Bush encroachment – the challenging resource for the renewable bioenergy in Namibia

SUBTASK FINAL REPORT – Draft

Wood chip production technology and costs for fuel in Namibia

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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 of Foreign Affairs in Finland and the Ministry of Agriculture, Water and Forest in Namibia.

The target of this study is to calculate the harvesting costs of bush chips at the power plant using the current harvesting technology and to look possibilities to develop harvesting technology in order to mechanize harvesting technology and to decrease the harvesting costs. The wood harvesting 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 harvesting technology. Also new machines for bush biomass chip harvesting have been tested. A new mechanized harvesting chain has been designed on the basis of this information. The harvesting costs for the CCF semi-mechanized and the new harvesting chain have been calculated. The target in the production is 20 w-% moisture content.

In the semi-mechanized wood chip harvesting chain the work is done partly manually, and the supply chain is organized into crews of 4-8 men. The harvesting 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 harvesting chain works well. The chipping and road transport capacity in the semi-mechanized harvesting chain is low.

New 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 harvesting chain. The working phases in this mechanized harvesting 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 harvesting chain is not fully tested in Namibia.

The calculated harvesting costs of using the designed new mechanized harvesting chain are about 24% lower than those of the semi-mechanized harvesting chain. The harvesting costs with the new mechanized harvesting chain are 167.5 N$/wet ton (4.3 Euros/MWh, 20 w-%)) for 5 MWe power plant, 179.6 N$/wet ton (4.6 Euros/MWh, 20 w-%)) for 10 MWe power plant and 191.7 N$/wet ton (4.9 Euros/MWh, 20 w-%) for 20 MWe power plant. The road transport distance in the calculation is 20 km for a 5 MWe, 30 km for 10 MWe and 40 km for 20 MWe power plants.

The semi-mechanized harvesting chain is not very suitable for wood chip production in large scale because of high costs and high labour force demand. The mechanised harvesting chain is the best. With the new mechanized harvesting chain the labour force demand of producing wood chips is 29 men for a 5 MWe, 60 men for 10 MWe and 127 men for 20 MWe power plant.

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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 harvesting technology.

The project has been financed by the Ministry of Foreign Affairs in Finland and the Ministry of Agriculture, Water and Forest in Namibia. The project is carried out between May the 1st 2006 and May the 30th 2007. The project manager is Markku Orjala from Technical Research Centre of Finland (VTT), who is also responsible for the feasibility study on the electricity production in the project. Dr. Arvo Leinonen is responsible for the bush harvesting 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 harvesting cost analysis for the project.

This report is dealing with the bush harvesting technology. The results from the harvesting tests, made at Cheetah Conservation Fund (CCF), have been presented in this report. The semi-mechanized bush chip harvesting 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 harvesting, have also been tested at CCF. Based on the information, gathered at CCF, it has been calculated the bush chip harvesting costs for power production.

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 harvesting 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.

Author

Contents

1 Introduction

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. 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 metric 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.

A number of different elements have to be taken in to consideration, when assessing the feasibility of harvesting the invader bush. Large scale harvesting has to be planned carefully, monitored and followed up.

At present there is one company in Namibia producing bush chips, the Cheetah Conservation farm (CCF) in Otjiwarongo region. CCF is producing bush chips for their briquette factory called Bushblok in Otjiwarongo town. At CCF the harvesting chain consists of following working phases: cutting, compiling, drying, chipping and road transport. The felling of bushes is made manually by axes. The bushes are left to dry after cutting at the harvesting site for about one to two weeks. After drying the bushes are compiled manually by pulling them by the side of the strip roads. 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 harvesting chain used at CCF is called CCF semi-mechanized chain.

International Development Consultancy (IDC) has made some assessment of wood chip harvesting in Namibia in 2002 (International Development Consultancy 2002). In this report it is stated that manual harvesting is not an option for large scale wood chip harvesting. IDC proposes the use of a semi-labour intensive harvesting chain. In this chain the bushes are cut manually by chainsaws. The chipping is made by tub grinder and road transport by containers. Total harvesting costs of this harvesting chain are 11.2 Euros per ton (106.8 N$ per wet ton) (2.74 Euros/MWh, 20 W-%). The share of felling and compiling costs of the total harvesting

costs is 33%, and the share of chipping and road transport 67%. The average road transport distance used in this calculation is 25 km. The high grinding capacity (100 tons per hour) in the calculation is one reason for the low wood chip harvesting costs.

2 Contents and target of the study

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

The wood harvesting 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 harvesting technology study is the field tests made at the Cheetah Conservation Farm (CCF) in Otjiwarongo region. Semi-mechanized harvesting technology is used for wood chip production at CCF for briquette production. Information on this semi-mechanized bush biomass harvesting technology has been gathered in the field tests. New machines for bush biomass chip harvesting 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.

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

All results are presented in this report.

3 The harvesting tests at CCF farm

3.1 The realization of the harvesting 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 harvesting tests were made at Cheetah view -farm. The CCF farm is located about 44 km from Otiwarongo 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 harvesting chain. The annual briquette output of CCF is about 6 000 tons.

