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Abstract

This work has been done in the project where the main target is to evaluate the technology and economy to use bush biomass for power production in Namibia. The project has been financed by the Ministry for Foreign Affairs of Finland and the Ministry of Agriculture, Water and Forestry of the Republic of Namibia.

The target of this study is to calculate the production costs of bush chips at the power plant using the current wood chip production technology and to look possibilities to develop production technology in order to mechanize production technology and to decrease the wood chip production costs. The wood chip production costs are used in feasibility studies, in which the technology and economy of utilization of wood chips for power generation in 5, 10 and 20 MW electric power plants and for power generation in Van Eck coal fired power plant in Windhoek are evaluated.

Field tests were made at Cheetah Conservation Farm (CCF) in Otjiwarongo region. CCF is producing wood chips for briquette factory in Otjiwarongo. In the field tests it has been gathered information about this CCF semi-mechanized wood chip production technology. Also new machines for bush biomass chip production have been tested. A new mechanized wood chip production chain has been designed on the basis of this information. The wood chip production costs for the CCF semi-mechanized and the new production chain have been calculated. The target in the moisture content to produce wood chips for energy is 20 w-%.

In the semi-mechanized wood chip production chain the work is done partly manually, and the supply chain is organized into crews of 4–8 men. The wood chip production chain consists of manual felling and compiling, drying, chipping with mobile chipper and manual feeding and road transport by a tractor with two trailer unit. The CCF production chain works well. The chipping and road transport productivity in the semi-mechanized production chain is low.

New wood chip harvesting machines, such as chainsaw, brush cutter, lawn mover type cutter, rotator saw in skid steer and Nisula harvester head for felling, were tested at CCF. The most effective felling device in the tests appeared to be rotary saw in the skid steer. Based on these tests it was designed a new totally mechanized production chain. The working phases in this mechanized production chain are felling with a rotary saw in

skid steer, compiling with a grapple fork in skid steer, drying in the heaps, chipping with a mobile chipper with a loader and road transport with a tractor trailer. This new production chain is not fully tested in Namibia.

The calculated harvesting and road transport costs of wood chips with the designed new mechanized production chain are about 15% lower than those of the semi-mechanized production chain. The wood chip production costs at power plant with the new mechanized production chain are 170.5 N\$/wet ton (4.4 Euros/MWh) for 5 MWe power plant, 181.4 N\$/wet ton (4.7 Euros/MWh) for 10 MWe power plant and 192.3 N\$/wet ton (4.9 Euros/MWh) for 20 MWe power plant. The average road transport distance in the calculation is 30 km for a 5 MWe, 40 km for 10 MWe and 50 km for 20 MWe power plants. The wet ton and MWh units are presented in 20 w-% moisture content.

The harvesting and road transport costs of wood chips from Okahandja to Van Eck power plant are 238.4 N\$/wet ton (6.1 Euros/MWh) and from Otjiwarongo 350.3 N\$/wet ton (9.0 Euros/MWh) using the new mechanized wood chip production chain.

The designed mechanized wood chip production chain is very effective and suitable for large-scale wood chip production. With the new mechanized wood chip production chain the labour force demand of producing wood chips is 32 men for a 5 MWe, 65 men for 10 MWe and 136 men for 20 MWe power plant.

The average yield in selective bush harvesting at CCF was 7.0 wet tons (moisture content 20 w-%) per hectare. The annual total production area is 4 600 ha in the case of a 5 MW_e power plant, 8 600 ha for a 10 MW_e and 16 900 ha for 20 MW_e power plant if the harvesting yield is 7.0 wet tons per ha in 20 w-% moisture content.

Preface

This work has been done in the ‘Bush encroachment – the challenging resource for the renewable bioenergy in Namibia’ -project. The objective of the project is to make feasibility studies on biomass utilization in power and pyrolysis oil production. Another target is to develop the bush chip production technology.

The project has been financed by the Ministry for Foreign Affairs of Finland and the Ministry of Agriculture, Water and Forestry of the Republic of Namibia. The project is carried out between May the 1st 2006 and October the 31st 2007. The project manager was Markku Orjala from Technical Research Centre of Finland (VTT), who was also responsible for the feasibility study on the power production in the project. Dr. Arvo Leinonen was responsible for the bush chip production technology -part in the project. Dr. Arvo Leinonen has also been in charge of the field tests and he has prepared this report. Research scientist Jyrki Raitila from VTT has made the production cost analysis for the project.

This report is dealing with the bush chip production technology. The results from the production tests, made at Cheetah Conservation Fund (CCF), have been presented in this report. The semi-mechanized bush chip production technology, used at CCF farm to produce wood chips for the briquette factory of CCF, has been investigated in the study. New machines to be used in bush chip production, have also been tested at CCF. Based on the information, gathered at CCF, it has been designed a new mechanized production chain and calculated the bush chip production costs at power plant for the semi-mechanized and the mechanized production chain.

I would like to thank especially Manager Bruce Brewer and Research assistant Matti Nghikembua from CCF for their help in organising and in putting the production tests at CCF farm into practise. I also thank Mr. Ian Galloway and Mr. Carter Hartz from Consulting Services Africa (CSA) for their assistance in carrying out the tests at CCF farm and for help in gathering information for the cost analysis.

Arvo Leinonen

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- Appendix 2. Results from the production tests at CCF.
- Appendix 3. The results from the cost analysis for the CCF semi-mechanized wood chip current production chain.
- Appendix 4. The results from the cost analysis for the new mechanized production chain.

1. Introduction

Bush encroachment problem

Invader bushes, appearing in varying densities, form a potential source of energy in the commercial farming areas in the northern half of the central and eastern Namibia (Fig. 1). The dominance of these bushes has drastically reduced the productive potential of large parts of the farming area. As a potential source of energy, it represents an almost unlimited source of biomass energy. The additional benefit is that it is renewable, if used in a sustainable manner.

Various studies estimate that 10–12 million hectares, representing 12–14% of Namibia, are seriously infested by undesirable bush species (de Klerk 2004). Other studies have shown that about 10 tons per hectare of excess wood biomass is available for production. This represents over 100 million tons of raw materials available for different kinds of uses.

To solve the encroachment problem in Namibia it is needed to harvest about 1 million hectares per year assuming that the production cycle of the bushes is 10 years. If the harvested biomass amount per hectare is 10 tons (moisture content 20 w-%), the total biomass potential to be harvested per year would be 10 million tons (moisture content 20 w-%). This means about 40.8 TWh per year. The total energy consumption in Namibia was 12.6 TWh in 1999. As a conclusion Namibia would be able to produce several times that amount of electricity with the help of bush biomass that is used at the moment.

The bush encroachment can be solved only by selective cutting in these areas. On encroachment areas there can be 1000–4000 stems per hectare. The target is to take away the most aggressive bushes and leave about 300 valuable bushes at the area. To get back at least some of the production costs it is needed to find several ways to use the harvested bushes. The alternatives of using harvested bushes as biomass are production of charcoal and briquettes, pellets and chips for energy. A number of different elements have to be taken in to consideration, when assessing the feasibility of production the invader bush. Large scale production has to be planned carefully, monitored and followed up (Fig. 2).



Figure 1. The map of Namibia. The capital of the Namibia is Windhoek.



Figure 2. The left figure is from 'too thick' bush area (CCF) and the right figure presents bush area with desirable density (photos by Arvo Leinonen).

Prevailing practices to solve the problem

The prevailing practices of using harvested bushes as biomass are production of firewood, charcoal and briquettes. Namibia Institute for Social and Economic Research (NISER) found out (1992) that in rural Ovamboland 90% of inhabitants use firewood for cooking and 80% of them would have preferred to use electricity. The consumption of firewood in Ovamboland per capita was 0.567 kg per day. In Katutura living area in Windhoek most people use electricity for cooking (FAO). Mendelsohn and Obeid

estimated that the commercial production of firewood is 100 000 cubic meters and domestic, non-cash consumption is 983 000 cubic meters (Mendelsohn and El Obeid 2005).

Namibia's annual production of charcoal in recent years has varied between about 40 000 and 50 000 tons (Mendelsohn and El Obeid 2005). Charcoal is produced by a thermo-chemical process (pyrolysis) in which heat is used to drive off volatile material, and the primary products are: gas (light hydrocarbons, CO, CO₂ and water vapour), oils (heavier hydrocarbons and tars) and charcoal (Fig. 3 and 4). Charcoal burns very evenly with little smoke, and is used both for cooking in large parts of the world and as a reducing agent in the metallurgical industry.



Figure 3. The billets (left) made manually by axes are 'burned' in the kilns (right) at the stand.



Figure 4. Raw charcoal at the stand (left) before it is transported to the charcoal factory (right) where the charcoal is screened and packaged.

At present there is one company in Namibia producing bush chips, the Cheetah Conservation farm (CCF) in Otjiwarongo region (Fig. 5). CCF is producing bush chips for their briquette factory called BushBlok in Otjiwarongo town. At CCF the production chain of wood chips consists of following working phases: cutting, compiling, drying, chipping and road transport. The felling of bushes is made manually by axes. After cutting the bushes are compiled manually by pulling them by the side of the strip roads. The bushes are dried in the stockpiles for about one to two weeks. Chipping is carried out at the strip roads directly into road transport units. Feeding of the bushes into the chipper is made manually. In road transport CCF uses tractor trailers and trucks. In this study this production chain used at CCF is called CCF semi-mechanized chain.



Figure 5. Briquette production line (left) and packaging of briquettes (right) at CCF in Otjiwarongo (photos by Arvo Leinonen).

Wood biomass for power production

International Development Consultancy (IDC) has made some assessment of wood chip production and use for electricity production in Namibia in 2002 (International Development Consultancy 2002).

In this report it is stated that manual production is not an option for large scale wood chip production. IDC proposes the use of a semi-labour intensive production chain. In this chain the bushes are cut manually by chainsaws. The chipping is made by tub grinder and road transport by containers. Total wood chip production costs of this production chain are 106.8 N\$/wet ton (2.75 Euros/MWh). The share of felling and compiling costs of the total production costs is 33%, and the share of chipping and road transport 67%. The average road transport distance used in this calculation was 25 km. The high grinding productivity (100 tons per hour) in the calculation is one reason for the low wood chip production costs (International Development Consultancy 2002). The measured productivity of drum chipper in this study was only 2.5 wet tons per hour.

In the same feasibility study IDC has made calculations to produce electricity in 30 MWe power plant using wood biomass chips as a raw material. The possible locations for the power plant in the study were Otjiwarongo, Grootfontein and Tsumeb. In the study it was assumed that the current price paid for electricity bought from Nampower in this area was 0.098 N\$/kWh (0.010 Euros/kWh). Working according to the assumption that the plant will be able to produce 240 GWh, total income from electricity sales will be N\$23 448 000 (2 461 000 Euros). Power generated by bio-fuel electricity plants will be 0.42 N\$/kWh (0.044 Euros/kWh), which means that the plant(s) should be subsidised with 0.32 N\$/kWh (0.034 Euros/kWh) (International Development Consultancy 2002).

2. Contents and target of the study

The target of the study is to calculate the production costs of bush chips at the power plant or at a process plant using the semi-mechanized production technology in Namibia. The second target is to develop production technology in order to mechanize production technology and to decrease the production costs.

The wood chip production costs are used in feasibility studies, in which the technology and economy of utilization of wood chips for power generation in 5, 10 and 20 MW electric power plants, for production of pyrolysis oil, and for power generation in Van Eck coal fired power plant in Windhoek, are evaluated.

The main part of the production technology study is the field tests made at the Cheetah Conservation Farm (CCF) in Otjiwarongo region. Semi-mechanized production technology is used for wood chip production at CCF for briquette production. Information on this semi-mechanized bush biomass production technology has been gathered in the field tests. New machines for bush biomass chip production have also been tested at the CCF farm. For instance the capacities of different machines and working phases, fuel consumption etc, have been measured in the tests.

Wood chip production costs of the semi-mechanized production technology have been calculated on the basis of this field information. A new mechanized production chain, based on the tests of the new machines, has been designed. Production costs of the new production chain have also been calculated.

All the results are presented in this report.

3. The production tests at CCF farm

3.1 The realization of the production tests at CCF farm

The total land area of the Cheetah Reservation Fund (CCF) is about 36 000 hectares. CCF Farm consists of several individual farms. In CCF the production tests were made at Cheetah view -farm. The CCF farm is located about 50 km from Otjiwarongo town. CCF produces bush chips for their own briquette factory located in Otjiwarongo town. Raw material for briquette production is produced using the semi-mechanized production chain. The annual briquette output of CCF is about 6 000 tons.

The semi-mechanized production chain and new production machines were studied and tested at CCF farm in two phases in 2007. The first test period was Feb. 12th–Feb. 23rd 2007, and the second May 28th–June 8th 2007.

Main target of the first period was to follow up the used semi-mechanized production chain, but some new machines were also tested. The following machines were included in the study:

- Felling with axe, chainsaw, brush cutter and lawn mover cutter.
- Combining with manual pulling,
- Chipping with the drum chipper and
- Road transport with truck.

The new machines were followed in the second period, and the following machines were tested:

- Felling with a rotary saw in skid steer and Nisula harvester head,
- New chipper,
- Terrain transport of bushes with tractor trailer and
- Road transport with tractor trailer unit.

The different machines were made at the test plots at the same area. The size of the test plots varied between 0.25–1 ha. Total number of test plots was 14. The test plot number 5 was not in use. The test plots were named by the felling method. The test plots of the first test period (Feb. 12th–Feb 23rd 2007) were:

- Test plot 1. Manual -felling method (Crew 1),
- Test plot 2. Brush cutter -felling method,
- Test plot 3. Brush cutter -felling method,
- Test plot 4. Chainsaw -felling method,

- Test plot 6. Manual -felling method (Crew 1),
- Test plot 7. Manual -felling method (Crew 2),
- Test plot 8. Lawn mover -felling method and
- Test plot 9. Lawn mover -felling method.

The test plots of the second test period (May 28th–June 8th 2007) were:

- Test plot 10. Nisula harvester head -felling method,
- Test pot 11. Nisula harvester head -felling method,
- Test plot 12. Nisula harvester head -felling method,
- Test plot 13. Rotary saw in skid steer -felling method and
- Test plot 14. Rotary saw in skid steer -felling method.

The working time of different working phases, e.g. felling, compiling, chipping and road transport, at each test plot was measured. The amount of wood, obtained from each test plot, was measured by weighing the truck loads. The weighing of the loads was carried out at the weighing station in Otjiwarongo town. The moisture content of the chips loads were also measured at the briquette factory. Based on these figures it was possible to calculate the working productivity of different working phases in wet tons per work place hour, as well as the productivity in hectares per work place hour (ha/h). Work place time means the total working time of the machine at the site. The wet ton unit in the report is presented in 20 w-% moisture content if it is not mentioned otherwise.

The following parameters were measured in the tests:

- The number of bushes and bush species per hectare before and after cutting,
- The productivity of the machines (ha/h or ha/day and ton/h or ton/day),
- The fuel consumption of the machines (l/ton),
- The drying of bushes at the cutting site (w-%),
- The bulk density of bush chips (kg/m³),
- The solid density of bush (kg/m³) and
- The weight of bushes (kg).

The main data of the tests during Feb. 12th–Feb. 23rd 2007 are presented in App. 2. The results of the second test period are presented in the text.

3.2 Harvesting practices at the test plots

3.2.1 Guidelines for bush production

The Ministry of Agriculture, Water and Forestry (MAWF) – Directorate of Forestry (DoF) requires a permit to be obtained for all commercial-scale bush production. This is a requirement set in the relevant legislation – the Forest Act, No 12 of 2001 as amended by the Forest Amendment Act, No 13 of 2005.

The procedure is that any person wishing to harvest bushes, has to apply for permission from the Directorate of Forestry. They visit the proposed production unit and determine the quantity of each species that may be harvested, and issue a ‘Production permit’.

Some of the major charcoal retailers in the UK require that the charcoal is manufactured according to the guidelines of the Forest Stewardship Council (FSC). FSC guidelines are comprehensive and are focused on social and environmental sustainability. FSC guidelines provide a good model to be applied, or at least considered, for a future industry of bush harvesting for biomass power plants. They are based on ten ‘Principles and Criteria’, which aim to ensure that the process of harvesting the bush and the utilization of ‘forest products’ is environmentally, socially and financially sustainable and ethical.

3.2.2 Production realization at the test plots

The number of test plots of the test period in February 2007 was 8 test plots. The bush species and the number of bushes before and after the production were monitored at the test plots 1, 6 and 9 (App. 2). The test plots 1–8 were quite similar and they were classified to have an average bush density. The test plot 9 was classified to have a very high bush density (Fig. 7).

