamburg) had a meeting with the local partners of the Nyanga sawmill. There only 88,000 t/a (76 % of the residues provided in the flow chart) were estimated so that the amount of residues seem to vary quite broad in the estimations done in half a year.

3.1.1.1 Size of a cogeneration plant

This section evaluates the potential capacity of the cogeneration plant in relation to the available fuel.

In Nyanga there is a steam demand of 52,000 tons/a at 5 bar for the kilns, the actual demand may change every six hours between 4 and 10 t/h. The enthalpy of the steam would be about 2,820 kJ/kg at a temperature of 180°C (steam table in Dubble 1997). Thus, the annually steam need would have an enthalpy content of 40.7 GWh and the remaining enthalpy for electricity production would be 168 GWh.

According to the feasibility study power will be produced with a 3.5 MW_{el} plant, this means an annually electrical output of 30,660 GWh (3.5 MW *8,760 h).

The efficiency of a plant is useable energy divided by energy input, i.e. the enthalpy of the residues. Even if the amount of fuel for the plant drops to only 80 % of the residues that are considered as available, the resulting energy output should be sufficient to generate 3.5 MW electrical power and 52,000 t/a steam in Nyanga. The overall efficiency for this case would be about 43 % for the cogeneration plant, as shown in the following calculation.

$$\boxed{\text{overall efficiency} = \frac{40.7\ GWh + 30.6\ GWh}{0.8 \times 208.5\ GWh} = 43\%}$$

The overall efficiency is not a very precise measure for cogeneration plants because the different values for the thermal and electrical energy are not included. Nevertheless it seems that the calculated overall efficiency is quite low for a cogeneration plant.

If the two end energies are investigated separately the thermal efficiency can be calculated to 24 % and the electrical efficiency to 18 % for the project. The latter corresponds well with the statement in "Hessen Energie 1999, p.4", where electrical efficiencies for cogeneration plants are listed for steam turbines and steam engines with 15-20 %. In Obernberger and Hammerschmid (1999) the overall-efficiencies of cogeneration plants are given as 8-18 for steam turbines and 8-20 for steam engines (both alternatives are possible which will be explained in chapter 3.3).

Although it has to be noticed, that the calculation is based on the minimal lower heating value and that an availability of 100 % is assumed which is not realistic, the electrical efficiency seems to be quite high, like an engineer from Spillingwerk GmbH (Mr. Augustin) also concluded. Considering the situation under which the plant will be constructed he casted doubt on the size of the planned plant. He estimates plant capacities of 2.5-3 MW_{el} for the plant in Nyanga with resulting electrical efficiencies of 10-11 %, assuming an availability of 85 %.

It can be concluded that the **planning data** for the cogeneration plant in Nyanga should be **reviewed**. If the total mass of residues mentioned in the study would be burnt the planned output of the plant would be more ensured.

3.1.1.2 Size of a power plant

This section evaluates the potential size of a plant in relation to the available fuel if the steam will not be produced in the plant, assuming that only 80 % of the fuel is available[3]. During the country visit this option emerged[4].

In Nyanga the steam needed by the kilns is currently generated in two four year-old boilers (manufacturer: Babcock & Wilcox). The mass of residues needed for the existing boilers is 96 t per day, i.e. 35,040 t per year, (14,948 BDT).

$$\textit{dry weight} = \textit{moist weight} \times \frac{49{,}084}{115{,}057}$$

For the power generation without steam use, wood residues currently used to generate steam for the kilns have to be subtracted, thus 24,319 BDT of wood residues would be available per year for power generation.

For the use in the boilers only residues with a moisture of 60 % are burnt, i.e. 52,008 t residues with a moisture of 60 % and 4,997 t with a moisture of 11% could be burnt to generate electricity. The enthalpy of the remaining wood residues is (52,008 t * 6 MJ/kg+4,997 t*16,4 MJ/kg) 108,789 MWh.

The electrical efficiency of a power plant in comparison of the one of a cogeneration plant should be higher because of the lower pressures until which the steam can be re-

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[3] An assumption provided in the feasibility study

[4] According to information provided during the country visit, it is not yet clear if the power plants will be designed as cogeneration plant as boilers used for steam productions are not yet depreciated.

laxed. That is why an electrical efficiency of 20 % is used which results in a possible power generation of 21,758 MWh.