The semi-mechanized harvesting chain and new harvesting 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 harvesting 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 0.5 - 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.
- 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
- 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 capacity of different working phases in tons per hour, as well as the productivity in hectares per hour (ha/h). The productivity in the working phases is presented in total site time.

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, ton/h),
- The fuel consumption of the machines (l/ton),
- The drying of bushes at the cutting site (w-%),
- The bulk density of bush chips (kg/m^3),

- The solid density of bush (kg/m^3) 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 harvesting

The Ministry of Agriculture, Water and Forestry (MAWF) - Directorate of Forestry (DoF) requires a permit to be obtained for all commercial-scale bush harvesting. 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 'Harvesting 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 Harvesting realization at the test plots

The number of test plots of the test period in February 2007 was 9 test plots. The bush species and the number of bushes before and after the harvesting were monitored at the test plots 1, 6 and 9 (app. 2). The test plots 1 - 9 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. 2).

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

Figure 2. Test plot 9 where the bush density was high (2 027 bushes per hectare).

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. 3).

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

The average harvested yield at the test plots 1 - 8 was 6.7 wet tons (20 w-%) per hectare. The yield at the test plot 9 was 22.0 wet tons per hectare (20 w-%).

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 13w-%) of wood chips in briquette production. The target in 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 3. Savanna landscape on test plots at CCF after harvesting in February 2007.

3.3 The results of the CCF semi-mechanized harvesting chain

3.3.1 The CCF semi-mechanized harvesting chain

Most of the harvesting 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 undelimbed 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 tractor.

Wood chips are hauled to the plant in the same trailers in which they are chipped into, two trailers articulated.

3.3.2 Making the strip roads

Strip roads have to be made before it is possible to start the harvesting. The strip roads (fig. 4) are designed for the vehicles used in the harvesting. The strip roads are made by bulldozers by pushing the vegetation aside from strip roads (fig. 5). 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 4. The strip road at felling stand. The distance of the strip road is 50 m (photo by Arvo Leinonen).

Figure 5. The bulldozer by which the strip roads are made (photo by Arvo Leinonen).

3.3.3 Felling

In the CCF semi-mechanized harvesting chain the felling is carried out manually by axes (fig. 6). Manual felling was tested at test plots 1, 6 and 7 at CCF. One felling crew consists of four men (fig. 7). 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 per man-day (20 w-%) when the density of bushes is average - 6.7 wet tons (20 w-%) per ha. With the crew 2 the productivity was only 0.82 wet tons (20 w-%) 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 (20 w-%) per ha. The average productivity of the felling crew 1 was 0.19 ha/man-day on the average density harvesting plot and 0.1 ha per man-day at the harvesting plot classified thick (app. 2).

One man 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.

As the manual felling capacity of 1.7 wet tons (20 w-%) per man-day is used in the cost calculations.

Figure 6. Felling of the bushes is made manually by axes (photo by Arvo Leinonen).

Figure 7. The felling crew consists of four men (photo by Arvo Leinonen).

3.3.4 Compiling

In the semi-mechanized method at CCF the bushes are compiled manually after cutting by pulling them into heaps by the side of the strip roads (fig. 8). In the compiling tests the distance between strip roads was 100 m. Sometimes the bushes were compiled inside a 1 ha harvesting plot. By this way the pulling distance is not too long. The compiling grew 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 is 2.0 wet tons per man-day and 0.27 ha per man-day (app. 3).

In the cost calculations the compiling productivity used was 2.0 wet tons per-man day (20 % moisture content).

Figure 8. 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. 9). 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 in the tests was 35.2% (Acacia milliner) (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 10. 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 9. Bush heaps beside the strip road (photo by Arvo Leinonen).

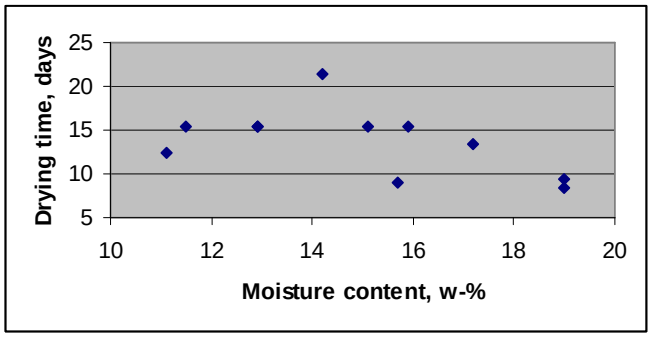

Figure 10. The drying of bushes in the heaps at different test plots at CCF.

3.4.1 Chipping

In the semi-mechanized harvesting 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. 12). At the CCF the truck trailer was not used anymore in June. At that time the chipper was connected to a tractor trailer (fig. 12) 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 capacity: up to 380 mm,
- Equipped with own diesel engine - 59 - 96 kW,
- Weight: 3 175 kg,
- Infeed throat opening: 51 cm x 38 cm and
- Drum diameter: 51 cm
- Drum width 58 cm.