The number of bushes per hectare before and after harvesting was calculated. The main aggressive bush species at the test plots were Blackhook thorn (*Acacia mellifera*), Sickle bus (*Dichrostachys cinerea*) and Sand acacia (*Acacia fleckii*) (Fig. 6). The number of bushes at the test plot 1 was 1 144 bushes per hectare, at the test plot 6 there was 1 118 bushes per hectare, and 2027 bushes at the test plot 9.



Figure 6. Acacia mellifera -bush at CCF in February at CCF (photo by Arvo Leinonen).



Figure 7. Test plot 9 where the bush density was high (2 027 bushes per hectare) (photo by Arvo Leinonen).

At the test plot 1 in total 257 bushes per hectare was left in harvesting to grow, corresponding to 23% of the original number of growing bushes at this plot. 167 bushes was left per hectare at the plot 6, corresponding to 15% of the original number, and at the test plot 9 in total 224 bushes per hectare (11% of the original) was left growing (Fig. 8).

The harvested yield at the test plot 1 was 8 630 kg per ha, so the average weight of one harvested bush was 9.7 kg. At the test plot 6 the harvested yield was 9 530 kg, the average weight of one harvested bush being 10.0 kg. At the test plot 9 the harvested yield was 22 010 kg and the average weight of one bush 12.2 kg. Weight (kg) is presented in 20 w-% moisture content.

The average harvested yield at the test plots 1–8 was 7.0 wet tons (20 w-%) per hectare. The yield at the test plots 1–8 varied from 5.1 to 8.6 wet tons per hectare. The yield at the test plot 9 was 22.0 wet tons per hectare.

The target in moisture content of wood chips at CCF was to get as low moisture content as possible. The reason for that is the very low moisture content (about 13 w-%) of wood chips in briquette production. The target in the moisture content to produce wood chips for energy is 20 w-%. In the power plant it can be used also wet wood chips (30–35 w-%). The main reason for 20 w-% moisture content target in wood chip production for energy is the high energy content. With high energy content the transport costs are lower. Also this 20 w-% moisture content can be achieved very well in Namibian conditions.



Figure 8. Savanna landscape on test plots at CCF after production in February 2007 (photo by Arvo Leinonen).

3.3 The results of the CCF semi-mechanized production chain

3.3.1 The CCF semi-mechanized production chain

Most of the production work is done manually, and the supply chain is organized into crews of 4–8 men. These crews work between parallel strip roads that run 50 meters from each other.

In a felling or cutting crew there are four men cutting bushes manually with simple axes. Combining crews (four men in each) follow the cutting crews and drag undelimited bushes to a strip road where they are piled for drying. In a warm and dry

climate seasoning takes only 1 to 2 weeks during which the moisture content of the wood decreases from initial 35 %-w to 20 %-w, sometimes even more. A chipping crew consists of eight men with a tractor hauled bush chipper. Seasoned bushes are fed manually into the chipper at the strip road side and are chipped directly into a trailer which is afterwards towed to the power plant by a truck or a tractor.

The wet ton unit is presented in 20 w-% moisture content. The productivity unit is presented as wet ton or ha per work place time (hour or day). One man-day or machine-day covers 8 hours. Normally the working day starts at 8 o'clock and ends at 17 o'clock. In a workday there is a one-hour lunch brake.

3.3.2 Making the strip roads

Strip roads have to be made before it is possible to start the production. The strip roads (Fig. 9) are designed for the vehicles used in the production. The strip roads are made by bulldozers by pushing the vegetation aside from strip roads (Fig. 10). The width of the strip roads is 3 m. The strip roads are parallel with each other and the distance between the track roads is 50 m. The maximum pulling distance of the bushes beside the strip road in this system is 25 m. Earlier the strip roads were made so that the strip roads formed a net structure where the distance of the roads were 100 m. The size of each plot was 1 ha. The main problem in this system is that the maximum pulling distance is about 50 m to strip road which is too high.



Figure 9. The strip road at felling stand. The distance of the strip road is 50 m (photo by Arvo Leinonen).



Figure 10. The bulldozer by which the strip roads are made (photo by Arvo Leinonen).

3.3.3 Felling

In the CCF semi-mechanized production chain the felling is carried out manually by axes (Fig. 11). Manual felling was tested at test plots 1, 6 and 7 at CCF. One felling crew consists of four men (Fig. 12). At present two felling crews are working at the CCF farm. In the tests the average productivity of the felling crew 1 was 1.7 wet tons (20 w-%) per day when the density of bushes is average – 7.0 wet tons per ha. With the crew 2 the productivity was only 0.82 wet tons per man-day at the average bush density. The productivity (crew 1) of the manual felling was slightly higher (1.9 wet tons per man-day) when the bush density was high – 22.0 wet tons per ha. The average productivity of the felling crew 1 was 0.19 ha/man-day on the average density production plot and 0.10 ha per man-day at the production plot classified thick in (App. 2).

The manual felling productivity, used in the cost calculation, was 1.7 wet tons per man-day in 20 w-% moisture content.



Figure 11. Felling of the bushes is made manually by axes (photo by Arvo Leinonen).



Figure 12. The felling crew consists of four men (photo by Arvo Leinonen).

3.3.4 Compiling

In the semi-mechanized production method at CCF the bushes are compiled manually after cutting by pulling them into heaps by the side of the strip roads (Fig. 13). In the compiling tests the distance between strip roads was 100 m. Sometimes the bushes were compiled inside a 1 ha production plot. By this way the pulling distance is not too long. The compiling crew is normally the same crew that makes also the felling. So the compiling crew consists of four men. In the tests the compiling productivity was measured only at two plots (1 and 4). In the tests the compiling productivity varied between 1.6 and 2.3 wet tons (20 w-%) per ha. The average compiling productivity was 2.0 wet tons per man-day and 0.27 ha per man-day (App. 3).

The compiling productivity, used in the cost calculation, was 2.0 wet tons per man-day in 20 w-% moisture content.



Figure 13. Compiling the bushes beside the strip road is made manually by pulling (photo by Arvo Leinonen).

3.4 Drying

The bushes are normally dried in bush stacks by the side of the strip road before chipping (Fig. 14). Drying of the bushes in the stacks was monitored in the study. Monitoring was carried out during the tests in February 2007. The measured initial moisture content of bushes (*Acacia mellifera*) in the tests was 35.2% (App. 2). The total truck loads of bush chips delivered to briquette factory from the test plots was 17. The measured average moisture content in these loads was 15.2 w-%. The drying time of the bush chips in the stacks in these loads varied between 8–24 days (App 2). The moisture contents of the loads and the corresponding drying time of the loads at the field are presented in the Figure 15. The figure shows that in the summer conditions of Namibia the target moisture content (20 w-%) can be reached in 8–9 days. It can also be seen that the 15 w-% moisture content can be reached if the drying time is about 14 days.



Figure 14. Bush heaps beside the strip road (photo by Arvo Leinonen).

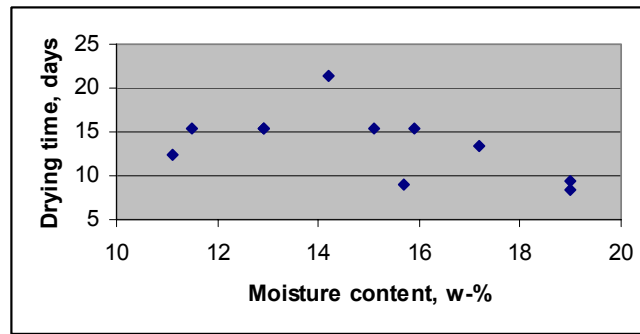


Figure 15. The drying of bushes in the heaps at different test plots at CCF.

3.4.1 Chipping

In the semi-mechanized production chain bushes are fed manually into the chipper (Fig. 11). A chipping crew consists of eight men. In the tests made in February the chipper was connected to a truck trailer (Fig. 16). At the CCF the truck trailer was not used anymore in June. At that time the chipper was connected to a tractor trailer (Fig. 17) pulled by a tractor. During the chipping the chipper blows the chips directly into the trailer.

CCF has two drum chippers. The older is Morbark Tornado Model 13 – a drum style chipper. This chipper was used in chipping tests in February 2007. The new drum chipper of CCF is Morbark Tornado model 15 – a drum style chipper. This chipper was used in the tests in June 2007. These chippers are equivalent to each other. The main technical parameters of the chippers are the same.

The main technical parameters of Tornado model 15 -drum chipper are:

- Productivity: 15 tons per hour,
- Chipping productivity: up to 380 mm,
- Equipped with own diesel engine: 59–96 kW,
- Weight: 3 175 kg,
- Infeed throat opening: 51 cm x 38 cm,
- Drum diameter: 51 cm and
- Drum width: 58 cm.

The measured productivity of the drum chipper (Model 13) at CCF was 20.14 wet tons per machine-day in 20 w-% moisture content (App. 2). The fuel consumption, measured in June 2007, was 4.4 l per wet ton. The reason for the low chipping productivity is the low manual feeding of the bushes into the chipper.

The chipper productivity, used in the cost calculations, was 20.14 wet tons per machine-day (8 h) in 20 w-% moisture content.



Figure 16. Bush chipping with Morbark Tornado Model 13 drum chipper at CCF in February 2007 (photo by Arvo Leinonen).



Figure 17. The bush chipping with Morbark Tornado Model 13 drum chipper at CCF in June 2007 (photo by Arvo Leinonen).

3.4.2 Road transport

The wood chips were fed directly into the truck trailer by the chipper. The loads were weighed at the weighing station in Otjiwarongo town, near the briquette factory (Fig. 18). In February, a truck trailer was used to transport the bush chips to Otjiwarongo. In June 2007 tractor trailers were used for road transport (Fig. 19). A tractor trailer unit consists of a tractor and two trailers. The main reason for the change in the road

transport system was to decrease the fuel costs in transport. Unloading of the truck trailer was made manually (Fig. 20). In tractor trailer the unloading is made by tipping unit (Fig. 21).

The volume of the truck trailer is 17.5 m^3 , the length of it 4.5 m, the width 2.3 m and the height 1.7 m. The average weight of truck trailer load was 4.1 wet ton. The average density of bush chips in the truck trailer was $199.8 \text{ kg/loose-m}^3$. The road transport distance to Otjiwarongo is 50 km. The average total transport time, including the chipping time, driving time to factory, time used for unloading and the driving time back to the CCF was 4.8 h. The measured average productivity at CCF was 7.4 wet tons (20 w-%) per machine-day. The measured average velocity of the truck trailer unit was 56.4 km/h on the road.

The volume of the tractor trailer is 15.0 m^3 , the length 5.0 m, the width 2.0 m and the height 1.5 m. The weight of tractor trailer load (2 trailers) was 5.1 wet tons (10.55 w-%) corresponding to 5.7 wet tons. The road transport distance to Otjiwarongo is 50 km. The average total transport time including the driving time to the factory, unloading and driving back to CCF was 4.7 h. The measured average productivity of tractor trailer unit was 9.7 wet tons per machine-day in 20 w-% moisture content. The consumption of the diesel oil in tractor trailer transport was 9.8 l per wet ton. The productivity of the tractor trailer road transport unit, used in the calculations was 10.5 wet tons per machine-day (8 h). This new productivity figure of road transport was obtained from later measurements made by Bruce Brewer from CCF.



Figure 18. Weighing the truck trailer at weighing station in Otjiwarongo in February 2007.



Figure 19. Unloading the truck trailer at briquette factory in Otjiwarongo (photo by Arvo Leinonen).



Figure 20. Tractor unit for bush chips road transport at CCF in June 2007 (photo by Arvo Leinonen).



Figure 21. Tipping of the tractor trailer at briquette factory in Otjiwarongo (photo by Arvo Leinonen).

3.5 Test results of the new machines

3.5.1 Brush cutter

The brush cutter is used in Finland for thinning of the sapling stands. The diameter of the saplings is under 5 cm. The brush cutter is used by an operator wearing the harness. The brush cutter is connected to the harness, which helps to operate the brush cutter. The rotating cutting blade is at the top of the rod in the brush cutter (Fig. 22 and 23). The rotating speed is controlled by the operator with the hand. The brush cutter for the tests in the tests was bought from Namibia.

The felling with brush cutter was tested at the test plots 2 and 3. The average felling productivity of the brush cutter was 0.41 ha or 2.5 wet tons (20 w-%) per man-day. In manual felling the productivity was 0.19 ha or 1.7 wet tons per man-day, so the productivity of the brush cutter is about 50 % higher than in manual felling when comparing the productivity in tons.

The operator liked to work with the brush cutter. The working position of the operator is good because he can keep his back straight. The power of the engine of the brush cutter, used in the tests, was a little bit too small. Because of the wide top of the bush it was difficult for the operator to go under the bush to fell the tree. This problem can, however, be solved by working as a team of two men. The assistant of the operator push the top of the bush forward which helps the cutter operator to fell the bush. The productivity of the brush cutter, when using a team of two men, is not good.

The brush cutter is not very good in large-scale wood chip production because of small productivity. But for small-scale bush felling like charcoal production it is very suitable.

The brush cutter, used in the felling tests, was STIHL FS550. The main parameters of the brush cutter are:

- Two stroke engine,
- Cylinder productivity 55 cm³
- Engine power 2.8 kW,
- Weight 10 kg and
- Fuel tank volume 0.75 l.



Figure 22. Felling bushes by brush cutter in February 2007 at CCF (photo by Arvo Leinonen).



Figure 23. Brush cutter STIHL FS550 at CCF (photo by Arvo Leinonen).

3.5.2 Chain saw

In Finland the chain saw is used for manual production of timber. The chain saw is operated by an operator wearing protective clothing. The cutting device of the chainsaw is a rotating saw equipped with cutting blades (Fig. 24–25). The operator controls the rotating speed of the chains by hand. The brush cutter for the tests in the project was bought from Namibia.

The felling tests were carried out at the test plot 4. The felling productivity of the chainsaw was 0.52 ha or 3.1 wet tons (20 w-%) per man-day. The productivity was

about 80% higher than in manual felling (0.19 ha or 1.7 wet tons per man-day) or 24% higher than in brush cutter felling (0.41 ha or 2.5 wet tons per man-day) when comparing the productivity in tons.

The operator did not like to work with the chainsaw. The working position of the operator is not good because he cannot keep the back straight. The engine of the brush cutter was big enough. Because of the wide top of the bush it was difficult for the operator to go under the bush to fell the tree. Stretching of the chain caused also trouble in using of the chainsaw. The chain stretched in one day so much that it could not be used anymore. The reasons for the stretching of the chain in Namibia are the hot weather and the sand.

The chainsaw used in the felling tests was STIHL MS 380. The main parameters of the chain saw are:

- Two stroke engine,
- Engine volume 72.2 m³
- Engine power is 3.9 kW,
- Weight 6.6 kg,
- Fuel tank volume 0.68 l,
- Chain oil tank volume 0.36 l and
- Price 3900 N\$ – 409 Euros.



Figure 24. Felling bushes by chainsaw at CCF in February 2007 (photo by Arvo Leinonen).



Figure 25. Sharpening the chainsaw at CCF.

3.5.3 Lawn mower type cutter

A lawn mover type cutter (Fig. 26) was also tested in the study for felling the bushes. The cutter was old and it was made for CCF some years ago. The cutter looks like a lawn mover from which the name for the cutter was derived. The cutter's frame is made of steel. There are two wheels under the frame. The cutter is moved on the wheels. The rotating cutting blade is installed ahead of the frame. The cutter was operated by one man pushing the cutting blade against the bush. Two men form a cutting crew – one operates the cutter and the second pushes the bushes away from the operator. By this way it was easy to cut the bushes near the ground. The lawn mover type cutter in the tests was owned by CCF.

The cutter is equipped with a HONDA GXV160 engine, the power of which is 4 kW. The diameter of the rotating cutting blade is 340 mm.

The lawn mover type cutter was tested at the test plot number 8. The productivity of the cutter was 0.32 ha or 2.3 wet tons (20 w-%) per man-day. The productivity is calculated for a crew consisting of two men. The productivity of the lawn mover type felling was higher than that of manual felling (0.19 ha or 1.7 tons per man-day) but it was lower than in brush cutter felling (0.41 ha or 2.5 wet tons per man-day) or in felling by chainsaw (0.52 ha or 3.1 wet tons per man-day).



Figure 26. Lawn mower type cutter (photo by Arvo Leinonen).

3.5.4 Nisula harvester head cutter

In Finland the Nisula 150E harvester head is used for production energy wood. The Nisula harvester head is a very simple machine, designed especially for energy wood production from thinnings. When using the Nisula harvester head all trees from thinnings go for energy purposes. The harvester head has no delimiting device. Nisula harvester head was brought from Finland for the tests.