Table 2 Separate production of steam and power (without cogeneration

	weight moist cond. t	weight dry cond. BDT	enthalpy MWh	efficiency %	elec.energy MWh	plant size MW
Annual total mass of residues	115,057	49,084	208,456			
Steam production	35,040	14,948	58,400			
Power prod. with 80% of total mass	57,006	24,319	108,789	20	21,758	3.10
Power Prod. in the other months	5,358	2,286	10,627	20	2,125	3.69
Power Prod. in the wet months	3,536	1,508	7,013	20	1,403	2.44

Source: calculations of Öko-Institut

Assuming a plant availability of 80 % a plant of the size of about 3 MW_{el} could be installed, following this calculations. But for the comparison of the two plant-options it has to be considered, that the electrical needs of the power plant are higher than those of the cogeneration plant because of the vacuum-condenser. Besides the electrical needs of the two boiler have to be subtracted from the electrical output of the power plant, i.e. the electrical efficiency of the power plant would be reduced by about 4 % (Mr. Augustin, Spillingwerk GmbH).

Continuous supply of residues

For the monthly supply of the boilers about 1,246 BDT of residues are needed, for a power plant of the size of 3 MW_{el} additional 2,027 BDT would have to be transported to the plant. According to the feasibility study, fuel will be stored only for four days. In the wet season the total supply is reduced by a third. The production of the sawmill will also be reduced by a third so that proportional less steam is needed in the kilns. So we only have to concentrate on the fuel reduction for the power production. If the total amount of residues is held constant for the year, only 1,508 BDT can be estimated in the wet months. Thus there will be fuel shortages during the wet season with a power plant size of 3 MW_{el}.

It can be concluded that the size of a power plant may not exceed the size of a cogeneration plant because of the high amount of residues which will be used to generate steam for the kilns.

3.1.2 Availability of fuel from other sites

The feasibility study of Nyanga mentions additional residues, which could be used as fuel for the plant if necessary or in a “second phase”: There are 8,200 BDT from the road side at an average distance of 13 kilometres and another 19,000 BDT from a neighbouring sawmill (Erin Sawmill). It seems to be likely that no fuel supply problems will be expected during operation of the Nyanga sawmill as these residues have not been taken into account in the calculations.

Options for a logistic “coupling” of the wood residues from the sawmills Nyanga and Erin have been discussed during the Zimbabwe visit. Using residues from two sawmills a bigger power plant could be planned.

3.1.3 Long-term availability of fuel

The continuos fuel supply is a very important detail in the configuration of a biomass plant because most of the problems in the operation of such a plant occur because of blockages in the fuel transport systems.

Plantations have been planted on sites with favourable soil conditions. In addition management practices as erosion control or fire management are installed. Pre-assessment reports for FSC certification do not report on activities that may influence long-term fuel supply in a negative way (SGS 1999).

3.2 Chimanimani power plant

3.2.1 Availability of fuel and power plant capacity

With the information of the feasibility study, for the Chimanimani site 32,000 tons[5] of residues will be provided from the sawmill that consist of dry fractions (wood saw dust and off-cuts) and moist fractions (wood chips, bark, saw dust and off cuts). No detailed information with regard to the amounts of dry and moist residues have been provided. A detailed estimation of the heating value and the enthalpy for the residues cannot be performed on this data basis. It may be assumed a similar situation as for the Nyanga site.

The Chimanimani plant design includes a power plant with 3 MW_{el}. The power plant will be located at several hundred meters to the sawmill. During the country visit information was provided that a cogeneration plant would be difficult because of the steam transport under pressure to the sawmill. The distance between the kilns and the plant would result in considerable energy losses, high installation costs and safety problems during the operation process if steam pipes would be installed above ground between the mill and the plant. Next to the sawmill the slope and the underground are not regarded as suitable for ground work and the installation of a plant. Comparable to Nyanga plant, existing boilers are not yet depreciated, a fact that also would perhaps not be in favour of a cogeneration plant. As no further information with regard to the plant concept has been provided by project developers in Zimbabwe, no further recommendations are possible.

As in the Nyanga case, options for a logistic “coupling” of the wood residues from different sawmills exist for Chimanimani. In the feasibility study the possibilities of getting supplementary fuel from Gwandugwe sawmill are mentioned. During the country visit possibilities of co-operation with Charter-Borders sawmill were explored. A new option to be considered would be the installation of the power plant at the Charters – Borders sawmill and transport of wood residues from Chimanimani to the power plant. This option would have the advantage that a cogeneration plant could be designed with-

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[5] No indication was provided if this value is in BDT or for wet residues.

out the problems encountered at the Chimanimani sawmill, and the final power plant could be designed with higher capacity using residues from two sites. A road with frequent trucks between the sawmill exists and transport of residues seemed to be a possible option. Partners visited agreed to consider appropriate logistics for this coupling, but have not delivered estimates of the associated costs for local transport to Öko-Institut.

3.3 Technology options

For power generation first the biomass has to be burnt in a boiler. A single unit is planned in this project at both sites. In principle there are three types of burning systems for biomass:

- the grate combustion,
- the powdered combustion
- and the fluidised bed combustion.