In the chipping tests the productivity of the drum chipper (Model 13) was 20.14 wet tons per day in 20 w-% moisture content (app. 2). The fuel consumption, measured in June 2007, was 4.4 l per wet ton (20 w-%). 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 day (8 h) in 20 w-% moisture content.

Figure 11. Bush chipping with Morbark Tornado Model 13 drum chipper at CCF in February 2007 (photo by Arvo Leinonen).

Figure 12. 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. 13). 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. 15). 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. 14). In tractor trailer the unloading is made by tipping unit (fig. 16).

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 4.0 wet ton (20 w-%). The average density of bush chips in the truck trailer is 229 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 4.65 h. The average productivity was 7.64 wet tons per day (20 w-%).

The volume of the tractor trailer is 15.0 m^3, the length 5.0 m, the width 5.0 m and the height 2.0 m. The weight of tractor trailer load (2 trailers) was 5.1 wet tons (10.55 w-%) corresponding to 5.7 wet tons (20 w-%). The road transport distance to Otjiwarongo is 50 km. The average total transport time including the chipping, driving time to the factory, unloading and driving back to CCF was 4.7 h. The average productivity was 9.7 wet tons per day (20 w-%). The consumption of the diesel oil in tractor trailer transport was 9.8 l per wet ton (20 w-%) and 0.28 l/km. The productivity of the road transport, used in the calculations was 10.5 wet tons (20 w-%) per day (8 h). This new figure was obtained from later measurements made by Bruce Brewer from CCF.

Figure 13. Weighing the truck trailer at weighing station in Otjiwarongo in February 2007.

Figure 14. Unloading the truck trailer at briquette factory in Otjiwarongo (photo by Arvo Leinonen).

Figure 15. Tractor unit for bush chips road transport at CCF in June 2007 (photo by Arvo Leinonen).

Figure 16. 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. 17 and 18). The rotating speed is controlled by the operator with the hand.

The felling with brush cutter was tested at the test plots 1 and 3. The average felling productivity of the brush cutter was 0.41 ha or 2.5 wet tons per man-day. In manual felling the productivity was 0.19 ha or 1.7 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, used in the felling tests, was STIHL FS550. The main parameters of the brush cutter are:

- Two stroke engine,
- Cylinder capacity 55 cm^3
- Engine power 2.8 kW,
- Weight 10 kg and
- Fuel tank volume 0.75 l.

Figure 17. Felling bushes by brush cutter in February 2007 at CCF (photo by Arvo Leinonen).

Figure 18. Brush cutter STIHL FS550 at CCF (photo by Arvo Leinonen).

3.5.2 Chain saw

In Finland the chain saw is used for manual harvesting 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. 18 - 20). The operator controls the rotating speed of the chains by hand.

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

The operator did not like to work with the brush cutter. 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 m^3
- 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 Euro.

Figure 19. Felling bushes by chainsaw at CCF in February 2007 (photo by Arvo Leinonen).

Figure 20. Sharpening the chainsaw at CCF (photo by Arvo Leinonen).

3.5.3 Lawn mower type cutter

A lawn mover type cutter (fig. 21) 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 cutter. By this way it was easy to cut the bushes near the ground.

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 on one test plot number 8. The productivity of the cutter was 0.32 ha or 2.3 wet tons per man-day. The productivity is calculated for a crew consisting of two men.

The productivity of lawn mover 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 21. Lawn mower type cutter.

3.5.4 Nisula harvester head cutter

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

Nisula harvester head was operated by a Terex 860SX backhoe loader. Harvester head was mounted to the boom at the back side of the loader (fig. 22). 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 Niusla 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 three day test period between May 29th and June 1st 2007 at the CCF farm (fig. 23 and 24). Area of about 1 ha was harvested with Nisula harvester head. 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. One test plot (number 2) was harvested totally with Nisula harvester head. The area of the test plot was 0.26 ha. It took 7 hours to harvest this plot. The capacity of Nisula harvester head was only about 0.30 ha per man-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 capacity 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 22. 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 23. Nisula harvester head at work (photo by Arvo Leinonen).

Figure 24. Nisula harvester head at work (photo by Arvo Leinonen).

3.5.5 Skid steer

Use of skid steer for felling the bushes was also studied in the project (fig. 25). 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. 26).

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 and in the second test 0.5 ha. The productivity in the first test was 0.33 ha per h and in the second test it was 0.29 ha per h. The average

productivity is 0.31 ha per hour and it is good. The productivity of manual cutting was only 0.2 ha per 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 25. Skid steer with rotary saw at CCF in June 2007(photo by Arvo Leinonen).

Figure 26. 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 capacity 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. A tractor trailer was used for transferring the material to road side (fig. 27). 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. 28). Unloading of the bushes from the tractor trailer is also made by Nisula harvester head (fig. 29 and 30).

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 at the roadside and to chip the material there.

Figure 27. The bushes are laoded to the trailer by Nisula harvester head (photo by Arvo Leinonen).