Nisula harvester head was operated by a Terex 860SX backhoe loader. Backhoe loader was rented from Windhoek. Harvester head was mounted to the boom at the back side of the loader (Fig. 27). An adapter was used for mounting the harvester on the boom. A rotator was also used to rotate the harvester head on the boom. The output power of the Terex backhoe loader is 74.5 kW. The main tools of Nisula harvester head include pressing arms and a cutting blade. When a tree is between the arms in the bucket of the head the arms are closed hydraulically, and they press the bush against cutting blade and which cuts the bush. After cutting the cutting head goes to horizontal position and the bush falls down. After cutting the bushes are transferred by the cutting head by the side of the strip road, after which the grab of the head is released.

Nisula harvester head was tested during a four day test period between May 29th and June 1st 2007 at the CCF farm (Fig. 28 and 29). Total area of about 1 ha was harvested with Nisula harvester head (test plots number 10–12). The Nisula harvester head was a totally new machine for the operator, because of which it took some time for the driver to learn how to use it. The area of the test plot 12 was 0.26 ha. It took 7 hours to harvest this plot. The productivity of Nisula harvester head was only about 0.30 ha per machine-day, which is less than with the brush cutter or the chainsaw.

The productivity obtained in the study does not give the real image of the productivity of Nisula harvester head. By small changes in basic machine the productivity of Nisula harvester head would be much higher. By using a farm tractor, equipped with the 7.5 m boom, the productivity would be significantly higher. With this combination it is possible to work all the time on a strip road. It is not necessary to go inside the felling area between the strip roads. The distance between the strip roads can be 15 m. The cutting power of the cutter should also be higher. With tested cutter the power was insufficient for cutting one bush with one grip when one bush consisted of several stems.

The main parameters of Nisula 150E harvester head are:

- The maximum cutting diameter 150 mm,
- Weight 108 kg,
- Opening 380 mm and
- Maximum hydraulic pressure about 180 bar.



Figure 27. Nisula harvester head mounted on the boom in Terex backhoe loader. The pressing arms and cutting blade can be seen in the picture (photo by Arvo Leinonen).



Figure 28. Nisula harvester head at work (photo by Arvo Leinonen).



Figure 29. Nisula harvester head at work (photo by Arvo Leinonen).

3.5.5 Rotary saw in the skid steer

Use of skid steer for felling the bushes was also studied in the project (Fig. 30). The skid steer was equipped with a rotary saw located in front of the skid steer. The skid steer, which looks like a small tractor, used in the study, was John Deere 332. The engine power in the skid steer is 85 hp. The skid steer in the study was equipped with puncture-proof tires. The diameter of the rotary saw is 100 cm (Fig. 31). The skid steer with rotary saw is owned by CCF.

The productivity tests of skid steer were made in June 5th – 6th 2007. The driver had not done the felling work before. He had operated a skid steer at the briquette factory. In the

first productivity test the working area was 0.25 ha (test plot number 13) and in the second test 0.5 ha (test plot number 14). The productivity in the first test was 2.64 ha per machine-hour and in the second test it was 2.32 ha per machine-hour. The average productivity is 2.48 ha per machine-hour and it is good. The productivity of manual cutting was only 0.2 ha per man-day. The use of skid steer in felling has many advantages. It is small, fast and cheap, and it can be equipped with puncture-proof tires.

It is also possible to make strip roads with a skid steer cutter. With a skid steer, equipped with a suitable head, it is also possible to compile the bushes at the side of a strip road.



Figure 30. Skid steer with rotary saw at CCF in June 2007 (photo by Arvo Leinonen).



Figure 31. Rotary saw in the skid steer (photo by Arvo Leinonen).

3.5.6 Bush transport by tractor trailer to the road side

In Finland the logging residues for fuel are transferred by timber forwarders into stockpiles located at the roadside. Logging residues are dried in the stockpiles. The productivity of the chipper is also higher because the material is in one place and there is no need to change the chipper and trailer all the time.

A research on transferring the bushes from the cutting plots to the roadside storage was carried out at the CCF during the project in June 2007. A tractor trailer was used for transferring the material to road side (Fig. 32). Loading of bushes into the tractor trailer was made by Nisula harvester head. The head was changed to operate as a loader. This operation is very easy because all you need to do is to open and tighten only two bolts. In loading the arms of the head are all the time in horizontal position (Fig. 33). Unloading of the bushes from the tractor trailer is also made by Nisula harvester head (Fig. 34 and 35).

The loads in the tractor trailer in the tests were very low. The reason for this is that the top of the bushes is very large, so there is space for only some bushes in the trailer. Because of this it seems that it is not profitable to transfer the bushes from the cutting plot to the roadside storage and to chip the material there.



Figure 32. The bushes are loaded to the trailer by Nisula harvester head (photo by Arvo Leinonen).



Figure 33. Terrain transport of bushes by tractor trailer (photo by Arvo Leinonen).



Figure 34. Unloading the bushes from the tractor trailer beside the road (photo by Arvo Leinonen).



Figure 35. The storage of bushes beside the road (photo by Arvo Leinonen).

3.5.7 Feeding the chipper by Nisula harvester head

In Finland a chipper is usually equipped with a loader, which is used for feeding the material into the chipper. In Finland the average productivity of the tractor chipper is about 50 loose-m³ of chips per hour. At the CCF the productivity was only about 12.5 loose-m³ of wood chips per hour. The main reason for the low chipping productivity is the slow feeding of the bushes into the chipper. The feeding of the bushes into the chipper can be intensified by doing it with a loader.

In the feeding tests at the CCF the moisture content of the material was too high (Fig. 36). Because of this the productivity of the chipper was low. However, the results show that the bush material can be fed into the chipper by a loader. The use of a loader in the chipping increases the productivity.



Figure 36. Feeding of the bushes to the chipper by Nisula harvester head (photo by Arvo Leinonen).

3.6 Bush chip quality

The variables, measured in the production tests in February 2007 included:

- The moisture content of bushes,
- Moisture content of wood chips,
- Loose density of wood chips,
- Grain size of wood chips and
- Solid density.

The initial moisture content of bushes in the tests was 35.2% (*Acacia mellifera*).

The measured average moisture content of bush chips harvested from the test plots was 15.2 w-% at the briquette factory in February 2007 (17 loads). In these loads the drying time of the bush chips at the stand in the heaps varied between 8–24 days.

The loose density of wood chips was measured with a box, the dimensions of which were 495 mm (width), 545 mm (length) and 540 mm (height) (Fig. 37). The density was measured 8 times. The moisture content in the measurements varied between 7.91 w-% and 35.2 w-%. The average loose density of wood chips was 135.5 kg per m³ in zero moisture content and 169.4 kg per m³ in 20 w-% moisture content.

The loose density of wood chips in the truck trailer was also measured. The density in the truck trailer was measured two times. The moisture contents in these measurements were 18.3–19.3 w-%. The measured average density of bush chips in the truck trailer was 199.8 kg/m³ in 20 w-% moisture content and 159.8 kg/m³ in zero moisture content.

The share of chips with particle size over 50 mm of all the chips was also measured (Table 1). In Finland the particle size of wood chips used in Finland in power plants should be under 50 mm. The share of chips, having particle size over 50 mm, was very high, 22–37%. The main reason for this was the worn cutting blades of the chipper. They should be sharpened to make good quality chips.

The solid density from the bush (*Acacia mellifera*) was measured. The weight of wood pieces was measured by a hanging scale. The volume of the same wood pieces was measured by measuring the volume of the water, replaced by the wood pieces. The total volume of the three wood pieces was 4.3 liters and the weight 4.8 kg. Based on these figures the solid density of bush was 1.1 kg/dm³. The moisture content of the measured bush was 25.7 w-%.

As an energy density of wood chips is used 4.08 MWh/ton in 20 w-% moisture content.

Table 1. Particle size measurements of wood chips (weight basis).

Experiment number	Moisture content w-%	Particle size < 50 mm	Particle size > 50 mm
1	6.9	78 %	22 %
2	19.0	71 %	29 %
3	19.0	63 %	37 %



Figure 37. Measuring the wood chip loose density at CCF briquette factory in Otjiwarongo (photo by Arvo Leinonen).

3.7 Conclusions from the production tests

The measured productivities of different tested machines in the production tests are presented in the Table 2.

The conclusions from the production study were:

- The CCF semi-mechanized production chain works well,
- Chipping productivity in CCF semi-mechanized production chain is low,
 - The productivity can be increased by using a loader for the feeding,
- The road transport productivity in the CCF semi-mechanized chain is low,
- Felling and compiling working phases in CCF semi-mechanized production chain can be mechanized,
- All the new tested new machines are suitable for felling of bushes,
 - The most effective machine in felling was a rotary saw in a skid steer,
- The bushes dry in the stockpiles beside the road very rapidly
 - It takes only two weeks to dry under 20 w-% moisture content and,
- The share of long particles in the wood chips is too high
 - This is possible to fix by keeping the cutting blades sharp.

Table 2. The productivity of the working machines in the production tests. The productivity is presented as wet ton per man-day or machine-day. Wet ton is presented in 20 w-% moisture content.

Machine	Productivity ha/man-day or ha/machine-day	Productivity wet tons/man-day or wet tons/machine-day
Felling		
- Manual felling - 4 men	0.19	1.7
- Felling with brush cutter	0.41	2.5
- Felling with chainsaw	0.52	3.1
- Felling with lawn mover type cutter	0.32	2.3
- Felling with Nisula harvester head	0.30	
- Felling with Skid steer rotary saw	2.48	
Compiling - 4 men	0.27	2.0
Chipping		
- Chipper + 8 men		20.14
Road transport - 50 km		
- Truck trailer		7.6
- Tractor trailers (2)		10.5

4. Cost analysis of the wood chip production

4.1 The CCF semi-mechanized production chain

4.1.1 Basic information

The average density of the harvesting stand in the calculation is about 1 000 bushes per hectare of which 80 % (800 bushes) are cut while production. Based on the study the average yield of wood fuel is 7.0 wet tons per hectare.

The wood chip production costs are calculated with the cost calculation model of VTT. The total annual costs for each working phase in the production chain are calculated first. When the annual total costs and number of work place hour are known, it is possible to calculate the cost of work place hour for each working phase. Dividing the hourly cost by productivity per work place hour we get the costs of wood chips per wet ton and per MWh. The moisture content of wood chips in the calculation was 20 w-%.

In the calculation it has been used also the parameter operating hour. Operating hour means the time while machine is in operation. The ratio of operating time and work place time is called utilization degree. Work place time means the total working time of the machine at the site. Utilization rate is defined for each working phase based on the Finnish experience. The use of operating time is better than the use of work place time to calculate the variable costs.

The costs in the analysis are divided into fixed costs, overhead costs, salary and variable costs. Fixed costs include the investment costs of the machines. Capital costs for felling and compiling are zero. Overhead costs contain e.g. the insurance costs, moving cost of the machine at production sites and the administration costs. The administration costs include e.g. the organization of the repairing for the machine. Wages include the worker's salaries. Variable costs consist of fuel, oil and maintenance costs. VAT (value added tax) is not included in the price of the investments.

The wood chip production costs are calculated for the prevailing production chain, consisting of:

- A manual cutting crew – four men,
- A manual compiling crew – four men,
- A chipping crew – chipper, tractor and nine men and
- A road transport crew – tractor, four trailers and one man.

The crews work between parallel strip roads located 50 meters from each other. Felling or cutting crews consist of four men cutting the bushes manually with simple axes.

Compiling crews (four men in each) follow cutting crews and drag undelimited bushes to strip roads, where they are piled for drying. In a warm and dry climate drying takes only 1 to 2 weeks, during which the moisture content of the wood decreases from initial 35 %-w to 20 %-w, sometimes even more.

A chipping crew consists of nine men with a chipper and a tractor. A tractor is needed to move the chipper from place to place. Eight men transfer bushes near the chipper and feed the bushes into the chipper and one man drives the tractor. The chipper used in the cost analysis is a Morbark Tornado 15 drum chipper.

Wood chips are hauled to the plant by the same trailers they are chipped into, two trailers articulated. Because chipping and road transport take place at the same time, two sets of trailers are needed. While two are being towed, two others stay on the strip road for chipping. In the same way, two tractors are needed, one for road transport and one for moving the chipper and trailers from pile to pile. In the calculation of the production costs of wood chips the transport crew consists of one man with a tractor and two trailers, while the other tractor and its driver are included in the chipping crew.

The road transport costs with different transport distances are calculated from the measured productivity (10.5 wet tons (20 w-%) per machine-day) of the tractor trailer - transport unit with the 50 km road transport distance (one-way). The average total transport time was 4.7 h including the driving time to the factory, unloading and driving back to CCF in 50 km road transport distance. The calculated productivity of road transport is 26.2 wet tons per day (8 h) with 20 km average transport distance (one-way), 17.4 wet tons per day with 30 km average road transport distance and 13.1 wet ton per day with 40 km average road transport distance. The share of unloading time from the total transport time is small.

The demand for the wood chips in different power plants is presented in the Table 4. The annual demand of wood chips is 32 000 wet tons (20 w-%) for a 5 MWe power plant, 60 000 wet tons for a 10 MWe power plant and 118 000 wet tons for a 20 MWe power plant. The annual total production area is 4 600 ha in the case of a 5 MW_e power plant, 8 600 ha for a 10 MW_e and 16 900 ha for 20 MW_e power plant if the harvesting yield is 7.0 wet tons per ha in 20 w-% moisture. In the calculation it is assumed that the yield is 7.0 wet ton per hectare. This is the yield achieved at CCF in the tests.

The main values used in the cost calculation are presented in the table 3. More precise information from the cost analysis is presented in the Appendix 3. The cost analysis for

chipping and road transport working phases is presented. The felling and compiling costs consists only of the worker's salaries. That is why they are not presented in the Appendix 3. The productivity of each working phase is got from the tests at CCF (chapter 3).

Table 3. Basic parameters in the cost calculation. The productivity unit is presented as wet ton per man-day or machine-day. The wet ton and MWh units are presented in 20 w-% moisture content.

Variable	Value	Additional information
Calorific value of wood	4.08 MWh/ton	20 % moisture content
Average salary of the workers	1 170 N\$ (94)	30 % of overhead included
Average salary for the supervisors	1 300 N\$	30 % overhead included
Utilization rate of the machines		
– Operating time/total site time	0.815 for chipper	0.823 for tractor trailer unit
Interest rate	8 %	
Working time	11 m/a, 5 d/w, 8 h/d, 1915h/a	
Fuel price	6.14 N\$/l for road transport	5.64 N\$ for chipper
Price of chipper	460 000 N\$ (48 300)	Morbark Tornado 15 brush chipper
Price of tractor for chipping unit	225 200 N\$ (23 600)	Massey Ferguson 80 hp
Price of tractor for road transport	294 800 N\$ (30 900)	Massey Ferguson 100 hp
Price of trailer	164 000 N\$ (17 200)	two trailer unit
Productivity of felling	1.7 wet ton/man-day/man	4 men in crew
Productivity of compiling	2.0 wet ton/man-day/man	4 men in crew
Productivity of chipping	20.14 wet ton/machine-day/crew	8 men in crew + 1 driver
Productivity of road transport (50 km)	10.5 wet ton/machine-day/crew	1 men in crew

Table 4. The wood chip demand for different power plant size. The wet ton and MWh units are presented in 20 w-% moisture content.

Power plant size	5 MWe	10 MWe	20 MWe
Wood chip demand per year, wet ton	32 000	60 000	118 000
Wood chip demand per year, MWh	131 000	243 000	481 000
Total production area in one year, ha	4 600	8 600	16 900
Total production area in 10 years' rotation, ha	46 000	86 000	169 000

4.1.2 The production costs

All wood chip production costs are presented in the Table 5. The production costs include also the organization costs. These costs consist of the management of the production groups. It is assumed that 10 men are needed for organizing the production of wood chips for 5 MWe power plant, 20 men for 10 MWe power plant and 30 men for 20 MW power plant. No profit is calculated for the production business.

The total wood chip production costs with the CCF semi-mechanized production chain are 185.6–226.8 N\$/wet ton (4.8–5.8 Euros/MWh) when the average road transport distance is 20–50 km. The maximum road transport distance is 30–60 km.

We can assume that the average road transport distance in 5 MWe power plant would be 30 km, in 10 MWe it would be 40 km and in 20 MWe power plant it would be 50 km. When using these road transport distances the production costs for 5 MWe power plant are 199.4 N\$/ton (5.1 Euros/MWh), for 10 MWe power plant 213.0 N\$/wet tons (5.5 Euros/MWh) and for 20 MWe 226.8 N\$/wet ton (5.8 Euros/MWh).

The main costs are the chipping costs. The share of the chipping cost of the total costs is 39–45% depending on the road transport distance (average road transport distance 30–50 km). The road transport costs are also high, 21–30% of the total costs (average road transport distance 30–50 km).

The labor costs in the different working phases are presented in the Table 6. The costs in the felling and compiling phases consist totally of labor costs. In chipping the labor costs are about 29% of the total chipping costs. In road transport the labor costs are about 8% of the total road transport costs. The rest of the costs consist mainly of the machine and material costs.