The grate combustion is a widespread application for biomass combustion which offers many variations to match the requirements of the different fuel qualities. The fuel remains on the grate during a relatively long period and with high temperatures, thus even residues with high moisture content can be burnt. Problems only occur with very small and dusty fuels.

For fuel with moisture contents of max. 15 % and size of particles 5 to 10 mm and more than 50 % dust the powdered combustion offers the best efficiencies. The fuel is sucked in and mixed with the air in the combustion chamber. This is an application which is used for dimensions from 2 to 7,5 MW.

The fluidised bed combustion is characterised through a very well mixed gas and solid fuel suspension because of an air stream from below. This combustion type provides highest efficiencies, but it is connected with high investment costs. Therefore, fluidised bed combustion is only interesting for plant dimensions above 50 MW.

The fuel from the sawmills in Zimbabwe will be very inhomogeneous in size (wood chips of different size, bark and sawdust) and humidity. Because of these fuel conditions, robust and fully developed techniques are needed and a grate-heating system seems the most practicable application for the planned cogeneration plants.

For wood processing industries the combination of a grate with a following powdered combustion is a very convenient system (Marutzky and Seeger 1999). It could be analysed if the share and the quality of the sawdust is high enough to justify an additional powdered firing, but more detailed information with regard to fuel quality would be needed. The combined firing system would ensure a better burning of the sawdust than it would be possible with a grate combustion. On the other hand, because the powdered firing is installed after the grate combustion, it would also improve the burning of the other residues so that there would be a better energetic use of the fuel. At the same time, costs may be higher for the combined system.

The design of the boiler determines the quality (the pressure) of steam which will be used to generate power. In general the pressure level is responsible for the efficiency of a plant- the higher the pressure, the more can be converted into mechanical energy. Surely there is a proportional relation between the quality of a boiler and the cost but it has to be noticed, that the costs of a boiler do not always rise proportional to the pressure of steam they can provide. There is a steep gradient at about 30 bar which has to be considered in the planning of the plant (Mr. Augustin, Spillingwerke personal communication, Obernberger and Hammerschmid 1999).

That means that for the boiler itself there will be two main installation variants. One simpler version, an industry boiler which could be manufactured e.g. in South Africa. It provides lower steam conditions (about 30 bar , 400°C) but at the same time has lower investment costs, which offers the possibility of installing two boilers to increase the availability. The other possibility would be the one which is assumed in the feasibility studies: a boiler with water cooled walls providing higher pressures of up to 60 bar. The efficiencies of a plant with such a boiler are higher than with a simple one, but the difference in the investment costs is considerable. The cleaning of a boiler like this can be done automatically, the simpler one has to be cleaned every 6-8 weeks manually, which causes lower availability rates.

According to the calculations of Mr. Augustin from Spillingwerk GmbH the difference in the electrical efficiencies of cogeneration plants between an industry boiler with steam-conditions of 25 bar and a water tube boiler with steam-conditions of 45 bar is 1.3 %.

There are currently two options for power generation with biomass which are ready for market:

- the steam engine, and
- the steam turbine.

Gas turbines need a gaseous fuel, and small-scale biomass gasification is not (yet) a commercially viable technology for developing countries.

Steam engine

Steam engines have the advantage of high robustness, relatively low operation costs and easy maintenance, but usually they are used for smaller plant capacities from 0,1-2 MW_{el}. Therefore two engines would have to be installed. Two steam engines would have the advantage of a higher availability in cases of technical problems, maintenance works or in period of reduced fuel supply. In these cases the plant could work with only one of the engines, but would continue to produce at least an reduced amount of electricity and steam.

For the use of steam motors it has to be considered that it is a process with many oscillating parts with high mechanical wear which needs oil for constant working (20-40 l/h). Oil-reduction systems after the cooling unit will have to be provided in most systems (Marutzky and Seeger 1999) especially if the exhaust should be used for drying tasks. The costs of the oil, including the purchase, transport, storage and disposal need to be taken into account in the calculations.

Since the beginning of the year there is a new technology of steam engines from Spillingwerk GmbH which does not need a continuous oil supply. Mr. Kiehne (Spillingwerke GmbH) considers the new technology to be ready for market. In co-operation with their local agent in South Africa the Spillingwerk GmbH made an offer for the Nyanga location which has been sent to Zimbabwe. The concept includes two engine generator sets with 2060 kW, the steam for the kilns is extracted from several stages of the engine.