Figure 28. Terrain transport of bushes by tractor trailer (photo by Arvo Leinonen).

Figure 29. Unloading the bushes from the tractor trailer beside the road (photo by Arvo Leinonen).

Figure 30. 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 m^3 of chips per hour. At the CCF the productivity was only about 8 m^3 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. 31). Because of this the chipper could not chip the material. 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 31. 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 harvesting 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 millifera).

The measured average moisture content of bush chips at the briquette factory was 15.0 w-% in February 2007. 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. 32). The density was measured 8 times. The moisture content in the measurements varied between 7.91 and 35.2 w-%. The average loose density of wood chips was 135.5 kg per m^3 (0 w-%) and 169.4 kg per m^3 (20 w-%).

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/m^3 in 20 w-% moisture content and 159.8 kg/m^3 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 millifera) 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 litters and the weight 4.8 kg. Based on these figures the solid density of bush was 1.1 kg/dm^3. The moisture content of the measured bush was 25.7 w-%.

Table 1. Particle size measurements of wood chips.

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

Figure 32. Measuring the wood chip density at CCF briquette factory in Otjiwarongo.

3.7 Conclusions from the harvesting tests

The measured productivities of different tested machines in the harvesting tests are presented in the table 2.

The conclusions from the harvesting study were:

- Ø The CCF semi-mechanized harvesting chain works well,
- Ø Chipping capacity in CCF semi-mechanized harvesting chain is low,
  - The productivity can be increased by using a loader for the feeding,
- Ø The road transport productivity in the CCF semi-mechanized chain is low,
- Ø 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,
- Ø The bushes dry in the stockpiles beside the road very rapidly
  - It takes only two weeks to dry under 20 w-% moisture content and,
- Ø 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 in different working with different machines in the harvesting tests.

Machine	Productivity	Productivity wet tons/

	ha/day	man-day(machine-day) 20 w-%
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	0.27	20.14
Road transport **- 50 km**		
- Truck trailer		7.6
- Tractor trailers (2)		10.5

4 Cost analysis of the bush chip harvesting

4.1 The CCF semi-mechanized harvesting 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 harvesting. Based on the study the total yield of wood fuel is 6.7 wet tons per hectare.

The harvesting costs are calculated with the cost calculation model of VTT. The total annual costs for each working phase in the harvesting chain are calculated first. When the total annual working time is known, it is possible to calculate the hourly costs for the working phase. Dividing the hourly cost by productivity we get the costs of wood chips per ton or per MWh. The costs in the analysis are divided into fixed costs, overhead costs, wages 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 harvesting 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.

The wood chip harvesting costs are calculated for the prevailing harvesting 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 undelimbed 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. 8 men feed the bushes into the chipper and 1 man drives the tractor. The chipper used in the cost analysis is a Morbark Tornado 145 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 productivity for 20, 30 and 40 km transport distance is calculated based on the road transport productivity got from the study. In the study the road transport distance was 50 km.

The demand for the wood chips in different power plants is presented in the table 4. The total harvesting area in 10 years' bush rotation is 48 000 ha in 5 MW_e power plant, 96 000 ha in 10 MW_e and 192 000 ha in 20 MW_e power plant. The radius of 48 000, 96 000 and 192 000 ha circle would correspondingly be 12.4, 17.5 and 24.7 km.

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.

Table 3. Basic parameters in the cost calculation. The productivity is presented in productive hour.

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
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/day/man	4 men in crew
Productivity of compiling	2.0 wet ton/day/man	4 men in crew
Productivity of chipping	20.14 wet ton/day/crew (2.55 ton/h)	8 men in crew + 1 driver
Productivity of road transport	10.5 wet ton/day/crew (1.31 ton/h)	1 men in crew, 50 km distance

Table 4. The wood chip demand for different power plant size.

Power plant size	5 MWe	10 MWe	20 MWe
Wood chip demand per year (tons, 20 w-%)	32 000	64 000	128 000
Wood chip demand per year (MWh, 20 w-%)	130 500	261 000	522 000
Total harvesting area in one year (ha)	4 800	9 600	19 200
Total harvesting area in 10 years' rotation (ha)	48 000	96 000	192 000

4.1.2 The harvesting costs

All harvesting costs are presented in the table 5. The harvesting costs include also the organization costs. These costs consist of the management of the harvesting groups. It is assumed that 10 men are needed for organizing the harvesting 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 harvesting business.

The total wood chip harvesting costs with the CCF semi-mechanized harvesting chain are 53.7 - 66.0 N$/MWh (5.6 - 6.9 Euro/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 in 5 MWe power plant would be 20 km, in 10 MWe it would be 30 km and in 20 MWe power plant it would be 40 km. With these road transport distances the harvesting area from the total land area would be about 10 %. When using these road transport distances the harvesting costs for 5 MWe power plant are 53.7 N$/ton(5.6 Euro/MWh), for 10 MWe power plant 57.8 N$/MWh (6.1 Euro/MWh) and for 20 MWe 61.9 N$/MWh (6.5 Euro/MWh).