Table 5. The total wood chip production costs with the current production chain using different road transport distance (one-way). The wet ton and MWh units are presented in 20 w-% moisture content.

Working phase	N\$/wet ton	Euros/wet ton	N\$/MWh	Euros/MWh
Felling	34.49	3.62	8.46	0.89
Compiling	29.33	3.08	7.19	0.75
Chipping	89.49	9.39	21.93	2.30
Road transport				
– 20 km	27.40	2.88	6.71	0.71
– 30 km	41.22	4.33	10.10	1.06
– 40 km	54.80	5.75	13.43	1.40
– 50 km	68.61	7.20	16.82	1.76
Organization	4.88	0.51	1.20	0.13
All together				
– 20 km	185.59	19.48	45.49	4.78
– 30 km	199.41	20.93	48.88	5.13
– 40 km	212.99	22.35	52.21	5.47
– 50 km	226.80	23.80	55.60	5.83

Table 6. The labour costs in the wood chip production chain. The wet ton and MWh units are presented in 20 w-% moisture content.

Working phase	Number of men in one crew	Salary including 30 % overhead	Total crew salary	Productivity	Labour costs	Labour costs
		N\$/man month	N\$/a	wet ton/a/crew	N\$/wet ton	Euros/MWh
Felling	4	1 170	56 160	1 628	34.49	0.89
Compiling	4	1 170	56 160	1 915	29.33	0.75
Chipping	9	1 170	126 360	4 820	26.22	0.67
Road transport						
– 20 km	1	1 170	14 040	6300	2.22	0.06
– 30 km	1	1 170	14 040	4200	3.34	0.09
– 40 km	1	1 170	14 040	3150	4.46	0.11
– 50 km	1	1 170	14 040	2500	5.62	0.14
Organization	10	1 300	156 000	32 000	4.88	0.13

4.1.3 The manpower and investments needed for production of wood chips for each power plants

The manpower needed in the production of wood chips for each power plant is presented in the Table 7. The number of machines for production wood chips for each power plant size is presented in the Table 8. For one road transport unit it is calculated to have four trailers. Two trailers in the road transport unit are reserved for chipping and two for transport. By this way we guarantee that the chipping crew do not need to wait

trailers for chipping. Table 9 presents the investments (Euros) for the production machinery for each power plant size. The manpower needed in the procurement chain of wood chips is presented in the following table.

The wood chip production chain in the calculation was the following:

- Felling crew – 4 men
- Compiling crew – 4 men
- Chipping crew – 9 men + 1 chipper + 1 tractor (80 hp)
- Road transport crew – 1 man + 1 tractor (100 hp) + 4 trailers (15 m³).

Production of wood chips with the CCF semi-mechanized production chain requires 232 men all year round for a 5 MWe plant, 432 men for a 10 MWe plant and 853 men for a 20 MWe power plant. It is very difficult to control a high number of workers in wood chip production.

The investments for the machines in the CCF semi-mechanized production chain to produce the demand of wood chips for 5 MWe power plant is 9.2 mill. N\$ (1.0 mill. Euro), 20.7 mill. N\$ (2.2 mill. Euros) for 10 MWe power plant and 47.0 mill. N\$ (4.9 mill. Euros) for 20 MWe.

The investments can be decreased by optimizing the working hours in a year. In the calculation it has been assumed that the work is done in one shift.

Table 7. The manpower needed in the CCF semi-mechanized wood chip production chain. Fuel demand in the 5 MWe power plant is 32 000 wet tons/a, in 10 MWe it is 60 000 wet tons/a and in 20 MWe power plant it is 118 000 wet tons/a. The wet ton unit is presented in 20 w-% moisture content.

Working phase	Productivity wet ton/a/crew	5 MWe	10 MWe	20 MWe
Felling	1 628	20 crews - 80 men	37 crews - 148 men	73 crews - 292 men
Compiling	1 915	17 crews - 72 men	32 crews - 128 men	62 crews - 248 men
Chipping	4 820	7 crews - 63 men	13 crews - 117 men	25 crews - 225 men
Road transport				
– 20 km	6 300			
– 30 km	4 200	7 crews - 7 men		
– 40 km	3 150		19 crews - 19 men	
– 50 km	2 500			48 crews - 48 men
Organization		10 men	20 men	40 men
Altogether		51 crews - 232 men	101 crews - 432 men	208 crews - 853 men

Table 8. The number of different machines for wood chip production in each power plant size.

Plant size	Tractor for chipping - 80 hp	Tractor for road transport – 100 hp	Chipper	Trailer
5 MWe	7	7	7	28
10 MWe	13	19	13	76
20 MWe	25	48	25	192

Table 9. The investments for the wood chip production machinery.

Working phase	5 MWe - Investment		10 MWe – Investment		20 MW – Investment	
	N\$	Euros	N\$	Euros	N\$	Euros
Felling						
Compiling						
Chipping	4 797 000	504 000	8 908 000	935 000	17 130 000	1 798 000
Road transport	4 360 000	457 000	11 834 000	1 241 000	29 895 000	3 135 000
All together	9 157 000	961 000	20 742 000	2 176 000	47 025 000	4 933 000

4.1.4 The harvesting area needed for production of wood chips for each power plants

The annual demand of wood chips is 32 000 wet tons (20 w-%) for a 5 MWe power plant, 60 000 wet tons for a 10 MWe power plant and 118 000 wet tons for a 20 MWe power plant (table 4).

The annual total production area is 4 600 ha in the case of a 5 MW_e power plant, 8 600 ha for a 10 MW_e and 16 900 ha for 20 MW_e power plant if the harvesting yield is 7.0 wet tons per ha in 20 w-% moisture content. If we assume that we are able to make selective cutting in the same area after ten years. The total production area in 10 years' bush rotation is 46 000 ha in 5 MW_e power plant, 86 000 ha in 10 MW_e and 169 000 ha in 20 MW_e power plant (table 4).

We have assumed that the radius of the harvesting area is 40 km in 5 MWe power plant, 50 km in 10 MWe power plant and 60 km in 20 MWe power plant. Correspondingly the total bushland area within these radii is 502 000 ha, 785 000 ha and 1 130 000 ha. Also we have assumed that the average road transport distance in 5 MWe power plant would be 30 km, in 10 MWe it would be 40 km and in 20 MWe power plant it would be 50 km.

The annual harvesting area (4 600 ha) in 5 MWe power plant is only about 1.0% from the total planned harvesting area (502 000 ha). In 20 MWe power plant the annual harvesting area (16 900 ha) is 1.5 % from the total planned harvesting area (1 130 000

ha). After ten years we have cut 10–15% from the total planned harvesting area depending on the power plant size. If we assume that the lifetime of the power plant is 20 years. In 20 years we have cut 20–30% of the total planned harvesting area. This means that we have a large wood chip production potential in the area.

4.2 The new mechanized production chain

4.2.1 The structure of the new mechanized production chain

A new wood chip production chain has been developed on the basis of the results of the study. The working phases in this chain are:

- Felling with skid steer with rotary saw (Fig. 38),
- Compiling with skid steer with grapple fork (Fig. 39),
- Chipping with the chipper with a loader + tractor (Fig. 40) and
- Road transport with tractor trailer (Fig. 41).

Only the skid steer with a rotary saw was used in the tests and the productivity for this machine is measured. All other machines are new and not tested in Namibian conditions. That is why the productivities of these machines are partly evaluated.

In the cost analysis the skid steer in the felling phase is John Deere 332 and the rotary saw is made by Grace Manufacturing in the USA. This equipment is the same as tested at the CCF farm (Fig. 32). The productivity of the skid steer in felling was 0.31 ha per h. This means that the productivity is 16.8 wet tons (20 w-%) per machine-day assuming that the bush density to be 7.0 wet tons per ha. The purchase price for skid steer is 240 000 N\$ (25 000 Euros) with puncture-proof tires delivered in Namibia. The purchase price for rotary saw is 30 000 N\$ (3 150 Euros). The total price of the felling unit is 270 000 N\$ (28 150 Euros). VAT (value added tax) is not included in the price of the investments.

A skid steer John Deere 332 and Grapple Fork (1.83 m wide), made by Grace Manufacturing in the USA, is used for compiling in the new production chain. With the grapple fork it is possible to grip the bushes and transfer them at the roadside. The productivity in compiling is assumed to be the same as in felling, 16.8 wet tons (20 w-%) per machine-day. The price of a grapple fork is 36 500 N\$ (3 830 Euros). The total price of the compiling unit is 276 000 N\$ (28 830 Euros).

After compiling the bushes at the roadside, the bushes are dried to 20 w-%, after which they are chipped and transported to power plant. Morbark Hurricane 18 drum chipper

with grapple loader is used for chipping in the new production chain. The main technical parameters of chipper, presented by the manufacturer, are: the productivity up to 30 tons of wood chips per hour, chipping productivity up to 550 mm in diameter of the bushes, power of the own diesel engine – 188–245 kW, weight 4 994 kg, infeed throat opening 790 mm x 510 mm and drum diameter 920 mm and drum width 720 mm. The productivity of Morbark Tornado 15 drum chipper in the tests was 20.14 wet tons (20 w-%) per machine-day. In the calculations, as the productivity of Hurricane 18 drum chipper was used 40.3 wet tons (20 w-%) per machine-day. Massey Ferguson tractor (80 hp) is used for the chipper transport. The price of Hurricane 18 drum chipper with a loader is 715 000 N\$ (75 000 Euros). The price of 80 hp Massey Ferguson is 225 000 N\$ (23 600 Euros). The total price of the chipping unit is 940 000 N\$ (98 600 Euros).

A tractor trailer is used for road transport in the new production chain. The trailer used in the calculation is Junkkari 18 made in Finland. The trailer volume of Junkkari 18 tractor trailer is 38 m³. In one tractor trailer unit there is one trailer. The productivity of the tractor trailer unit in the tests at the CCF was 10.5 wet tons (20 w-%) per day (50 km road transport distance). The total volume of the two trailers at CCF is 30 loose-m³. The productivity of the new tractor trailer would be 12.8 wet tons (20 w-%) per machine-day (50 km road transport distance). The tractor in road transport would be 100 hp Massey Ferguson. The price for the Junkkari 18 trailer is 286 000 N\$ (30 000 Euros). The price of the tractor is 295 000 N\$ (30 900 Euros). The total price of the road transport unit is 581 000 N\$ (60 900 Euros).

The road transport costs with different transport distances are calculated from the presented productivity (12.8 wet tons per machine-day) of tractor trailer transport unit with the 50 km road transport distance. It is assumed that the total road transport time is 4.7 h including the road transport and unloading time in 50 km road transport distance. The total road transport time is the same as using the tractor trailer unit in the semi-mechanized production chain. The calculated productivity of road transport is 32.1 wet tons per machine-day (8 h) with 20 km average transport distance (one-way), 21.4 wet tons per machine-day with 30 km average road transport distance and 16.0 wet tons per machine-day with 40 km average road transport distance.

It must be noticed that the new production chain is not fully tested in Namibian conditions. That is why the calculated production costs are just preliminary. The main parameters in the cost calculation are presented in the Table 10. The detailed information of the production calculation is presented in Appendix 4.



Figure 38. A skid steer (left)equipped with a rotary saw for felling (right). This machine is tested in Namibian conditions (photos by Arvo Leinonen).



Figure 39. A skid steer (left) equipped with grapple for compiling the bushes (right). Not tested in Namibian conditions.



Figure 40. A drum chipper with loader (Morbark Hurricane 18 drum chipper). Not tested in Namibian conditions.



Figure 41. Tractor trailer for road transport of wood chips (Junkkari 18 from Finland). Not tested in Namibian conditions.

Table 10. Basic parameters in the cost calculation. The productivity is presented as wet ton per machine-day. Wet ton is presented in 20 w-% moisture content.

Variable	Value	Additional information
Calorific value of wood	4.08 MWh/ton	20 % moisture content
Average salary of the workers	1 170 N\$ (123)	30 % of overheads included
Average salary for the supervisor	1300 N\$(137)	30 % of overhead included
Utilization rate of the machines – Operation time/total site time	0.85 for felling, compiling and road transport	0.84 for chipper
Interest rate	8 %	
Working time	11 m/a, 5 d/w, 8 h/d, 1915h/a	
Fuel price	6.14 N\$/l for tractor trailer	5,64 N\$/l for chipper
Price of the skid steer for felling and compiling	240 000 N\$ (25 000)	John Deere 332
Price of the rotary saw for felling	30 000 N\$ (3 150)	Grace Manufacturing, USA
Price of the grapple fork for compiling	36 500 N\$ (3 830)	Grace Manufacturing, USA
Price of the chipper	715 000 N\$ (75 000)	Morbark Hurricane model 18
Price of the tractor trailer	286 000 N\$ (30 000)	Junkkari 18, Finland
Price of tractor for chipping unit	225 200 N\$ (23 600)	Massey Ferguson 80 hp
Price of the tractor for road transport	294 800 N\$ (30 900)	Massey Ferguson 100 hp
Productivity of felling	16.8 wet ton/machine-day	Skid steer + rotary saw + 1 man
Productivity of compiling	16.8 wet ton/machine-day/crew	Skid steer + grapple fork + 1 man
Productivity of chipping	40.3 wet ton/machine-day/crew	Chipper + tractor + 1 man
Productivity of road transport (50 km)	12.8 wet ton/machine-day/crew	Tractor trailer + tractor + 1 man

4.2.2 The production costs

The wood chip production costs of the new production chain is presented in the Table 11 and App. 4. The production costs include also the organization costs. These costs consist of the management of the production groups. Management costs in the new production chain are calculated to be 50 % lower than in the CCF semi-mechanized method because the number of workers is lower in the new production chain. It is assumed that 5 men are needed for organizing the production of wood chips for 5 MWe power plant, 10 men for 10 MWe power plant and 20 men for 20 MW power plant. No profit is calculated for the production business.

The wood chip production costs for 5 MWe power plant are 170.5 N\$/wet tons (4.4 Euros/MWh), for 10 MWe power plant 181.4 N\$/wet ton (4.7 Euros/MWh) and for 20 MWe 192.3 N\$/wet ton (4.9 Euros/MWh). The average road transport distance (one-way) for a 5 MWe plant is 30 km, 40 km for a 10 MWe plant and 50 km for a 20 MWe power plant. The wet ton and MWh units are presented in 20 w-% moisture content.

The production costs of the new mechanized production chain are about 15% lower than with the CCF semi-mechanized production chain. The felling costs of the semi-mechanized and mechanized harvesting chain are nearly the same. The compiling costs of the new production chain are higher (23%), but the chipping costs are 28% smaller than in the CCF semi-mechanized chain. The road transport costs are about 21% smaller than in the new production chain.

By the new chipper it is possible to decrease as well the labour costs as the capital costs. Capital costs are lower because the productivity of the chipper is assumed to be about 2 times higher than with the current chipper. The main costs are still the chipping costs. The share of the chipping cost of the total costs is 33–38% depending on the road transport distance (average transport distance 30–50 km). The road transport costs are also high, 19–28% of the total costs (average transport distance 30–50 km).

Table 11. The total wood chip production costs in the new mechanized production chain with different road transport distance (one-way). The wet ton and MWh units are presented in 20 w-% moisture content.

Working phase	N\$/wet ton	Euros/wet ton	N\$/MWh	Euros/MWh
Felling	35.47	3.72	8.69	0.91
Compiling	35.72	3.75	8.76	0.92
Chipping	64.36	6.75	15.77	1.65
Road transport				
– 20 km	21.66	2.27	5.31	0.56
– 30 km	32.54	3.41	7.98	0.84
– 40 km	43.43	4.56	10.64	1.12
– 50 km	54.29	5.70	13.31	1.40
Organizaton	2.43	0.26	0.60	0.06
All together				
– 20 km	159.64	16.75	39.13	4.10
– 30 km	170.52	17.89	41.80	4.38
– 40 km	181.41	19.04	44.46	4.66
– 50 km	192.27	20.18	47.13	4.94

4.2.3 The manpower and investments needed for production of wood chips for each power plant

The manpower needed in the production of wood chips for each power plant is presented in the Table 12, and the number of machines required by each power plant scale in the Table 13. Table 14 presents the investments for the production machinery for each power plant size. The manpower needed in the procurement chain of wood chips is presented in the following table.

The production chain was the following:

- Felling crew – Skid steer + rotary saw + 1 man
- Compiling crew – Skid steer + grapple fork + 1 man
- Chipping crew – Chipper equipped with loader + 1 tractor (80 hp) + 2 man
- Road transport crew – Junkkari-trailer (38 m³) + 1 tractor (100 hp) + 1 man.

In the new production chain the labour demand is lower than in the CCF semi-mechanized chain. Production of wood chips for a 5 MWe power plant requires 232 workers in the CCF semi-mechanized production chain, but in the new production chain only 32 workers. The ratio in the workers in the CCF semi-mechanized and new mechanized production chain in wood chip production for 10 and 20 MWe is nearly the same. The target in developing the mechanized production chain is to develop as efficient and competitive production chain as possible not to decrease jobs.