There are other opinions in literature that conclude that with the use of steam engines a major part of the heat produced by the engines is only at a low temperature level and cannot be used for further processes, that is why the efficiency of turbines should be considerably higher. Such a conclusion is drawn e.g. by Basler und Partner (1999) with regard to a wood processing company in Slovakia. It seems that this problem has also been resolved by the new technological concept used by Spillingwerk GmbH.

Steam turbine

Steam turbines are generally used for plants of dimensions above 2 MWel and the electrical efficiency increases with the size of the turbine. Therefore it would be unusual to combine several small turbines instead of a bigger one though the availability may be lower.

Steam turbines in general have higher efficiencies at maximum load, but steam engines have better partial load efficiencies. This means that the controls of turbines is not as good as the controls of steam engines but this is only an important fact, if the plant has to follow changing loads (e.g. fluctuating steam needs). Because steam turbines require a higher quality of the steam, auxiliary plant equipment is needed which increases the investment costs. For the production of steam a direct steam-extraction at the adequate pressure level can be provided, thus efficient use of the steam produced by the boiler can be ensured.

It seems adequate to use a generation unit with a high pressure (HP) and a low pressure (LP) turbine. As mentioned in the feasibility study the HP turbine could provide direct steam extraction to supply the kilns, the LP turbine would be a condensing unit, utilising two 50 % duty open forced draught cooling water systems.

A final recommendation in favour or against steam engines or turbines cannot be drawn because both options seem possible from a technical viewpoint at this stage. The size of the plant allows both technical options. The described robustness of steam engines may be an important advantage, as well as the installation of two modules to increase the availability, but the higher efficiencies of the turbines and water cooled boiler might offset these advantages.

Planing of a cogeneration plant

Before a final decision for the technical alternatives will be found, the details which are interesting for the design of the plant have to be determined:

- Cogeneration or not,

- the size of the plant,
- the priorities for steam and/or power production:

If a cogeneration plant is planned, the design of the plant depends on the steam extraction. The steam demand is not continuos, i.e. the steam, which is not extracted could be used to generate power if the plant is designed for produce supplementary steam volume. For the optimal plant design, the steam demand is a key feature, i.e. if the steam demand is planned according to the requirements of the plant itself or if the excess steam is produced. The different design options are connected with different efficiencies and costs.

Comparison with other cogeneration plant

For both options (steam turbine and steam engine), comparable projects can be found. There are several difficulties if cogeneration plants are compared with regard to costs and efficiencies:

- For cogeneration plants and especially for biomass plants no standard type of plant exists for comparisons because the requirements of each plant are different.
- Even if the capacities of power and heat are similar, the technical circumstances may vary because the heat may be used on a different temperature level. If this is the case the technical details are different (e.g. the steam extractions are on different levels or backpressure turbines are used instead of condensation turbines).
- The requirements of a plant installed in Zimbabwe are not comparable with those in European regions: While the latter are designed for high efficiencies those in Zimbabwe will have to be designed for robustness and easy maintenance.
- Finally the circumstances of planning and installation are very different in Zimbabwe, compared to those in Europe. Costs for human labour and materials differ considerably. Therefore the costs can be reduced if parts of the plant are manufactured in the region. This means that prices, proposed by European manufacturers may change significantly if regional partners are involved. In addition, there are different regional standards concerning e.g. the buildings, handling of the exhaust and ashes. Furthermore, import taxes must be considered.

The comparison of the costs of components cannot be performed without the detailed design of the plant. Only roughly estimated costs could be obtained and many manufacturers of biomass plants have not been willing to provide detailed cost data. They fear to provide cost data that is to high as they could not explore detailed possibilities of cost reductions. E.g. by involving local or regional partners like in the case of Spillingwerk GmbH which has the organisation to produce boilers in South Africa. Besides, the cost of single components can be reduced significantly when they are bought together with other components from the same manufacturer. Some components (like the boiler) are not available as standard component and have to be designed individually which present s problems for the cost estimate.

Options for the project

Three main alternatives should be taken into consideration at the Nyanga site:

1. The plant only produces power, steam is generated in the existing boilers. This would be the version with the lowest investment costs but also with the lowest amount of CO_2-credits.
2. A cogeneration plant is installed which provides the base load for the steam (in Nyanga this would mean 4 t/h at 9 bar), the peak loads are provided in the existing boilers. This would increase the amount of CO_2-credits because of the higher power output of the plant, whereas the investment costs would increase. The advantage of this version could be the possibility of installing a plant which could be copied at other locations without the need of much adaptation works in the planning phase, perhaps also with the possibility of reducing the manufacturing costs because of higher number of pieces.
3. A cogeneration plant is installed which covers the whole steam need of the sawmill, which would be the most ecological version with the highest overall efficiency. The adaptation level would be very high because of the problems mentioned above, this would result in a maximum of the investment costs.