The main costs are the chipping costs. The share of the chipping cost of the total costs is 43 - 53% depending on the road transport distance. The road transport costs are also high, 15 - 31% of the total costs.

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 22% of the total chipping costs. In road transport the labor costs are about 7% of the total road transport costs. The rest of the costs consist mainly of the machine and material costs.

Table 5. The total harvesting costs with the current harvesting chain using different road transport distance (one –way).

Working phase	N$/ton	Euro/ton	N$/MWh	Euro/MWh
Felling	34.49	3.62	8.46	0.89
Compiling	29.33	3.08	7.19	0.75
Chipping	116.61	12.23	28.56	3.00
Road transport				
- 20 km	33.67	3.53	8.25	0.87
- 30 km	50.51	5.30	12.37	1.30
- 40 km	67.13	7.04	16.44	1.73
- 50 km	84.05	8.81	20.58	2.16
Organization	4.88	0.51	1.20	0.13
All together				
- 20 km	218.98	22.97	53.66	5.64
- 30 km	235.82	24.74	57.78	6.07
- 40 km	252.44	26.48	61.85	6.50
- 50 km	269.36	28.25	65.99	6.93

Table 6. The labour costs in the harvesting chain. The total annual working time at the site is 1915 h.

Working phase	Number of men in one crew	Salary including 30 % overhead N$/month/man	Total crew salary N$/a	Productivity wet ton/a/crew	Cost N$/ton	Cost N$/MWh (euro/MWh)
Felling	4	1 170	56 160	1 628	34.49	8.46 (0.89)
Compiling	4	1 170	56 160	1 915	29.33	7.19 (0.75)
Chipping	9	1 170	126 360	4 820	26.22	6.43 (0.67)
Road transport						
- 20 km	1	1 170	14 040	6300	2.22	0.55 (0.06)
- 30 km	1	1 170	14 040	4200	3.34	0.82 (0.09)
- 40 km	1	1 170	14 040	3150	4.46	1.09(0.11)
- 50 km	1	1 170	14 040	2500	5.62	1.38 (0.14)
Organization	10	1 300	156 000	32 000	4.88	1.19 (0.13)

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

The manpower needed in the harvesting of wood chips for each power plant is presented in the table 7. The number of machines for harvesting wood chips for each power plant size is presented in the table 8. Table 9 presents the investments (Euro) for the harvesting machinery for each power plant size. The manpower needed in the procurement chain of wood chips is presented in the following table.

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.

The harvesting 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 m^3).

Table 7. The manpower needed in the semi-mechanized harvesting chain of wood chips.

Working phase	**Productivity wet ton/a/crew**	**5 MWe**	**10 MWe**	**20 MWe**
Felling	1 628	20 crews - 80 men	40 crews - 160 men	80 crews - 320 men
Compiling	1 915	17 crews - 72 men	34 crews - 136 men	67 crews - 268 men
Chipping	4 820	7 crews - 63 men	14 crews - 126 men	27 crews - 243 men
Road transport				
- 20 km	6 300	6 crews - 6 men		
- 30 km	4 200		16 crerws - 16 men	
- 40 km	3 150			41 crews - 41 men
Organization		10 men	20 men	40 men
All together		**50 crews-231 men**	**104 crews-458 men**	**215 crews-912 men**

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

Plant size	Tractor - 80 hp	Tractor - 100 hp	Chipper	Trailer
5 MWe	**7**	**6**	**7**	**24**
10 MWe	**14**	**16**	**14**	**64**
20 MWe	**27**	**41**	**27**	**164**

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

Working phase	5 MWe - Investment N$	Euro	10 MWe – Investment N$	Euro	20 MW – Investment N$	Euro
Felling						
Compiling						
Chipping	4 797 000	504 000	9 593 000	1 007 000	18 501 000	1 942 000
Road transport	3 737 000	393 000	9 965 000	1 045 000	25 535 000	2 680 000
All together	**8 534 000**	**897 000**	**19 558 000**	**2 052 000**	**44 036 000**	**4 622 000**

4.2 The new mechanized harvesting chain

4.2.1 The structure of the new mechanized harvesting chain

A new harvesting 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. 32),
- Compiling with skid steer with grapple fork (fig. 33),
- Chipping with the chipper with a loader + tractor (fig. 34) and
- Road transport with tractor trailer (fig. 35).

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 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 per day (20 w-%) assuming that the bush density to be 6.7 wet tons per ha. The purchase price for skid steer is 25 000 Euro (240 000 N$) with puncture-proof tires delivered in Namibia. The purchase price for rotary saw is 3 150 Euro (30 000 N$). The total price of the felling unit is 28 150 Euro (270 000 N$).

A skid steer John Deere 332 and Grapple Fork (72 inches wide), made by Grace Manufacturing in the USA, is used for compiling in the new harvesting chain. With the grapple fork it is possible top grip the bushes and transfer them at the roadside. The capacity in compiling is assumed to be the same as in felling, 16.8 wet tons (20 w-%) per day. The price of a grapple fork is 3 830 Euro (36 500 N$). The total price of the compiling unit is 28 830 Euro (276 500 N$).