The investments in the new mechanized production chain are in the 5 MWe power plant 12.2 mill. N\$ (1.3 mill. Euros), in the 10 MWe power plant 24.1 mill. N\$ (2.6 mill. Euros) and in 20 MWe power plant 51.3 mill. N\$ (5.4 mill. Euros). The investments are 9–33 % higher than in the semi-mechanized production chain depending on the power plant size. The investments can be decreased by optimizing the working hours per day. In the calculation it has been assumed that the work is done in one shift.

Table 12. The man power needed in the production chain of wood chips. Fuel demand in the 5 MWe power plant is 32 000 wet tons/a, in 10 MWe it is 60 000 wet tons/a and in 20 MWe power plant it is 118 000 wet tons/a. The wet ton unit is presented in 20 w-% moisture content.

Working phase	Productivity wet tons/a/crew	5 MWe	10 MWe	20 MWe
Felling	4020	8 crews - 8 men	16 crews - 16 men	32 crews - 32 men
Compiling	4020	8 crews - 8 men	16 crews - 16 men	32 crews - 32 men
Chipping	9 650	4 crews - 4 men	7 crews - 7 men	13 crews - 13 men
Road transport				
– 30 km	5110	7 crews - 7 men		
– 40 km	3830		16 crews - 16 men	
– 50 km	3060			39 crews - 39 men
Organization		5 men	10 men	20 men
All together		27 crews - 32 men	55 crews – 65 men	116 crews – 136 men

Table 13. The number of different machines for wood chip production in each power plant size.

Plant size	Skid steer + rotary saw for felling	Skid steer + grapple fork for compiling	Tractor for chipping 80 hp	Tractor for road transport 100 hp	Chipper	Trailer
5 MWe	8	8	4	7	4	7
10 MWe	15	15	7	16	7	16
20 MWe	30	30	13	39	13	39

Table 14. The investments for the wood chip production machinery.

Working phase	5 MWe – Investment		10 MWe – Investment		20 MW – Investment	
	N\$	Euros	N\$	Euros	N\$	Euros
Felling	2 160 000	227 000	4 050 000	425 000	8 100 000	845 000
Compiling	2 212 000	232 000	4 148 000	436 000	8 295 000	865 000
Chipping	3 761 000	395 000	6 582 000	690 000	12 223 000	1 282 000
Road transport	4 066 000	427 000	9 293 000	975 000	22 651 000	2 375 000
All together	12 199 000	1 281 000	24 073 000	2 526 000	51 269 000	5 367 000

4.3 The fuel supply costs to Van Eck power plant

Changing of one coal fired boiler to biomass boiler in Van Eck coal fired power plant has been analysed in the study. Thermal output of one boiler would be 100 MW, and the consumption of wood chips is nearly the same as in 20 MW electricity plant, 128 000 wet tons (20 w-%).

Costs of woods chips supply to Van Eck power station consist of production costs of wood chips and long-distance transport costs. The wood chips are assumed to be produced in the north from Windhoek. The production area would be the triangle formed by Otjiwarongo, Grootfontein and Tsumeb cities. The wood chip production costs are got from the cost calculations with CCF semi-mechanized (chapter 4.1) and the new mechanized production chain (chapter 4.2). The short-distance road transport distance in the study was 50 km.

4.3.1 Road transport of wood chips from the north to Windhoek

There are two alternatives for transportation of bush chips from the north to Van Eck, the rail wagons or grain trucks equipped with tipping device.

The volume of a rail wagon is 82.3 loose-m³, the length being 12.7 m, the width 2.4 m and the height 2.7 m. The load productivity of the wagons is 44 tons (Galloway 2007). The load achieved by bush chips is 18.5 tons, assuming that the density of bush chips is 225 kg/loose-m³. Transnamib will charge at a rate of 44 tons' load per rail wagon.

The transport costs of wood chips from Grootfontein, Otjiwarongo and Okahandja to Windhoek by rail wagons is presented in the Table 15. The transport costs from Grootfontein are 892.7 N\$/wet ton (23.0 Euros/MWh), from Otjiwarongo 642.3 N\$/wet ton (16.5 Euros/MWh) and from Okahandja 244.9 N\$/wet ton (6.3 Euros/MWh). It is possible to negotiate discounts from these prices with Transnamib. The wet ton and MWh units are presented in 20 w-% moisture content.

The road transport costs of using the trucks are much cheaper (Table 16). The volume of a Interlink truck trailer is 108 loose-m³, the length being 18.0 m, the width 2.4 m and the height 2.5 m. Typical rate for the Interlink truck trailer is 16 N\$ per km (Galloway 2007). The load per interlink truck trailer is 24.3 wet tons assuming that the density of bush chips is 225 kg/loose-m³. The road transport costs using Interlink truck trailer, not equipped with a tipping device.

The transport costs from Grootfontein are 296.3 N\$/wet ton (7.6 Euros/MWh), from Otjiwarongo 158.0 N\$/wet ton (4.1 Euros/MWh) and from Okahandja 46.1 N\$/wet ton (1.2 Euros/MWh).

The most economic way is to use trucks to transport the wood chips from the north to Windhoek. The truck trailers should be grain trucks equipped with tipping device.

Table 15. Transport cost of bush chips using rail wagons. The wet ton and MWh units are presented in 20 w-% moisture content.

	Rate N\$/wet ton (Euros/MWh)	Rate N\$/load (Euros/load) Net load 44 wet ton	Transport costs of wood chips N\$/ton (Euros/MWh) Net load 20.6 wet tons
Grootfontein – Windhoek (450 km)	375.35 (39.4)	16 515.4 (1 733.0)	892.7 (23.0)
Otjiwarongo – Windhoek (240 km)	270.09 (28.3)	11883.4 (1 244.9)	642.3 (16.5)
Okahandja – Windhoek (70 km)	102.95 (10.8)	4529.8 (475.3)	244.9 (6.3)

Table 16. Transport cost of bush chips using trucks without any tipping device. The wet ton and MWh units are presented in 20 w-% moisture content.

	Distance km	Rate N\$/load (Euros/load)	Transport costs N\$/wet ton (Euros/MWh)
Grootfontein – Windhoek	450	7 200 (755.5)	296.3 (7.6)
Otjiwarongo – Windhoek	240	3 840 (402.9)	158.0 (4.1)
Okahandja – Windhoek	70	1 120 (117.5)	46.1 (1.2)

4.3.2 The Total supply costs to Van Eck power plant

The total supply costs consist of wood chip production and long distance transport costs (Table 17). The wood chips supply costs from Okahandja are 272.9 N\$/wet tons (7.0 Euros/MWh) and from Otjiwarongo 384.8 N\$/wet ton (9.9 Euros/MWh) using the CCF semi-mechanized production method. The wood chip supply costs to Van Eck are lower with the new mechanized production method. The wood chips supply costs from Okahandja are 238.4 N\$/wet ton (6.1 Euros/MWh) and from Otjiwarongo 350.3 N\$/wet ton (9.0 Euros/MWh) using the new mechanized production method. In these figures the wood chips are transported to Windhoek by truck trailers. The loading and unloading costs are not calculated in the road transport cost.

Table 17. Total supply cost of wood chips to Van Eck power plant. The wet ton and MWh units are presented in 20 w-% moisture content.

	N\$/wet ton	N\$/MWh	Euros/MWh
Wood chip production – road transport 50 km			
– CCF semi-mechanized method	226.8	55.6	5.8
– New mechanized method	192.3	47.1	4.9
Long-distance transport by truck from			
– Otjiwarongo	158.0	38.7	4.1
– Okahandja	46.1	11.3	1.2
Total			
– Semi-mechanized method from Otjiwarongo	384.8	94.3	9.9
– New mechanized method from Otjiwarongo	350.3	85.8	9.0
– Semi-mechanized method from Okahandja	272.9	66.9	7.0
– New mechanized method from Okahandja	238.4	58.4	6.1

5. Conclusions

- The bushes dry very well in the stacks by the side of a strip road. Usually it takes only two weeks to dry bushes in the stacks to moisture content less than 20 w-%.
- The CCF semi-mechanized production chain works well.
- The chipping costs in the CCF mechanized production chain are too high because of low chipping productivity.
- The number of workers in the CCF semi-mechanized production chain is high.
- The test show that new machines like chainsaw, bush cutter, lawn mover type cutter, Nisula harvester head and skid steer with rotator saw are suitable for bush felling.
- The most effective felling device is a skid steer with rotator saw in large-scale wood chip production.
- Brush cutter is suitable for felling in small-scale production (charcoal production).
- Bushes are not economical to transfer from the cutting stand by the side of the gravel road because of the low transport load.
- A new mechanized production chain was designed.
- With the new mechanized production chain the production costs are lower than those of the CCF semi-mechanized production chain.
- The investments for the production machinery in the new production chain are a little bit higher than in the CCF semi-mechanized chain.
- There is a need to test the new mechanized production chain in practice.

6. Executive Summary

Introduction

This study has been done in a project, the main target of which is to study the technology and economy of using bush biomass for power production in Namibia. The project has been funded by the Ministry for Foreign Affairs of Finland and the Ministry of Agriculture, Water and Forestry of the Republic of Namibia. The duration of the project is from May 1st 2006 to October 31st 2007.

Target of the study

The target of the study is to calculate the production costs of bush chips at the power plant or at process plant using the current production technology used in Namibia. The second target is to develop production technology in order to mechanize production and -to decrease the production costs.

The wood production costs are utilized in the feasibility studies, in which the technology and economy of utilizing wood chips for electricity production in 5, 10 and 20 MW electricity power plants, for pyrolysis oil production and for electricity production in Van Eck coal fired power plant in Windhoek are evaluated.

Realization of the study

At the moment the Cheetah Conservation Farm (CCF) manufactures wood chips for their own briquette factory in Otjiwarongo town. This semi-mechanized production chain was investigated at the CCF. New machines for production of wood chips were also tested at the CCF. For instance the capacities of different machines and working phases, fuel consumption etc have been measured in the tests.

Production costs of CCF semi-mechanized production chain has been calculated on the basis of the results of the field data. A new mechanized production chain, based on the tests of the new machines, has been designed. The production costs of the new production chain have also been calculated.

The production tests at CCF

The number of bushes per hectare before and after the production was calculated. The tests were made at the plots (1–8), there the average bush density was 1118–1144. These plots were classified to have an average bush density of the area. At one test plot (plot 9) there was 2 027 bushes per hectare. This plot is classified to have high bush density.

10–25% of the bushes were felled in the production in the tests. The number of bushes left to grow after production was 170–260 bushes. The average harvested yield at the test plots 1–8 was 7.0 wet tons (20 w-%) per hectare. The test plots 1–8 were classified to have an average bush density in the area. The yield at the test plot 9 was 22.0 wet tons (20 w-%) per hectare. This plot was classified to have very high bush density.

CCF semi-mechanized production chain

At the CCF most of the wood chip production work is done manually, and the supply chain is organized into crews of 4–9 men. These crews work between parallel strip roads located 50 meters from each other. The production chain consists of felling, compiling, drying, chipping and road transport working phases.

In a felling or cutting crew there are four men cutting bushes manually with simple axes. The productivity of manual felling in the tests was 1.7 wet tons (20 w-%) per man-day (8 h). Compiling crews (four men in each) follow the cutting crews and drag undelimited bushes to a strip road where they are piled for drying. In the tests the productivity of manual compiling was 2.0 wet tons (20 w-%) per man-day (8 h). The bushes dry in the heaps very rapidly. In a warm and dry climate seasoning takes only 1 to 2 weeks during which the moisture content of the wood decreases from initial 35 %-w to 20 %-w, sometimes even more.

A chipping crew consists of nine men with a tractor-hauled bush chipper. Seasoned bushes are fed manually into the chipper (Morbark Tornado model 15) on the strip roadside and are chipped directly into a trailer which is afterwards towed to the power plant by a tractor. In the tests the productivity of the chipping crew was 20.14 wet tons (20 w-%) per day (8 h). Wood chips are hauled to the plant in the same trailers they are chipped into, two trailers articulated. The trailers are pulled by a 100 hp tractor. The productivity of the two trailer unit was 10.5 wet tons (20 w-%) per day (8 h). The road transport distance was 50 km.

Designed new mechanized production chain

New production machines were tested at work in order to develop a production chain. Chainsaw, brush cutter, lawn mover type cutter, rotator saw in skid steer and Nisula harvester head were tested for felling. The tests showed that all these new machines are suitable for felling of the bushes. The most effective felling device was a rotary saw in the skid steer.

A new mechanized production chain was designed on the basis of these tests. The working phases in this chain are: felling with skid steer with rotary saw, compiling with

skid steer with grapple fork, chipping with a chipper with a loader + tractor and road transport with tractor trailers.

Rotary saw is mounted in front of the skid steer (John Deere 332). The productivity of the rotary saw in skid steer for felling was measured and it was 0.31 ha per h. This means that the productivity is 16.8 wet tons (20 w-%) per machine-day (8 h). It is about 9 times more effective than one manual felling man. For Compiling in the new production chain a grapple fork is mounted to the skid steer (John Deere 332). The grapple fork is also mounted in front of the skid steer. With a grapple fork it is possible to grip on the bushes and to transport them at the roadside. The productivity in compiling is assumed to be the same as in felling, 16.8 wet tons per machine-day (8 h).

After compiling the bushes at the roadside the bushes are dried up to 20 w-%. After drying the bushes are chipped and transported to a power plant. A drum chipper (Morbark Hurricane 18) with grapple loader is used for chipping in the new production chain. The productivity of Hurricane 18 drum chipper, used in the calculations, is 40.3 wet tons (20 w-%) per day. This is three times more than with Morbark Tornado drum chipper. Massey Ferguson tractor is used for the transport of the chipper.

Tractor trailers are used for road transport in the new production chain. The trailer used in the calculation is Junkkari 18 made in Finland. The trailer volume of the Junkkari 18 tractor trailer is 38 m³. The productivity of the new tractor trailer would be 12.8 wet tons (20 w-%) per day with 50 km road transport distance. The tractor in road transport would be 100 hp Massey Ferguson.

It must be mentioned that this new mechanized production chain is not tested totally in Namibian conditions.

Production costs of the CCF semi-mechanized production chain

The total wood chip production costs of the current production chain are 185.6–226.8 N\$/wet ton (4.8–5.8 Euros/MWh) when the average road transport distance is 20–50 km. The maximum road transport distance is 40–100 km.

We can assume that the average road transport distance for a 5 MWe power plant would be 30 km, 40 km for 10 MWe and 50 km for 20 MWe power plant. With these road transport distances the production costs for 5 MWe power plant are 199.4 N\$/wet ton (5.1 Euros/MWh), for 10 MWe power plant 213.0 N\$/wet ton (5.5 Euros/MWh) and for 20 MWe 226.8 N\$/wet ton (5.8 Euros/MWh).

The main costs are the chipping costs. The share of the chipping cost of the total costs is 39–45% depending on the road transport distance. The road transport costs are also high, 21–30% of the total costs.

Production costs of the new production chain

Using the new mechanized production chain the production costs for 5 MWe power plant are 170.5 N\$/wet ton (4.4 Euros/MWh), for 10 MWe power plant 181.4 N\$/wet ton (4.7 Euros/MWh) and for 20 MWe 192.3 N\$/MWh (4.9 Euros/MWh). The average road transport distance for a 5 MWe plant is 30 km, 40 km for a 10 MWe plant and 50 km for a 20 MWe power plant.

By the new chipper it is possible to decrease as well the labour costs as the capital costs. Capital costs are lower because the productivity of the chipper is assumed to be about 3 times higher than with the current chipper. The main costs are still the chipping costs. The share of the chipping cost of the total costs is 33–38% depending on the road transport distance (average transport distance 30–50 km). The road transport costs are also high, 19–28% of the total costs.

The production costs of the new mechanized production chain are about 15% lower than with the CCF semi-mechanized production chain. The felling costs of the semi-mechanized and mechanized harvesting chain are nearly the same. The compiling costs of the new production chain are higher (23%), but the chipping costs are 28% smaller than in the CCF semi-mechanized production chain. The road transport costs are about 21% smaller than in the CCF semi-mechanized production chain.

Production costs of wood chips to Van Eck power plant

The total supply costs consist of wood chip production and long distance transport costs. The wood chips supply costs from Okahandja are 272.9 N\$/wet ton (7.0 Euros/MWh) and from Otjiwarongo 384.8 N\$/wet ton (9.9 Euros/MWh) using the CCF semi-mechanized production method. The wood chip supply costs to Van Eck are lower with the new mechanized production method. The wood chips supply costs from Okahandja are 238.4 N\$/wet ton (6.1 Euros/MWh) and from Otjiwarongo 350.3 N\$/wet ton (9.0 Euros/MWh) using the new mechanized production method. In these figures the wood chips are transported to Windhoek by truck trailers. The loading and unloading costs are not calculated in the road transport cost.