For all three versions different technical solutions are possible and should be considered, such as the quality and number of the boilers and the installation of turbines or steam engines.

Further technical details

A missing point in the feasibility study seems to be the theoretical option to use the thermal energy of the exhaust and the steam returning from the kilns to dry the residues to increase their heating value. This feature would result in a more complicated construction. Response from the partners in Zimbabwe to the issue of drying of wood residues was that this option will not be considered further. Another possibility is the optional drying of the residues in the kilns if there is enough space left in the kilns because of a lower production of the sawmill (e.g. in the wet months). This possibility includes probably handling difficulties but it should be checked if it can be realised.

Regardless of the option chosen, a back-up steam supply has to be provided directly from the boiler to the kilns to secure the steam supply for the sawmill.

3.3.1 Technological risks

Technical risks in the implementation of the turbine and the steam engines are low, as state-of-the-art technology would be used. Technical risks in operation are comparable to other power plant projects using state-of-the-art technology. The most important element for the risk in operation would be the continuous supply of fuel which is ensured according to the project data.

In past years droughts have been a problem in Zimbabwe, which had a strong impact on Zimbabwe's economy. It has to be considered if droughts could decrease the timber output of plantations and in conjunction the output of the sawmills and the power plant.

The plant availability is assumed to be 60 % in the feasibility studies which seems already sufficiently low to include uncertainties with the handling of the plant or fuel supply problems caused by blockages. If several engines are installed the overall availability could be higher than with the installation of only one turbine.

4 Financial analysis

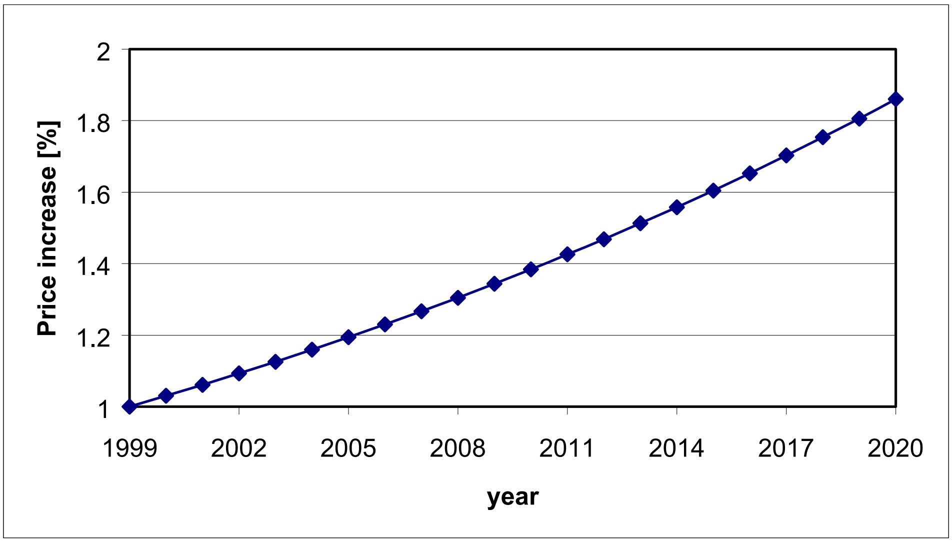
The financial analysis focuses on the basic design parameters and their implications for overall project result including the assessment of alternative technical options. The relevant parameters for the financial feasibility are discussed and recommendations for improvement of the analysis are provided.

4.1 Description of the Financial Plan of the Feasibility studies

The financial plans of the Nyanga and Chimanimani plants have similar structure, therefore this section only describes the financial plan of Nyanga plant. The plan is based on the technical solution which is supposed to be the most expensive one: the installation of two steam turbines with steam extraction in the high pressure turbine. The estimated project cost for this technical option amount to US$ 5,423,000 for Nyanga and US$ 5,533,000 for Chimanimani. The calculation is made for a lifetime of the project of 20 years.

The financial plan is calculated in US$ with an exchange rate of ZW$ 38.52 for US$ 1. The price increase is estimated as follows:

Figure 2: Estimated price increase till the year 2020



The financial plan is based on the estimated project costs, which will occur in the first two years (27% in the first, 73% in the second year).

The sales are based on the assumptions for the ZESA-tariff (see 4.2.2), the operating expenses are:

- Fuel (1 US$/t)
- O&M (1,25 US$/MWh)
- Administration (7,5 % of operating revenue)

- Depreciation (linear for 20 years)

The dept/equity rate is 60/40, with other words, it is assumed that 40% of the project cost will be financed through the means of private investors and 60% through a commercial loan at an interest rate of 12.5%. ZPC will provide a share of 30% of the equities, they assume five years of repayment and an interest rate of 10 %. Wattle Company and the Forestry Commission will not contribute equities. They contribute to the joint venture with so called in kind contributions (site, building etc.). The contribution of 70% of the projected equities is lacking up to now. This shall provided by third partner in a possible joint venture.