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 harvesting chain. The main technical parameters of chipper, presented by the manufacturer, are: the productivity up to 30 tons of wood chips per hour, chipping capacity 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 per day. In the calculations, as the productivity of Hurricane 18 drum chipper is used 60.4 wet tons per day. Massey Ferguson tractor (80 hp) is used for the chipper transport. The price of Hurricane 18 drum chipper with a loader is 75 000 Euros with VAT (715 000 N$) (No VAT). The price of 80 hp Massey Ferguson is 23 600 Euros (225 000 N$). The total price of the chipping unit is 98 600 Euros (940 000 N$).

A tractor trailer is used for road transport in the new harvesting chain. The trailer used in the calculation is Junkkari 18 made in Finland. The trailer volume of Junkkari 18 tractor trailer is 38 m^3. The road transport distance, used in the calculation, is 50 km. One tractor trailer unit uses two trailers. One of the trailer is being loaded with the chipper and the other one is under road transport to power plant. The capacity of the tractor trailer unit in the tests at the CCF was 10.5 wet tons per day (20 w-%) (50 km road transport distance). The total volume of the trailers at the CCF is 30 loose-m^3. The productivity of the new tractor trailer would be 12.8 wet tons per 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 30 000 Euros (286 000 N$). The

price of the tractor is 30 900 Euros (295 000 N$). The total price of the road transport unit is 60 900 Euros (581 000 N$).

It must be noticed that the new harvesting chain is not fully tested in Namibian conditions. That is why the calculated harvesting costs are just preliminary.

The main parameters in the cost calculation are presented in the table 10.

Figure 33. A skid steer (left)equipped with a rotary saw for felling (right).

Figure 34. A skid steer (left) equipped with grapple for compiling the bushes (right).

Figure 35. A drum chipper with loader (Morbark Hurricane 18 drum chipper).

Figure 36. Tractor trailer for road transport of wood chips (Junkkari 18 from Finland).

Table 10. Basic parameters in the cost calculation. The productivity is presented per total field hour. The productivity is presented per total site time.

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$(137 €)	30 % of overhead included
Utilization rate of the machines	0.85 for felling, compiling and	0.84 for chipper
- Operation time/total site time	road transport	
Interest rate		
	8 %	
Working time	11 m/a, 5 d/w, 8 h/d, 1915h/a	
Fuel price	6.14 N$/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	225 000 N$ (23 600€)	Massey Ferguson 80 hp
Price of the tractor for road transport	295 000 N$ (30 900 €)	Massey Ferguson 100 hp
Productivity of felling	16.8 wet ton/day/crew	Skid steer + rotary saw + 1 men
Productivity of compiling	16.8 wet ton/day/crew	Skid steer + grapple fork + 1 men
Productivity of chipping	60.4 wet ton/day/crew	Chipper + tractor + 1 men
Productivity of road transport (50 km)	12.8 wet ton/day/crew	Tractor trailer + tractor + 1 men

4.2.2 The harvesting costs

The harvesting costs of the new harvesting chain is presented in the table 11 and app. 4. The harvesting costs include also the organization costs. These costs consist of the management of the harvesting groups. Management costs in the new harvesting chain are calculated to be 50 % lower than in the CCF semi-mechanized method because the number of workers is lower in the new harvesting chain. It is assumed that 5 men are needed for organizing the harvesting 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 harvesting business.

The harvesting costs for 5 MWe power plant are 41.0 N$/MWh (4.3 Euro/MWh), for 10 MWe power plant 44.0 N$/MWh (4.6 Euro/MWh) and for 20 MWe 47.0 N$/MWh (4.9 Euro/MWh). The road transport distance (one-way) for a 5 MWe plant is 20 km, 30 km for a 10 MWe plant and 40 km for a 20 MWe power plant.

The harvesting costs of the new mechanized harvesting chain are about 24% lower than with the CCF semi-mechanized harvesting chain. However, the felling and compiling costs of the new harvesting chain are higher (19 - 41%), but the chipping costs are 50% smaller than in the CCF semi-mechanized chain. The road transport costs are also about 28% smaller than in the new harvesting 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 capacity 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 28 - 35% depending on the road transport distance.

Table 11. The total harvesting costs in the new mechanized harvesting chain with different road transport distance (one-way).

Working phase	N$/ton	Euro/ton	N$/MWh	Euro/MWh
Felling	41.40	4.34	10.14	1.06
Compiling	41.40	4.34	10.14	1.06
Chipping	58.04	6.09	14.23	1.49
Road transport				
- 20 km	24.21	2.54	5.93	0.62
- 30 km	36.31	3.81	8.90	0.93
- 40 km	48.41	5.08	11.87	1.25
- 50 km	60.51	6.35	14.83	1.56
Organizaton	2.43	0.26	0.60	0.06
All together				
- 20 km	167.48	17.57	41.04	4.29
- 30 km	179.58	18.84	44.01	4.60
- 40 km	191.68	20.11	46.98	4.92
- 50 km	203.78	21.38	49.94	5.23

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

The manpower needed in the harvesting 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 (in Euros) for the harvesting machinery for each power plant size. The manpower needed in the procurement chain of wood chips is presented in the following table.