Wood chip harvesting area for the power plants

The annual total production area is 4 600 ha in the case of a 5 MW_e power plant, 8 600 ha for a 10 MW_e and 16 900 ha for 20 MW_e power plant if the harvesting yield is 7.0 wet

tons per ha in 20 w-% moisture content. If we assume that we are able to make selective cutting in the same area after ten years. The total production area in 10 years' bush rotation is 46 000 ha in 5 MW_e power plant, 86 000 ha in 10 MW_e and 169 000 ha in 20 MW_e power plant (Table 4).

We have assumed that the radius of the harvesting area is 40 km in 5 MWe power plant, 50 km in 10 MWe power plant and 60 km in 20 MWe power plant. Correspondingly the total bushland area within these radii is 502 000 ha, 785 000 ha and 1 130 000 ha. Also we have assumed that the average road transport distance in 5 MWe power plant would be 30 km, in 10 MWe it would be 40 km and in 20 MWe power plant it would be 50 km.

The annual harvesting area (4 600 ha) in 5 MWe power plant is only about 1.0% from the total planned harvesting area (502 000 ha). In 20 MWe power plant the annual harvesting area (16 900 ha) is 1.5 % from the total planned harvesting area (1 130 000 ha). After ten years we have cut 10–15% from the total planned harvesting area depending on the power plant size. If we assume that the lifetime of the power plant is 20 years. In 20 years we have cut 20–30% of the total planned harvesting area. This means that we have a large wood chip production potential in the area.

Labour force and investments for the fuel supply

Production of wood chips with the CCF semi-mechanized production chain requires 232 men all year round for a 5 MWe plant, 432 men for a 10 MWe plant and 853 men for a 20 MWe power plant. With the new mechanized production chain it labour need for production of wood chips is only 32 men for 5 MWe, 65 men for 10 MWe and 136 men for 20 MWe power plant. The labour demand in the new production chain is only about 15% of the labour demand in the old production chain.

The investments for the machines in the CCF semi-mechanized production chain to produce the demand of wood chips for 5 MWe power plant is 9.2 mill. N\$ (1.0 mill. Euros), 20.7 mill. N\$ (2.2 mill. Euros) for 10 MWe power plant and 47.0 mill. N\$ (5.0 mill. Euros) for 20 MWe. The investments in the new mechanized production chain are a little bit higher: 12.2 mill. N\$ (1.3 mill. Euros) for 5 MWe, 24.1 mill. N\$ (2.6 mill. Euros) and for 20 MWe 51.3 mill. N\$ (5.4 mill. Euros).

The investments can be decreased by optimizing the working hours in a year. In the calculation it has been assumed that the work is done in one shift.

Conclusions

- The bushes dry very well in the stacks by the side of a strip road. It usually takes only two weeks to dry bushes in the stacks to moisture content less than 20 w-%.
- The CCF semi-mechanized production chain works well.
- The main disadvantages in the semi-mechanized production chain are the low productivity in all working phases.
- The test show that new machines like chainsaw, bush cutter, lawn mover type cutter, Nisula harvester head and skid steer with rotator saw are suitable for bush felling.
- The most effective felling device is a skid steer with rotator saw.
- A new mechanized production chain was designed.
- With the new mechanized production chain the production cost are lower than those of the CCF semi-mechanized production chain.
- The investments for the production machinery in the new production chain are a little higher than in the CCF semi-mechanized chain.
- There is a need to test the new mechanized production chain in practice in order to verify the evaluated the productivity and calculated production costs.

References

De Klerk, J.N. 2004. Bush Encroachment in Namibia. Ministry of Environment and Tourism, Government of the Republic of Namibia. 254 p.

Galloway, I. 2007. Printed information.

International Development Consultancy, 2002. Situation of the present and possible future applications of excess wood biomass and business plan for Woodco. Ministry of Agriculture, Water and Rural Development. Pp. 5–9.

Mendelsohn, J. and El Obeid, S. 2005. Forest and Woodlands of Namibia. ISBN 99916-780-3-4.

Appendix 1: The coefficients and abbreviations used in the study

Table 1. The coefficients used in the study.

Parameter	Unit
1 Euro	9.53 N\$
1 Euro	1.3 US\$
Energy content of wood chips	4.08 MWh/ton in 20 w-% moisture content

Table 2. Abbreviations used in the study.

Abbreviation	Meaning
a	Year
h	Hour
ha	Hectare
kg	Kilogram
kWh, MWh	Energy content unit
l	Litre
m	Month, metre
manh	Man-hour
mach	Machine-hour
mand	Man-day
macd	Machine-day
m ³	Cubic meter
ton	Ton
w	Week
w-%	Moisture content on wet basis

Appendix 2: Results from the production tests at CCF during 12.2–23.2.2007

Table 1. The number of different bush species per hectare before and after production at the test plot 1.

Bush species	The number of bushes before production	The standing number of bushes after production
<i>A. mellifera</i>	368	44
<i>D. cinerea</i>	373	50
<i>A. herbeclada</i>	16	14
<i>A. fleckii</i>	190	12
<i>A. reficiencia</i>	71	12
<i>G. flava</i>	87	86
<i>G. flavescens</i>	39	39
<i>Total</i>	1144 (100 %)	257 (22.5 %)

Table 2. The number of different bush species per hectare before and after production at the test plot 6.

Bush species	The number of bushes before production	The standing number of bushes after production
<i>A. mellifera</i>	216	26
<i>D. cinerea</i>	387	16
<i>A. herbeclada</i>	12	12
<i>A. fleckii</i>	256	5
<i>A. reficiencia</i>	160	22
<i>G. flava</i>	65	64
<i>G. flavescens</i>	22	22
<i>Total</i>	1118 (100 %)	167 (14.9 %)

Table 3. The number of different bush species per hectare before and after production at the test plot 9.

Bush species	The number of bushes before production	The standing number of bushes after production
<i>A. mellifera</i>	1531	66
<i>D. cinerea</i>	342	35
<i>A. herbeclada</i>	13	13
<i>A. fleckii</i>	31	13
<i>A. tortilis</i>	4	4
<i>A. reficience</i>	31	18
<i>G. flava</i>	53	53
<i>G. flavescens</i>	22	22
<i>Total</i>	2027	224 (11.1 %)
<i>Overall density per hectare</i>		2025

Table 4. The measured data on bush felling and compiling in production tests at CCF in 12.2–23.2.2007. Wet ton is presented in 20 w-% moisture content. Time in the table means the work place time.

Plot	Area ha	Felling type	Number of men	Felling		Total felling time man-hour	Compiling		Total compiling time man-hour	Average moisture content w-%	Total yield wet ton (20 w-%)	Total yield dry ton
				Start	Stop		Start	Stop				
1	1	Manual crew 1	4	Mo 12.2	Tu 13.2	40.00	Th 15.2	Th 15.2	30.00	19.00	8.63	6.90
2	1	Brush cutter	1	Tu 13.2	Th 15.2	19	*	*	*	17.34	6.40	5.12
3	0,7	Brush cutter	1	We 20.2	Fr 22.2	14.25	*	*	*	15.10	4.22	3.38
4	1	Chainsaw	1	Th 15.2	We 20.2	15.5	*	*	*	15.40	6.10	4.88
6	1	Manual crew 1	4	Tu 13.2	We14.2	44.5	Th 22.2	Th 22.2	30.00	14.65	9.53	7.62
7	1	Manual crew 2	4	We 14.2	Th 15.2	50	*	*	*	11.49	5.11	4.09
8	1	Lawn mover	2	We 14.2	Th 15.2	24.5	*	*	*	12.86	6.97	5.58
9	1	Manual crew 2	4	Fr 16.2	Th 21.2	94	*	*	*	14.90	22.01	17.61

Table 5. The calculated productivity of felling and compiling in bush production tests at CCF in 12.2.–23.2.2007. Productivity in wet tons per man-day is presented in 20 w-% moisture content. Wet ton is presented in 20 w-% moisture content. Time in the table means work place time.

Plot	Area ha	Felling method	Yield		Total felling time man-hour	Felling produc- tivity ha/man-day	Felling productivity		Total compiling time man-hour	Compiling produc- tivity ha/man-day	Compiling productivity	
			dry ton	wet ton			wet ton/man-day	dry ton/man-day			wet ton/man-day	dry ton/man-day
1	1	Manual crew 1	6.90	8.63	40.00	0.20	1.73	1.38	30.00	0.27	2.30	1.84
2	1	Brush cutter	5.12	6.40	19	0.42	2.69	2.15	*	*		*
3	0,7	Brush cutter	3.38	4.22	14.25	0.39	2.37	1.90	*	*	*	*
4	1	Chainsaw	4.88	6.10	15.5	0.52	3.14	2.52	30.00	0.27	1.63	1.30
6	1	Manual crew 1	7.62	9.53	45	0.18	1.69	1.35	*	*	*	*
7	1	Manual crew 2	4.09	5.11	50	0.16	0.82	0.65	*	*	*	*
8	1	Lawn mover	5.58	6.97	24.5	0.32	2.28	1.82	*	*	*	*
9	1	Manual crew 1	17.61	22.01	94	0.09	1.87	1.50	*	*	*	*

Table 6. The measured data on chipping and road transport in production tests at CCF in 12.2.–23.2.2007. Weight in wet tons is presented in origina lmeasured moisture content. Mark * means that the moisture content is evaluated.

Plot	Load	Date	Chipping		Number of men	Road transport		Unloading		Number of men	Weight wet ton (original)	Moisture content w-%
			Start	Stop		Start	Stop	Start	Stop			
1	1	We 21.2.07	8:00	9:30	7	10:00	11:35	10:45	11:35	2	4.02	19.00
1	2	Th 22.2.07	8:15	9:50	7	10:00	10:45	10:45	11:35	2	3.9	19.00
1	3	Th 22.2.07	14:00	14:20	7			8:00		2	0.6	19.00*
2	3	Th 22.03.07	14:20	15:30	7						3.28	19.00*
2	4	Fr 23.2.07	13:00	15:44	7	16:30	17:46	7:30	*	2	2.91	15.68
6	4	Fr 23.02.07	15:50	16:20	7						0.97	15.68
6	5	Mo 26.2.07	9:30	11:30	7	12:00	12:30	14:30	15:30	2	3.48	11.08
6	6	Tu 27.02.07	6:30	8:50	7	10:09	10:45	11:58	16:50	2	4.48	17.18
7	7	Th 1.03.07	7:24	10:17	7	11:20	12:30	14:35	16:00	2	4.62	11.49
8	8	Fr 02.03.07			*	*	*	*	*	2	2.48	12.86
8	9	Fr 02.03.07	10:35	12:43	7	14:40	15:07	15:30	16:12	2	3.92	12.87
3	10	Mo 05.03.07	7:11	7:52	7	9:53	10:30	10:40	11:50	2	3.98	15.1
4	11	Mo 05.03.07	13:19	15:11	7	15:20	16:14	7:18	7:30	2	3.4	15.9
9	12	Tu 06.03.07	9:57	11:27	7	11:34	13:04	14:40	15:15	2	3.4	9.69
9	13	We 07.03.07	7:45	9:25	7	9:31	11:04	11:13	11:48	2	4	18.68
9	14	We 07.03.07	14:15	15:22	7	15:32	16:20	7:10	7:40	2	3.32	21
9	15	Th 08.03.07	10:04	11:17	7	11:21	12:33	12:40	13:00	2	3.44	13.27
9	16	Fr 09.03.07	8:30	10:23	7	10:30	13:10	14:23	15:00	2	4.16	11.84
9	17	Mo 12.03.07	7:02	8:15	7	10:00	11:05	11:14	11:40	2	2.37	14.90*
4	17	Mo 12.03.07	8:22	9:35	7					2	2.37	14.90*

Table 7. The calculated data in chipping at CCF in 12.2.–23.2.2007. Wet ton is presented in 20 w-% moisture content. Time in the table means the work place time.

Plot	Load	Chipping time machine-hour	Load weight		Chipping productivity	
			dry ton	wet ton	wet ton/machine-day	dry ton/machine-day
1	1	1.50	3.26	4.07	21.71	17.37
1	2	1.58	3.16	3.95	19.99	15.99
1+2	3	1.50	3.15	3.94	21.00	16.80
2+6	4	3.33	3.27	4.09	9.82	7.86
6	5	2.00	3.09	3.87	15.47	12.38
6	6	2.33	3.71	4.64	15.92	12.74
7	7	2.88	4.09	5.11	14.20	11.36
8	8		2.16	2.70		
8	9	2.13	3.42	4.27	16.04	12.83
3	10	0.68	3.38	4.22	49.69	39.76
4	11	1.87	2.86	3.57	15.29	12.23
9	12	1.50	3.07	3.84	20.47	16.38
9	13	1.67	3.25	4.07	19.48	15.58
9	14	1.12	2.62	3.28	23.42	18.71
9	15	1.22	2.98	3.73	24.46	19.56
9	16	1.88	3.67	4.58	19.51	15.61
4+9	17	2.55	4.04	5.05	15.84	12.67
Average			3.25	4.06	20.14	16.12

Table 8. The calculated data on road transport at CCF farm in 12.2.–23.2.2007. Wet ton is presented in 20 w-% moisture content. Time in the table means the work place time.

Plot number	Load number	Load weight wet ton	Chipping time machine-hour	Road transport time to factory machine-hour	Road transport speed km/h	Unloading time machine-hour	Total road trans- port time machine-hour	Road transport productivity	
								wet ton/ machine-day	dry ton/ machine-day
1	1	4.07	1.50	1.58	31.65	0.83	5.49	5.95	4.76
1	2	3.95	1.91	0.75	66.67	0.83	3.91	7.45	5.96
1+2	3	3.94	1.50	-	-	-	-	-	-
2+6	4	4.09	3.33	1.27	39.3	-	-	-	-
6	5	3.87	2.00	0.50	100.00	1.00	4.00	7.72	6.18
6	6	4.64	2.33	0.60	83.3	-	-	-	-
7	7	5.11	2.88	1.17	42.74	1.42	6.64	6.16	4.93
8	8	2.70	-	-	-	-	-	-	-
8	9	4.27	2.13	0.45	111.11	0.70	3.73	9.18	7.3
3	10	4.22	0.68	0.62	80.65	1.17	3.09	10.95	8.76
4	11	3.57	1.87	0.90	55.56	-	-	-	-
9	12	3.84	1.50	1.50	33.33	0.58	5.08	6.05	4.84
9	13	4.07	1.67	1.55	32.26	0.58	5.35	5.98	4.79
9	14	3.28	1.12	0.80	62.50	0.50	3.22	8.15	6.52
9	15	3.73	1.22	1.20	41.67	0.33	3.95	7.55	6.04
9	16	4.58	1.88	2.67	18.73	0.62	7.84	4.68	3.75
4+9	17	5.05	2.55	1.08	46.30	0.43	5.14	7.86	6.29
Average		4.06	1.86	1.11	56.39	0.75	4.79	7.36	5.89

Table 9. The drying of bushes in the heaps at CCF in 12.2.–23.2.2007.

Plot number	Truck load number	Moisture content w-%	Drying time d
Plot 1	1	19.0	8–9
Plot 1	2	19.0	9–10
Plot 1-2	3	19.0	-
Plot 2-6	4	15.7	8–10
Plot 6	5	11.1	12–13
Plot 6	6	17,2	13–14
Plot 7	7	11.5	15–16
Plot 8	8	12.9	15–16
Plot 8	9	12.9	15–16
Plot 3	10	15.1	13–18
Plot 4	11	15.9	13–18
Plot 9	12–17	14.9	19–24

Appendix 3: The results from the cost analysis for the CCF semi-mechanized wood chip production chain

Table 1. The cost breakdown of Morbark Tornado Model 13 drum chipper-tractor chipping unit. The wet ton and MWh units are presented in 20 w-% moisture content.