With an availability of 60 % the return on invested capital for the project is 6.17 %.

4.2 Key Parameters for the Financial Analysis

4.2.1 Project Cost Estimates

Specific cost for the steam turbines are projected as 400 US$/kW for Nyanga and 450 US$/kW for Chimanimani. These figures are in the range of comparable projects. Marutzky und Seeger (1999, p. 254) state specific cost of 400 US$/kW for a comparable but smaller plant. List prices of an American manufacturer (Trigen Ewing Power 1999) are pointing in the same direction, they show a heavy decrease which ends for their products with 440 US$/kW for turbines with 150 kW. List prices of Siemens (1999) for steam turbines including plant control equipment are about 20% above the figures assumed by ZPC. However, if it comes to a tender, prices of Siemens may be in the range of the ZPC figures.

The overall project cost estimates for Nyanga are US$ 5.4 million and US$ 5.5 million for Chimanimani. The specific overall project cost derived from these figures are 1,550 US$/kW for Nyanga and 1,840 US$/kW for Chimanimani. Overall project cost for biomass projects are at the lower range comparable to coal fired plants 1,750 US$/kW (EM database 1999). Overall project costs of existing biomass cogeneration plants in Sweden, Denmark, Finland and UK are listed together with those of the potential ones in Nyanga and Chimanimani in Table 3.

Table 3 Comparison of specific investment costs of biomass cogeneration plants

Output (av.)		Kempten (G)	Stockelsdorf (G)	Neumarkt i.d.Opf. (G)	Maabjerg (DK)	Thretford (UK)	Chimanimani (Zim)	Brista Kraft (S)	Nyanga (Zim)	Sandvik II (S)	Forsa (F)
Electrical cap.	MW	2.1	0.6	11.0	28.0	38.5	3.0	44.0	3.5	38.0	17.2
Thermal cap.	MW	12.5	?	73.5	68.0	?	?	85.0	8.0	66.0	48.0
Inv. costs	Mio US$	28.8	8.0	106.4	80.0	109.7	5.5	80.5	5.4	51.0	15.4
Spec. Inv.costs	US$/kW$_{el}$	13,714	13,333	9,673	2,858	2,850	1,844	1,830	1,549	1,342	897

Source: Caddet 1998,1999; C.A.R.M.E.N. 1998, 1999; Calculations of Öko-Institut

Compared to the existing biomass plants in Europe the estimated overall project cost for Nyanga and Chimanimani are rather at the lower range. However, they are not out of the possible range.

In chapter 3.3 there was explained why the comparison of biomass cogeneration plants is difficult, e.g. the costs for the surroundings (buildings etc.) of the plant are included in the overall costs. Especially in Germany this is a fact which increases the investment costs seriously (Mr. Schäfer, eta Energieberatung (Pfaffenhofen), personal communication) besides the very differing costs for human labour and materials. One reason for the lower overall projected costs of the planned plants may be due to the fact that some plant modules have been neglected: A new hogger is required to break down small logs as well as bark. It depends on the grate used in the boiler to which granulation and how the residues have to be chopped. Nevertheless, the cost for a new hogger should be taken into account in the financial analysis.

However, assumed that the estimates carried out by ZPC are based on detailed price information given by potential manufacturers and suppliers of the projected plant configuration they could be taken into account for the financial analysis. If not, it is essential for a sound financial analysis to obtain more detailed information on the individual parts of the plant.