The harvesting chain was the following:

- Felling crew - Skid steer + rotary saw + 1 man
- Compiling crew – Skid steer + grapple for + 1 man
- Chipping crew - Chipper equipped with loader + 1 tractor (80 hp) + 1 man
- Road transport crew – Junkkari-trailer (38 m^3) + 1 tractor (100 hp) + 1 man.

In the new harvesting chain the labour demand is lower than in the CCF semi-mechanized chain. Harvesting of wood chips for a 5 MWe power plant requires 231 workers in the CCF

semi-mechanised harvesting chain, but in the new harvesting chain only 29 workers. The ratio in the workers in the CCF semi-mechanised and new mechanized harvesting chain in wood chip production for 10 and 20 MWe is nearly the same.

The investment costs are a little bit higher than in the new mechanized than in the CCF semi-mechanized chain even though the whole harvesting chain is mechanised. The main reason for this is that the capacity in chipping and road transport in the new harvesting chain is so high that the need for the machine is less than in the current harvesting chain.

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 manpower needed in the harvesting chain of wood chips. Fuel demand in the 5 MWe power plant is 32 000 wet ton/a, in 10 MWe it is 64 000 wet ton/a and in 20 MWe power plant it is 128 000 wet tons/a (20 w-%).

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	14460	3 crews - 3 men	5 crews - 5 men	9 crews - 9 men
Road transport				
- 20 km	7680	5 crews - 5 men		
- 30 km	5110		13 crews - 13 men	
- 40 km	3830			34 crews - 34 men
Organization		5 men	10 men	20 men
All together		**24 crews - 29 men**	**50 crews - 60 men**	**107 crews-127men**

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

Plant size	Skid steer	Tractor – 80 hp	Tractor - 100 hp	Chipper	Trailer
5 MWe	**16**	**3**	**5**	**3**	**5**
10 MWe	**32**	**5**	**13**	**5**	**13**
20 MWe	**64**	**9**	**34**	**9**	**34**

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

Working phase	5 MWe – Investment N$	Euro	10 MWe – Investment N$	Euro	20 MW – Investment N$	Euro
Felling	2 160 000	227 000	4 320 000	454 000	8 640 000	908 000
Compiling	2 212 000	232 000	4 424 000	464 000	8 848 000	928 000
Chipping	2 820 000	296 000	4 700 000	493 000	8 460 000	888 000
Road transport	2 905 000	305 000	7 553 000	793 000	19 754 000	2 073 000
All together	**10 097 000**	**1 060 000**	**20 997 000**	**2 204 000**	**45 702 000**	**4 797 000**

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-%).

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

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 82.30 loose-m^3, the length being 12.7 m, the width 2.4 m and the height 2.7 m. The load capacity of the wagons is 44 tons. The load achieved by bush chips is 27.2 tons, assuming that the density of bush chips is 330 kg/loose-m^3. 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 148.8 N$/MWh (15.6 Euro/MWh), from Otijiwarongo 107.1 N$/MWh (11.2 Euro/MWh) and from Okahandja 40.8 N$/MWh (4.3 Euro/MWh). It is possible to negotiate discounts from these prices with Transnamib.

The road transport costs of using the trucks are much cheaper (table 16). Here the costs are calculated using the Interlink truck trailer, not equipped with a tipping device. The transport costs from Grootfontein are 54.5 N$/MWh (5.7 Euro/MWh), from Otijiwarongo 29.0 N$/MWh (3.0 Euro/MWh) and from Okahandja 8.48 N$/MWh (0.9 Euro/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.

	Rate N$/ton (Euro/ton) Net load 44 tons	**Rate N$/load (Euro/load)**	**Rate N$/ton (Euro/ton) Net load 27.2 tons**
Grootfontein – Windhoek	**375.35 (39.4)**	**16 515.40 (1733)**	**607.2 (63.7)**
Otjiwarongo – Windhoek	**270.09 (28.3)**	**11883.36 (1247)**	**436.9 (45.8)**
Okahandja - Windhoek	**102.95 (10.8)**	**4529.80 (475)**	**166.5 (17.5)**

Table 16. Transport cost of bush chips using trucks without any tipping device.

	Distance km	**Rate N$/ton (Euro/ton)**	**Rate N$/load (Euro/load) Net load 27.2 tons**
Grootfontein – Windhoek	450	222.2 (23.3)	6043.5 (634.2)
Otjiwarongo – Windhoek	240	118.5(12.4)	3223.2 (338.2)
Okahandja – Windhoek	70	34.6 (3.6)	940.3 (98.7)

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 cots from Okahandja are 70.4 N$/MWh (7.4 Euro/MWh) and from Otijiwarongo 90.9 N$/MWh (9.5 Euro/MWh) using the CCF semi-mechanized harvesting method. The wood chip supply costs to Van Eck are slightly lower with the new mechanized harvesting method. The wood chips supply costs from Okahandja are 55.5 N$/MWh (5.8 Euro/MWh) and from Otijiwarongo 76.0 N$/MWh (7.9 Euro/MWh) using the new mechanized harvesting method. In these figures the wood chips are transported to

Windhoedk 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 VanEck power plant.