	Chipper	Tractor
1. Basic data	Drum chipper Morbark Tornado Model 15.	Massey Ferguson: 80 hp and 2 wheel drive.
Utilization rate (= operating time/work place time)	81.45 %	61.00 %
Average productivity, wet ton/work place h	2.52	
Work place time, h/a	1 915.00	1 915.00
Operating time, h	1 559.77	1168.15
Number of workers	8	1
Salary including overheads, N\$/m	1 170.00 N\$	1 170.00 N\$
Price, N\$	460 000.00	225 217.00
Life time, a	7	10
Operating time during lifetime, h	10 925	
Depreciation degree, %	25.00	20.00
Depreciation value, N\$	61 402.59	24 182.49
Interest rate, %	8.00	8.00
Insurance, N\$ per a	2 300.00	1126.09
Administration (office etc.), N\$/a	4 600.00	2252.17
Fuel price, N\$/l	5.64	6.14
Fuel consumption, l/operating hour	13.60	5.00
Fuel cost, N\$/operating hour	76.70	30.70
Price of hydraulic oil, N\$/l	11.40	11.40
Consumption of hydraulic oil, l	0.05	0.00
Cost of hydraulic oil, N\$/operating h	0.57	0.00
Price of motor oil, N\$/l	11.40	11.40
Consumption of motor oil, l/operating h	0.05	0.10
Cost of motor oil, N\$/operating hour	0.57	1.14
Repair and maintenance, % of depreciation	35.00	25.00
Moving costs, N\$/km	1.50	0.00
Moving distance, km/a	500	0.00
2. Fixed costs		
Capital depreciation, N\$/a	56 942.50	20 103.45
Interest cost, N\$/a	23 133.80	10 708.12
Total, N\$/a	80 076.30	30 811.57
3. Overhead costs		
Administration, N\$/a	4 600	2 252.17
Moving costs, N\$/a	750	0.00
Insurance, N\$/a	2 300	1 126.09
Margin, N\$/a	0	0.00
Total costs, N\$/a	7 650	3 378.26
4. Salary costs		
Total, N\$	112 320.00 (eight men)	14 040.00 (one man)
5. Variable cost		
Fuel	119 634.36	35 872.95
Repair and maintenance	19 929.88	5 025.86
Hydraulic oil	889.07	0
Motor oil	889.07	1 331.69
Travel allowance	0	0
Total, N\$/a	141 342.38	42 230.5
6. Summary		
Total costs, N\$/a	341 388.68	90 460.33
7. Summary – chipper + tractor		
Total costs, N\$/a	431 849.01	
Cost, N\$/work place hour	225.51	
Cost, N\$/wet ton (20 w-%)	89.49	
Cost, N\$/MWh (20 w-%)	21.93	

Table 2. The cost breakdown of the tractor trailer road transport unit. Road transport distance is 20 km (one-way). The wet ton and MWh units are presented in 20 w-% moisture content.

	Tractor trailer unit	Remarks
1. Basic data	Four trailers: 15 m ³ /trailer. Massey Ferguson tractor :100 hp and 2 wheel drive.	Two trailers for transportation and 2 for chipping.
Utilization rate (operating time/work place time)	82.28 %	
Average productivity, wet ton/work place h	3.28	Road transport distance 20 km (one-way).
Work place time, h/a	1 915.00	
Operating time, h	1 575.66	
Number of workers in the unit	1	
Salary including overheads, N\$/m	1 170.00 N\$	
Price, N\$	622 783.00	Tractor - 294 783 and trailers 328 000.
Life time, a	10	
Operating time during lifetime, h	15 756.60	
Depreciation degree, %	20	
Depreciation value, N\$	66 870.82	
Interest rate, %	8.00	
Insurance, N\$/a	1473.92	
Administration (office etc.), N\$/a	6 227.83	
Fuel price, N\$/l	6.14	
Fuel consumption, l/operating hour	5.00	
Fuel cost, N\$/operating hour	30.70	
Price of hydraulic oil, N\$/l	11.40	
Consumption of hydraulic oil, l	0.05	
Cost of hydraulic oil, N\$/operating h	0.57	
Price of motor oil, N\$/l	11.40	
Consumption of motor oil, l/operating h	0.10	
Cost of motor oil, N\$/operating hour	1.14	
Repair and maintenance, % of depreciation	25.00	
Moving costs, N\$/km	1.50	
Moving distance, km/a	0.00	
2. Fixed costs		
Capital depreciation, N\$/a	55 591.22	
Interest cost, N\$/a	29 809.80	
Total, N\$	85 401.02	
3. Overhead costs		
Administration, N\$/a	6227.83	
Moving costs, N\$/a	0.00	
Insurance, N\$/a	1 473.92	
Margin, N\$/a	0	
Total, N\$/a	7 701.76	
4. Salary costs		
Total, N\$	14 040.00	One man
5. Variable cost		
Fuel	48 372.76	
Repair and maintenance	13 897.80	
Hydraulic oil	898.13	
Motor oil	1796.25	
Travel allowance	0	
Total, N\$/a	64 958.94	
6. Summary		
Total costs, N\$/a	172 107.72	
Cost, N\$/work place hour	89.87	
Cost, N\$/wet ton (20 w-%)	27.40	
Cost, N\$/MWh (20 w-%)	6.72	

Table 3. The cost breakdown of a tractor trailer road transport unit. Road transport distance is 30 km (one-way). The wet ton and MWh units are presented in 20 w-% moisture content.

	Tractor trailer unit	Remarks
1. Basic data	Four trailers: 15 m ³ /trailer. Massey Ferguson tractor :100 hp and 2 wheel drive.	Two trailers for transportation and 2 for chipping.
Utilization rate (operating time/work place time)	82.28 %	
Total Production, ton/a	32 000	Road transport distance 30 km (one-way).
Average productivity, ton/work place hour	2.18	
Work place time, h/a	1 915.00	
Operating time, h	1 575.66	
Number of workers in the unit	1	
Salary including overheads, N\$/m	1 170.00 N\$	
Price, N\$	622 783.00	Tractor - 294 783 and trailers 328 000.
Life time, a	10	
Operating time during lifetime, h	15 756.60	
Depreciation degree, %	20	
Depreciation value, N\$	66 870.82	
Interest rate, %	8.00	
Insurance, N\$/a	1473.92	
Administration (office etc.), N\$/a	6 227.83	
Fuel price, N\$/l	6.14	
Fuel consumption, l/operating hour	5.00	
Fuel cost, N\$/operating hour	30.70	
Price of hydraulic oil, N\$/l	11.40	
Consumption of hydraulic oil, l	0.05	
Cost of hydraulic oil, N\$/operating h	0.57	
Price of motor oil, N\$/l	11.40	
Consumption of motor oil, l/operating h	0.10	
Cost of motor oil, N\$/operating hour	1.14	
Repair and maintenance, % of depreciation	25.00	
Moving costs, N\$/km	1.50	
Moving distance, km/a	0.00	
2. Fixed costs		
Capital depreciation, N\$/a	55 591.22	
Interest cost, N\$/a	29 809.80	
Total, N\$	85 401.02	
3. Overhead costs		
Administration, N\$/a	6227.83	
Moving costs, N\$/a	0.00	
Insurance, N\$/a	1 473.92	
Margin, N\$/a	0	
Total, N\$/a	7 701.76	
4. Salary costs		
Total, N\$	14 040.00	
5. Variable cost		
Fuel	48 372.76	
Repair and maintenance	13 897.80	
Hydraulic oil	898.13	
Motor oil	1796.25	
Travel allowance	0	
Total, N\$/a	64 963.94	
6. Summary		
Total costs, N\$/a	172 106.72	
Cost, N\$/work place hour	89.87	
Cost, N\$/wet ton (20 w-%)	41.22	
Cost, N\$/MWh (20 w-%)	10.10	

Table 4. The cost breakdown of the tractor trailer unit. Road transport distance is 40 km (one-way). The wet ton and MWh units are presented in 20 w-% moisture content.

	Tractor trailer unit	Remarks
	Four trailers: 15 m ³ /trailer. Massey Ferguson tractor: 100 hp and 2 wheel drive.	Two trailers for transportation and 2 for chipping.
1. Basic data		
Utilization rate (= operating time/work place time)	82.28 %	Road transport distance 40 km (one-way).
Average productivity, wet ton/work place h	1.64	
Time at site, h/a	1 915.00	
Operating time, h	1 575.66	
Number of workers in the unit	1	
Salary including overheads, N\$/m	1 170.00 N\$	
Price, N\$	622 783.00	Tractor - 294 783 and trailers 328 000.
Life time, a	10	
Operating time during lifetime, h	15 756.60	
Depreciation degree, %	20	
Depreciation value, N\$	66 870.82	
Interest rate, %	8.00	
Insurance, N\$/a	1 473.92	
Administration (office etc.), N\$/a	6 227.83	
Fuel price, N\$/l	6.14	
Fuel consumption, l/operating hour	5.00	
Fuel cost, N\$/operating hour	30.70	
Price of hydraulic oil, N\$/l	11.40	
Consumption of hydraulic oil, l	0.05	
Cost of hydraulic oil, N\$/operating h	0.57	
Price of motor oil, N\$/l	11.40	
Consumption of motor oil, l/operating h	0.10	
Cost of motor oil, N\$/operating hour	1.14	
Repair and maintenance, % of depreciation	25.00	
Moving costs, N\$/km	1.50	
Moving distance, km/a	0.00	
2. Fixed costs		
Capital depreciation, N\$/a	55 591.22	
Interest cost, N\$/a	29 809.80	
Total, N\$	85 401.02	
3. Overhead costs		
Administration and maintenance, N\$/a	6 227.83	
Moving costs, N\$/a	0.00	
Insurance, N\$/a	1 473.92	
Margin, N\$/a	0	
Total, N\$/a	7 701.76	
4. Salary costs		
Total, N\$	14 040.00	
5. Variable cost		
Fuel	48 372.76	
Repair and maintenance	13 897.80	
Hydraulic oil	898.13	
Motor oil	1 796.25	
Travel allowance	0	
Total, N\$/a	64 963.94	
Total, N\$/operating h		
6. Summary		
Total costs, N\$/a	172 106.72	
Cost, N\$/work place hour	89.87	
Cost, N\$/wet ton (20 w-%)	54.80	
Cost, N\$/MWh (20 w-%)	13.43	

Table 5. The cost breakdown of the tractor trailer unit. Road transport distance is 50 km (one-way). The wet ton and MWh units are presented in 20 w-% moisture content.

	Tractor trailer unit	Remarks
	Four trailers: 15 m ³ /trailer. Massey Ferguson tractor: 100 hp and 2 wheel drive.	Two trailers for transportation and 2 for chipping.
1. Basic data		
Utilization rate (= operating time/work place time)	82.28 %	
Average productivity, wet ton/work place h	1.31	Road transport distance 40 km (one-way)
Work place time, h/a	1 915.00	
Operating time, h	1 575.66	
Number of workers in the unit	1	
Salary including overheads, N\$/m	1 170.00 N\$	
Price, N\$	622 783.00	Tractor - 294 783 and trailers 328 000.
Life time, a	10	
Operating time during lifetime, h	15 756.60	
Depreciation degree, %	20	
Depreciation value, N\$	66 870.82	
Interest rate, %	8.00	
Insurance, N\$/a	1473.92	
Administration (office etc.)	6 227.83	
Fuel price, N\$/l	6.14	
Fuel consumption, l/operating hour	5.00	
Fuel cost, N\$/operating hour	30.70	
Price of hydraulic oil, N\$/l	11.40	
Consumption of hydraulic oil, l	0.05	
Cost of hydraulic oil, N\$/operating h	0.57	
Price of motor oil, N\$/l	11.40	
Consumption of motor oil, l/operating h	0.10	
Cost of motor oil, N\$/operating hour	1.14	
Repair and maintenance, % of depreciation	25.00	
Moving costs, N\$/km	1.50	
Moving distance, km/a	0.00	
2. Fixed costs		
Capital depreciation, N\$/a	55 591.22	
Interest cost, N\$/a	29 809.80	
Total, N\$	85 401.02	
3. Overhead costs		
Administration and maintenance, N\$/a	6227.83	
Moving costs, N\$/a	0.00	
Insurance, N\$/a	1 473.92	
Margin, N\$/a	0	
Total, N\$/a	7 701.76	
4. Salary costs		
Total, N\$	14 040.00	
5. Variable cost		
Fuel	48 372.76	
Repair and maintenance	13 897.80	
Hydraulic oil	898.13	
Motor oil	1796.25	
Travel allowance	0	
Total, N\$/a	64 964.94	
6. Summary		
Total costs, N\$/a	172 106.72	
Cost, N\$/work place hour	89.87	
Cost, N\$/wet ton (20 w-%)	68.61	
Cost, N\$/MWh (20 w-%)	16.82	

Appendix 4: The results from the cost analysis for the new mechanized production chain

Table 1. The cost breakdown of a rotary saw in a skid steer felling unit. The wet ton and MWh units are presented in 20 w-% moisture content.

	A rotary saw in Skid steer	Remarks
	John Deere332 Skid steer. Grace manufacturing Inc. Rotary saw	
1. Basic data		
Utilization rate (= operating time/work place time)	84.85 %	
Average productivity, wet ton/work place h	2.10	
Work place time, h/A	1 915.00	
Operating time, h	1 624.88	
Number of workers	1	
Salary including overheads, N\$/m	1 300 N\$	
Price, N\$	270 000.00	Skid steer 240 000 and Rotary saw 30 000.
Life time, a	10	
Depreciation degree, %	20.00	
Depreciation value, N\$	28 991.03	
Interest rate, %	8.00	
Insurance, N\$/a	1 200.00	
Administration (office etc.), N\$/a	5 530.00	
Fuel price, N\$/l	6.14	
Fuel consumption, l/operating hour	7.00	
Fuel cost, N\$/operating hour	42.98	
Price of hydraulic oil, N\$/l	11.40	
Consumption of hydraulic oil, l	0.20	
Cost of hydraulic oil, N\$/operating h	2.28	
Price of motor oil, N\$/l	11.40	
Consumption of motor oil, l/operating h	0.20	
Cost of motor oil, N\$/operating hour	2.28	
Repair and maintenance, % of depreciation	25.00	
Moving costs, N\$/km	1.50	
Moving distance, km/a	0.00	
2. Fixed costs		
Capital depreciation, N\$/a	24 100.90	
Interest cost, N\$/a	12 933.68	
Total, N\$	37 034.58	
3. Overhead costs		
Administration, N\$/a	5 530.00	
Moving costs, N\$/a	0.00	
Insurance, N\$/a	1 200.00	
Margin, N\$/a	0	
Total, N\$/a	6 730.00	
4. Salary costs		
Total, N\$	15 600.00	
5. Variable cost		
Fuel	69 829.61	
Repair and maintenance	6 025.23	
Hydraulic oil	3 704.32	
Motor oil	3 704.32	
Travel allowance	0	
Total, N\$/a	83 263.48	
6. Summary		
Total costs, N\$/a	142 628.06	
Cost, N\$/work place hour	74.48	
Cost, N\$/wet ton (20 w-%)	35.47	
Cost, N\$/MWh (20 w-%)	8.69	

Table 2. The cost breakdown of a grapple fork in a skid steer compiling unit. The wet ton and MWh units are presented in 20 w-% moisture content.

	A rotary saw in Skid steer	Remarks
	John Deere 332 Skid steer. Grace manufacturing Inc. Grapple fork.	
1. Basic data		
Utilization rate (= operating time/work place time)	84.85 %	
Total Production, wet ton/a	32 000	
Average productivity, wet ton/work place h	2.10	
Time at site, h/a	1 915.00	
Operating time, h	1 624.88	
Number of workers	1	
Salary including overheads, N\$/m	1 300 N\$	
Price, N\$	276 500.00	Skid steer 240 000 and Rotary saw 36 500.
Life time, a	10	
Depreciation degree, %	20.00	
Depreciation value, N\$	29 688.95	
Interest rate, %	8.00	
Insurance, N\$/a	1 200.00	
Administration (office etc.), N\$/a	5 530.00	
Fuel price, N\$/l	6.14	
Fuel consumption, l/operating hour	7.00	
Fuel cost, N\$/operating hour	42.98	
Price of hydraulic oil, N\$/l	11.40	
Consumption of hydraulic oil, l	0.20	
Cost of hydraulic oil, N\$/operating h	2.28	
Price of motor oil, N\$/l	11.40	
Consumption of motor oil, l/operating h	0.20	
Cost of motor oil, N\$/operating hour	2.28	
Repair and maintenance, % of depreciation	25.00	
Moving costs, N\$/km	1.50	
Moving distance, km/a	0.00	
2. Fixed costs		
Capital depreciation, N\$/a	24 681.09	
Interest cost, N\$/a	13 234.80	
Total, N\$	37 915.89	
3. Overhead costs		
Administration, N\$/a	5 530.00	
Moving costs, N\$/a	0.00	
Insurance, N\$/a	1 200.00	
Margin, N\$/a	0	
Total, N\$/a	6 730.00	
4. Salary costs		
Total, N\$	15 600.00	
5. Variable cost		
Fuel	69 829.61	
Repair and maintenance	6 170.27	
Hydraulic oil	3 704.32	
Motor oil	3 704.32	
Travel allowance	0	
Total, N\$/a	83 408.51	
6. Summary		
Total costs, N\$/a	143 654.40	
Cost, N\$/work place hour	75.01	
Cost, N\$/wet ton (20 w-%)	35.72	
Cost, N\$/MWh (20 w-%)	8.76	

Table 3. The cost break down of Morbark Hurricane drum chipper equipped with a loader-tractor chipping unit. The wet ton and MWh units are presented in 20 w-% moisture content.