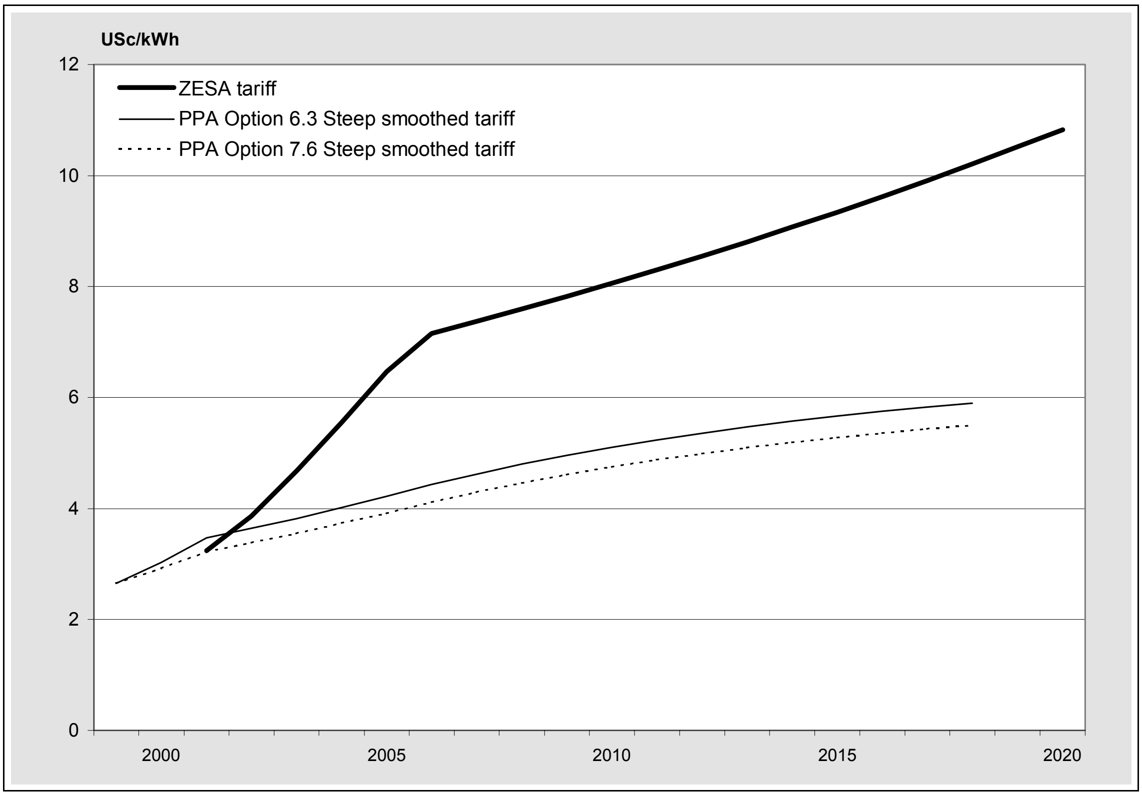
4.2.2 ZESA Tariffs

The ZESA tariff profile considered for the financial calculations is a crucial element for the economic efficiency of the investment projects. There are several aspects that have to be taken into account for the assumed profile.

Until today government policy has limited tariffs increases to reduce the impact on overall national inflation (GoZ 1999, p. 8). Recent Tariffs are too low to cover the operational cost of ZESA, in particular those for electricity imports from Mozambique and South Africa and have lead to insolvency of ZESA. Moreover these tariffs prevent any further investment in Zimbabwe's power supply as they do not allow to recover invested capital. Price increases in the future are inevitable.

In a recent study to determine the next power supply expansion projects in Zimbabwe PAA (1999) has developed and discussed various scenarios of tariff increases which could cover the investment need for the necessary power expansion in Zimbabwe.

Figure 3 Comparison of Average Electricity Tariff Profiles for Zimbabwe



Source: PAA 1999, p. 139, 142, 144, ZPC

In Figure 3 the two proposed price profiles with the future tariff development for the most favourable power expansion projects are shown (Option 6.3 and 7.6) together with the tariff profile assumed by ZPC for the feasibility study of Nyanga and Chimanimani. The tariff profile assumed by ZPC is substantially higher than the tariff profile proposed by PAA. The crucial point is whether Zimbabwe's government is willing to support future price increases or not. The Electricity White Paper gives some indications on that issue. There it is proposed to increase tariffs from November 1, 1999 to the equivalent of 3 USc/kWh and increase tariffs in each of the following 3 months by 0.33 USc/kWh so that the average tariff will be 4 USc/kWh from February 1, 1999 (GoZ 1999, p38). After that period further price increases should be discussed with the consumers, that showed some willingness to pay more in order to improve the reliability of electricity supply (GoZ 1999, p. 8). From an private investment perspective this seems to be a first step into the right direction. However, power expansion projects are long term investment. They need reliable tariff projections. If such projections are not available the assumed tariff profiles for an individual project have to be carried out in a very conservative way to reduce risks for private power investors.

Therefore we recommend that the tariff profiles assumed in the assessed feasibility studies need be carried out in a more conservative way or it should be given additional indication on the validity of the assumed price profile.

ZPC assumes that electricity generated in Nyanga and Chimanimani could be sold to

ZESA for 80% of the average tariff. Taking into account that both plants are operated with base load characteristics at a comparable low availability of 60%, this assumption seems to be optimistic. In developed countries – with often high excess generation capacities – the ratio of the feed-in tariff to average electricity tariff would be rather 60 than to 80%. However, in developing countries with increasing electricity demand and capacity shortages this may be different. Moreover the avoided transmission and distribution losses due to decentralised feeding-in into the ZESA system give some reason for a feed-in tariff closer to the average tariff than in developed countries. Finally, the fact that ZPC was set up by ZESA to develop commercially viable generation projects and its status as wholly owned subsidiary of ZESA may have influenced this assumption. To avoid any doubt about this assumption it should be stated clearly in the financial analysis if any detailed agreement on this ratio has already been achieved.