	Chipper	Tractor
	Drum chipper Morbark Hurricane equipped with a loader.	Massey Ferguson: 80 hp and 2 wheel drive.
1. Basic data		
Utilization rate (= operating time/work place time)	83.55 %	61.0 %
Average productivity, ton/work place h	5.04	
Time at site, h/a	1 915.00	1 915.00
Operating time, h	1 559.98	1168.15
Number of workers	1	1
Salary including overheads, N\$/m	1 300.00 N\$	1 300.00 N\$
Price, N\$	714 750.00	225 217.00
Life time, a	7	10
Operating time during lifetime, h	10 919.89	11 681.5
Depreciation degree, %	25.00	20.00
Depreciation value, N\$	95 407.61	24 182.49
Interest rate, %	8.00	8.00
Insurance, N\$ per a	3 573.75	1 126.09
Administration and maintenance	7 147.50	2 252.17
Fuel price, N\$/l	5.64	6.14
Fuel consumption, l/operating hour	39.00	5.00
Fuel cost, N\$/operating hour	219.96	30.70
Price of hydraulic oil, N\$/l	11.40	26.00
Consumption of hydraulic oil, l	0.10	0.00
Cost of hydraulic oil, N\$/operating h	1.14	0.00
Price of motor oil, N\$/l	11.40	11.40
Consumption of motor oil, l/operating h	0.10	0.10
Cost of motor oil, N\$/operating hour	1.14	1.14
Repair and maintenance, % of depreciation	35.00	25.00
Moving costs, N\$/km	1.50	0.00
Moving distance, km/a	500.00	0.00
2. Fixed costs		
Capital depreciation, N\$/a	88 477.48	20 103.45
Interest cost, N\$/a	35 945.40	10 708.12
Total, N\$	124 422.89	30 811.57
3. Overhead costs		
Administration, N\$/a	7 147.50	2 252.17
Moving costs, N\$/a	750	0.00
Insurance, N\$/a	3 573.75	1 126.09
Margin, N\$/a	0	0.00
Total, N\$/a	11 471.25	3 378.26
4. Salary costs		
Total, N\$	15 600.00 (one man)	15 600.00 (one man)
5. Variable cost		
Fuel	343 133.20	35 862.21
Repair and maintenance	30 967.12	5025.86
Hydraulic oil	1778.37	0
Motor oil	1778.37	1 331.69
Travel allowance	0	0
Total, N\$/a	377 657.06	42 219.76
6. Summary		
Total costs, N\$/a	529 151.20	92 009.59
7. Summary – chipper + tractor		
Total costs, N\$/a	621 160.79	
Cost, N\$/work place hour	324.37	
Cost, N\$/wet ton (20 w-%)	64.36	
Cost, N\$/MWh (20 w-%)	15.77	

Table 4. The cost breakdown of the tractor trailer -road transport unit. Road transport distance is 20 km (one-way). The wet ton and MWh units are presented in 20 w-% moisture content.

	Tractor trailer unit	Remarks
	A Junkkari-trailer – 38 m ³ . Massey Ferguson tractor: 100 hp and 2 wheel drive.	
1. Basic data		
Utilization rate (= operating time/work place time)	84.45 %	Road transport distance 20 km (one-way).
Average productivity, ton/work place h	4.01	
Work place, h/a	1 915.00	
Operating time, h	1 617.22	
Number of workers in the unit	1	
Salary including overheads, N\$/m	1 300.00 N\$	
Price, N\$	580 783.00	Tractor 294 783 and trailer 286 000.
Life time, a	10	
Operating time during lifetime, h	16 172.2	
Depreciation degree, %	20	
Depreciation value, N\$	57 233.98	
Interest rate, %	8.00	
Insurance, N\$/a	1473.92	
Administration (office etc.), N\$/a	5 330.33	
Fuel price, N\$/l	6.14	
Fuel consumption, l/operating hour	5.00	
Fuel cost, N\$/operating hour	30.70	
Price of hydraulic oil, N\$/l	11.40	
Consumption of hydraulic oil, l	0.05	
Cost of hydraulic oil, N\$/operating h	0.57	
Price of motor oil, N\$/l	11.40	
Consumption of motor oil, l/operating h	0.10	
Cost of motor oil, N\$/operating hour	1.14	
Repair and maintenance, % of depreciation	25.00	
Moving costs, N\$/km	1.50	
Moving distance, km/a	0.00	
2. Fixed costs		
Capital depreciation, N\$/a	51 842.19	
Interest cost, N\$/a	27 799.45	
Total, N\$	79 641.64	
3. Overhead costs		
Administration, N\$/a	5 330.33	
Moving costs, N\$/a	0.00	
Insurance, N\$/a	1 473.92	
Margin, N\$/a	0	
Total, N\$/a	6 804.25	
4. Salary costs		
Total, N\$	15 600.00	
5. Variable cost		
Fuel	49 648.65	
Repair and maintenance	11 894.98	
Hydraulic oil	921.82	
Motor oil	1843.63	
Travel allowance	0	
Total, N\$/a	64 309.08	
6. Summary		
Total costs, N\$/a	166 354.97	
Cost, N\$/work place hour	86.87	
Cost, N\$/wet ton (20 w-%)	21.66	
Cost, N\$/MWh (20 w-%)	5.31	

Table 5. The cost breakdown of the tractor trailer road transport unit. Road transport distance is 30 km (one-way). The wet ton and MWh units are presented in 20 w-% moisture content.

	Tractor trailer unit	Remarks
	A Junkkari-trailer – 38 m ³ . Massey Ferguson tractor: 100 hp and 2 wheel drive.	
1. Basic data		
Utilization rate (= operating time/ work place time)	84.45 %	Road transport distance 30 km (one-way).
Average productivity, wet ton/work place h	2.67	
Work place time, h/a	1 915.00	
Operating time, h	1 617.22	
Number of workers in the unit	1	
Salary including overheads, N\$/m	1 300.00 N\$	
Price, N\$	580 783.00	Tractor - 294 783 and trailer 286 000.
Life time, a	10	
Depreciation degree, %	20	
Depreciation value, N\$	57 233.98	
Interest rate, %	8.00	
Insurance, N\$/a	1 473.92	
Administration (office etc.), N\$/a	5 330.33	
Fuel price, N\$/l	6.14	
Fuel consumption, l/operating hour	5.00	
Fuel cost, N\$/operating hour	30.70	
Price of hydraulic oil, N\$/l	11.40	
Consumption of hydraulic oil, l	0.05	
Cost of hydraulic oil, N\$/operating h	0.57	
Price of motor oil, N\$/l	11.40	
Consumption of motor oil, l/operating h	0.10	
Cost of motor oil, N\$/operating hour	1.14	
Repair and maintenance, % of depreciation	25.00	
Moving costs, N\$/km	1.50	
Moving distance, km/a	0.00	
2. Fixed costs		
Capital depreciation, N\$/a		
Interest cost, N\$/a	51 842.19	
Total, N\$	27 799.45	
	79 641.64	
3. Overhead costs		
Administration, N\$/a		
Moving costs, N\$/a	5 330.33	
Insurance, N\$/a	0.00	
Margin, N\$/a	1 473.92	
Total, N\$/a	0	
	6 804.25	
4. Salary costs		
Total, N\$	15 600.00	
5. Variable cost		
Fuel		
Repair and maintenance		
Hydraulic oil	49 648.65	
Motor oil	11 894.98	
Travel allowance	921.82	
Total, N\$/a	1843.63	
	0	
6. Summary		
Total costs, N\$/a	64 309.08	
Cost, N\$/work place hour	166 354.97	
Cost, N\$/wet ton (20 w-%)	86.87	
Cost, N\$/MWh (20 w-%)	32.54	
	7.97	

Table 6. The cost breakdown of the tractor trailer road transport unit. Road transport distance is 40 km (one-way). The wet ton and MWh units are presented in 20 w-% moisture content.

	Tractor trailer unit	Remarks
	A Junkkari-trailer – 38 m ³ . Massey Ferguson tractor: 100 hp and 2 wheel drive.	
1. Basic data		
Utilization rate (operating time/work place time)	84.45 %	Road transport distance 40 km (one-way).
Average productivity, wet ton/work place h	2.00	
Work place time, h/a	1 915.00	
Operating time, h	1 617.22	
Number of workers in the unit	1	
Salary including overheads, N\$/m	1 300.00 N\$	
Price, N\$	580 783.00	Tractor 294 783 and trailer 286 000.
Life time, a	10	
Operating time during lifetime, h	16 172.2	
Depreciation degree, %	20	
Depreciation value, N\$	57 233.98	
Interest rate, %	8.00	
Insurance, N\$/a	1 473.92	
Administration (office etc.), N\$/a	5 330.33	
Fuel price, N\$/l	6.14	
Fuel consumption, l/operating hour	5.00	
Fuel cost, N\$/operating hour	30.70	
Price of hydraulic oil, N\$/l	11.40	
Consumption of hydraulic oil, l	0.05	
Cost of hydraulic oil, N\$/operating h	0.57	
Price of motor oil, N\$/l	11.40	
Consumption of motor oil, l/operating h	0.10	
Cost of motor oil, N\$/operating hour	1.14	
Repair and maintenance, % of depreciation	25.00	
Moving costs, N\$/km	1.50	
Moving distance, km/a	0.00	
2. Fixed costs		
Capital depreciation, N\$/a	51 842.19	
Interest cost, N\$/a	27 779.45	
Total, N\$	79 641.64	
3. Overhead costs		
Administration, N\$/a	5 330.33	
Moving costs, N\$/a	0.00	
Insurance, N\$/a	1 473.92	
Margin, N\$/a	0	
Total, N\$/a	6 804.25	
4. Salary costs		
Total, N\$	15 600.00	
5. Variable cost		
Fuel	49 648.65	
Repair and maintenance	11 894.98	
Hydraulic oil	921.82	
Motor oil	1 843.63	
Travel allowance	0	
Total, N\$/a	64 309.08	
6. Summary		
Total costs, N\$/a	166 354.97	
Cost, N\$/work place hour	86.87	
Cost, N\$/wet ton (20 w-%)	32.54	
Cost, N\$/MWh (20 w-%)	7.97	

Table 7. The cost breakdown of the tractor trailer road transport unit. Road transport distance is 50 km (one-way). The wet ton and MWh units are presented in 20 w-% moisture content.

	Tractor trailer unit	Remarks
	A Junkkari-trailer – 38 m ³ . Massey Ferguson tractor :100 hp and 2 wheel drive.	
1. Basic data		
Utilization rate (= operating time/work place time)	84.45 %	Road transport distance 50 km (one-way).
Average productivity, wet ton/work place h	1.60	
Time at site, h/a	1 915.00	
Operating time, h	1 617.22	
Number of workers in the unit	1	
Salary including overheads, N\$/m	1 300.00 N\$	
Price, N\$	580 783.00	Tractor 294 783 and trailer 286 000.
Life time, a	10	
Operating time during lifetime, h	16 172.2	
Depreciation degree, %	20	
Depreciation value, N\$	57 233.98	
Interest rate, %	8.00	
Insurance, N\$/a	1 473.92	
Administration (office etc.), N\$/a	5 330.33	
Fuel price, N\$/l	6.14	
Fuel consumption, l/operating hour	5.00	
Fuel cost, N\$/operating hour	30.70	
Price of hydraulic oil, N\$/l	11.40	
Consumption of hydraulic oil, l	0.05	
Cost of hydraulic oil, N\$/operating h	0.57	
Price of motor oil, N\$/l	11.40	
Consumption of motor oil, l/operating h	0.10	
Cost of motor oil, N\$/operating hour	1.14	
Repair and maintenance, % of depreciation	25.00	
Moving costs, N\$/km	1.50	
Moving distance, km/a	0.00	
2. Fixed costs		
Capital depreciation, N\$/a		
Interest cost, N\$/a	51 842.19	
Total, N\$	27 799.45	
	79 641.64	
3. Overhead costs		
Administration, N\$/a		
Moving costs, N\$/a	5 330.33	
Insurance, N\$/a	0.00	
Margin, N\$/a	1 473.92	
Total, N\$/a	0	
	6 804.25	
4. Salary costs		
Total, N\$	15 600.00	
5. Variable cost		
Fuel	49 648.65	
Repair and maintenance	11 894.98	
Hydraulic oil	921.82	
Motor oil	1843.63	
Travel allowance	0	
Total, N\$/a	64 309.08	
6. Summary		
Total costs, N\$/a	166 354.97	
Cost, N\$/work place hour	86.87	
Cost, N\$/wet ton (20 w-%)	32.54	
Cost, N\$/MWh (20 w-%)	7.92	

Author(s) Leinonen, Arvo		
Title Wood chip production technology and costs for fuel in Namibia		
Abstract <p>This work has been done in the project where the main target is to evaluate the technology and economy to use bush biomass for power production in Namibia. The project has been financed by the Ministry for Foreign Affairs of Finland and the Ministry of Agriculture, Water and Forestry of the Republic of Namibia.</p> <p>The target of this study is to calculate the production costs of bush chips at the power plant using the current production technology and to look possibilities to develop production technology in order to mechanize production technology and to decrease the production costs. The wood production costs are used in feasibility studies, in which the technology and economy of utilization of wood chips for power generation in 5, 10 and 20 MW electric power plants and for power generation in Van Eck coal fired power plant in Windhoek are evaluated.</p> <p>Field tests were made at Cheetah Conservation Farm (CCF) in Otjiwarongo region. CCF is producing wood chips for briquette factory in Otjiwarongo. In the field tests it has been gathered information about this CCF semi-mechanized wood chip production technology. Also new machines for bush biomass chip production have been tested. A new mechanized production chain has been designed on the basis of this information. The production costs for the CCF semi-mechanized and the new production chain have been calculated. The target in the moisture content to produce wood chips for energy is 20 w-%.</p> <p>In the semi-mechanized wood chip production chain the work is done partly manually, and the supply chain is organized into crews of 4–8 men. The production chain consists of manual felling and compiling, drying, chipping with mobile chipper and manual feeding and road transport by a tractor with two trailers. The CCF production chain works well. The chipping and road transport productivity in the semi-mechanized production chain is low.</p> <p>New production machines, such as chainsaw, brush cutter, lawn mover type cutter, rotator saw in skid steer and Nisula harvester head for felling, were tested at CCF. The most effective felling device in the tests appeared to be rotary saw in the skid steer. Based on these tests it was designed a new totally mechanized production chain. The working phases in this mechanized production chain are felling with a rotary saw in skid steer, compiling with a grapple fork in skid steer, drying in the heaps, chipping with a mobile chipper with a loader and road transport with a tractor trailer. This new production chain is not fully tested in Namibia.</p> <p>The calculated production and road transport costs of wood chips with the designed new mechanized production chain are about 15% lower than those of the semi-mechanized production chain. The production costs with the new mechanized production chain are 170.5 N\$/wet ton (4.4 Euros/MWh) for 5 MWe power plant, 181.4 N\$/wet ton (4.7 Euros/MWh) for 10 MWe power plant and 192.3 N\$/wet ton (4.9 Euros/MWh) for 20 MWe power plant. The average road transport distance in the calculation is 30 km for a 5 MWe, 40 km for 10 MWe and 50 km for 20 MWe power plants. The production and road transport costs of wood chips from Okahandja to Van Eck power plant are 238.4 N\$/wet ton (6.1 Euros/MWh) and from Otjiwarongo 350.3 N\$/wet ton (9.0 Euros/MWh) using the new mechanized wood chip production chain. The wet ton and MWh units are presented in 20 w-% moisture content.</p> <p>The designed mechanized production chain is very effective and suitable for large-scale wood chip production. With the new mechanized production chain the labour force demand of producing wood chips is 32 men for a 5 MWe, 65 men for 10 MWe and 136 men for 20 MWe power plant.</p> <p>The average yield in selective bush harvesting at CCF was 7.0 wet tons (20 w-%) per hectare. The annual total wood chip production area is 4 600 ha in the case of a 5 MWe power plant, 8 600 ha for a 10 MWe and 16 900 ha for 20 MWe power plant if the harvesting yield is 7.0 wet tons per ha in 20 w-% moisture content.</p>		
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Bush encroachment is a very big national problem in Namibia. Approximately 25 million hectares of land is subjected to some form of encroachment. The bush encroachment has drastically reduced the productive potential of large parts of the farming area. Traditionally bushes have been utilized in Namibia as firewood. VTT has evaluated to use bush biomass for power production. In the feasibility studies it has been evaluated the economy to produce electricity in 5, 10 and 20 MWe power plants. This report is focused on the bush chip production technology and costs. Very important part of the wood chip production study has been the field tests at Cheetah Conservation farm (CCF) in Otjiwarongo region. CCF is producing wood chips for briquette factory in Otjiwarongo town. In the field tests it has been gathered information about the CCF semi-mechanized wood chip production chain. Also new machines for wood chip production have been tested at CCF. A new mechanized production chain has been designed based on the test results.

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