4.2.3 Fuel

Fuel cost are calculated with 2.15 US$/MWh in and with 1.44 US$/MWh in Chimanimani. However, in the meantime the involved project partner have agreed to set fuel cost to zero.[6] This seems to be reasonable mainly because the sawmills could reduce their operational cost if they avoid the burning of wood waste. Economic advantages from reduced electricity shortages for the sawmills have not been considered in the financial analysis. This should be analysed by ZPC and sawmills.

4.2.4 Operation &Maintenance

Costs for operation & Maintenance (O&M) are calculated with 1,25 US$/MWh electricity generated. For comparison with figures of other power plants O&M costs have to be transformed to specific costs with regard to plant capacity (US$/kW). In case of the Nyanga project this leads to O&M costs of 6.31 US$/kW and in case of the Chimanimani project to 7.80 US$/kW. In the table below these figures are compared to O&M costs for coal fired power plants in developing countries.

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[6] This was a result of the mission by Uwe Fritsche.

Table 4 Comparison of Operation & Maintenance Costs

	$US\$_{1996}/kW$	$US\$_{1999}/kW$
Brasil		
Power Plant 1	17,50	19,12
Power Plant 2	17,69	19,33
China		
Power Plant 1	36,05	39,39
India		
Power Plant 1 & 2	27,89	30,48
Russia		
Power Plant 1	32,99	36,05
Zimbabwe		
Nyanga		6,31
Chimanimani		7,80

Source: OECD/IEA 1998b, p. 62; own calculations

Table 4 shows that the figures taken into account for both projects are substantially below those of coal fired plants. O&M costs range from 19 US$/kW up to about 40 US$/kW. Revisions of the financial analysis should consider O&M costs within the range shown in the table above or give additional evidence why O&M cost in Nyanga and Chimanimani will be rather low.

4.2.5 Administration

Cost for administration have been accounted with 7.5% of the operation revenue of electricity generation. Considering that all electricity will be sold to ZESA (except the small share that goes to the host companies) and that the plants will be operated with less than 10 employees this assumption for the administrative cost seems to be a rather pessimistic estimation.

4.2.6 Other Parameters

Some relevant parameters, both additional costs as well as benefits have not been taken into account or could not be identified in the financial assessment.

- Water needed for the plant has to be treated before it can be pumped and vaporised. Costs for water treatment are estimate at 5 ZWD/m³ H_2O. They have not been taken into account yet.[7]Costs for on site or off site transport or handling of fuel (fuel, residue etc.) are not mentioned in financial analysis. As O&M costs are already at the lower bound of the range expenses for transport couldn't also be covered by this cost category.No cost for flue dust deposits were give in the financial statement. This implies the assumption that flue dust could be deposed in Zimbabwe at no cost.Due to the decentralised electricity feed-in by ZPC into the ZESA system, investment in

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[7] Information on the amount of water needed is not given in the feasibility study. Thus, the absolute amount of this cost factor could not be calculated.

ZESA sub-stations could be reduced. This effect could be taken into account either with higher feed-in tariff or with single payment by ZESA equivalent to a share of the avoided investment for the ZESA sub-station.

- Furthermore, the private benefits of on-site-generation should be identified, e.g., the reduced burn-out of motors, reduced off-service hours etc.

4.2.7 Plant Life Time

The period taken into account for the financial analysis ranges from commissioning in 2002 up to the year 2020. This corresponds to a plant life time of 18 year. In general plant life time for biomass plants is considered to be 10-20 years (see part I of the report). Forecasts for some variables (e.g. ZESA tariff) are rather difficult and mostly speculative. Shorter plant life times would reduce the financial risks that derive from substantially wrong forecast of future development of some variables. Therefore it would be helpful for the assessment of the whole project to carry out at least one additional sensitivity analysis with a plant life time of only 15 years.

4.3 Recommendations and Representation of Results

The investment cost assumptions for the wood-waste (co)generation plants should be reviewed using a wider range of data sources.

Regarding plant availability, the 'technology cases' should be treated differently, because the steam engine option would consist of a modular design offering generically higher availability.

The cost analysis should be focused on the IRR and NPV of the overall project, and should be presented for the whole matrix of options under consideration. Furthermore, a sensitivity analysis of the results should be carried out for variations of the interest rate for capital, the plant availability, and the purchase tariff.

Finally, a graphical representation of the comparative analysis is recommended.

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