	N$/wet ton 20 w-%	Euro/wet ton 20 w-%	N$/MWh 20 w-%	Euro/MWh 20 w-%
Wood chip production – road transport 40 km				
- CCF semi-mechanized method	252.4	26.5	61.9	6.5
- New mechanized method	191.7	20.1	47.0	4.9
Long-distance transport by truck from				
- Otjiwarongo	118.5	12.4	29.0	3.0
- Okahandja	34.6	3.6	8.5	0.9
Total				
- Semi-mechanized method from Otjiwarongo	**370.9**	**38.9**	**90.9**	**9.5**
- New mechanized method from Otjiwarongo	**310.2**	**32.5**	**76.0**	**7.9**
- Semi-mechanised method from Okahandja	**287.0**	**30.1**	**70.4**	**7.4**
- New mechanized method from Okahandja	**226.3**	**23.7**	**55.5**	**5.8**

5 Conclusions

- Ø 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-%.
- Ø The CCF semi-mechanized harvesting chain works well.
- Ø The chipping costs in the CCF mechanized harvesting chain are too high because of low chipping capacity.
- Ø The number of workers in the CCF semi-mechanized harvesting chain is high. That is why it is difficult to control.
- Ø 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.
- Ø The most effective felling device is a skid steer with rotator saw.
- Ø Bushes are not economical to transfer from the cutting stand by the side of the gravel road because of the low transport load.
- Ø A new mechanized harvesting chain was designed.
- Ø With the new mechanized harvesting chain the harvesting cost are lower than those of the CCF semi-mechanized harvesting chain.

- The number of workers with the new mechanized harvesting chain is much morelower than in the CCF semi-mechanized harvesting chain.
- The investments for the harvesting machinery in the new harvesting chain area little higher than in the CCF semi-mechanized chain.
- There is a need to test the new mechanized harvesting 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 of Foreign Affairs in Finland and the Ministry of Agriculture, Water and Forest. The duration of the project is from May 1st 2006 to May 30th 2007.

Target of the study

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

The wood harvesting 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 harvesting chain was investigated at the CCF. New machines for harvesting 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.

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

The harvesting tests at CCF

The number of bushes per hectare before and after the harvesting was calculated. The tests were made at the plots (1 – 8), there the average bush density was 1 118 – 1 144. 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.

20 – 25% of the bushes was felled in the harvesting in the tests. The number of bushes left to grow after harvesting was 220 – 250 bushes. The average harvested yield at the test plots 1 – 8 was 6.7 wet tons (20 w-%) per hectare. The yield at the test plot 9 was 22.0 wet tons per hectare (20 w-%).

CCF semi-mechanized harvesting chain

At the CCF most of the wood chip harvesting work is done manually, and the supply chain is organized into crews of 4 - 8 men. These crews work between parallel strip roads located 50 meters from each other. The harvesting 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 capacity of manual crew in the tests was 1.7 wet tons (20 w-%) per day (8 h). Compiling crews (four men in each) follow the cutting crews and drag undelimbed bushes to a strip road where they are piled for drying. In the tests the productivity of compiling crew was 2.0 wet tons (20 w-%) per 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 eight 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 capacity 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 capacity of the two trailer unit was 10.5 wet tons (20 w-%) per day (8 h). The road transport distance was 50 km.

New mechanized harvesting chain

New harvesting machines were tested at work in order to develop a harvesting 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 harvesting 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 day (8 h). It is about 9 times more effective than one manual felling crew (4 men). For Compiling in the new harvesting 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 top grip on the bushes and to transport them at the roadside. The capacity in compiling is assumed to be the same as in felling, 16.8 wet tons (20 w-%) per 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 harvesting chain. The productivity of Hurricane 18 drum chipper, used in the calculations, is 60.4 wet tons 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 harvesting chain. The trailer used in the calculation is Junkkari 18 made in Finland. The trailer volume of the Junkkari 18 tractor trailer is 38 m^3. The productivity of the new tractor trailer would be 12.8 wet tons 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 harvesting chain is not tested totally in Namibian conditions.

Harvesting costs of the CCF semi-mechanized harvesting chain

The total wood chip harvesting costs of the current harvesting chain are 53.7 - 66.0 N$/MWh (5.6 - 6.9 Euro/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 20 km, 30 km for 10 MWe and 40 km for 20 MWe power plant. With these road transport distances the harvesting area of the total land area would be about 10%. With these road transport distances the harvesting costs for 5 MWe power plant are 53.7 N$/ton(5.6 Euro/MWh), for 10 MWe power plant 57.8 N$/MWh (6.1 Euro/MWh) and for 20 MWe 61.9 N$/MWh (6.5 Euro/MWh).

The main costs are the chipping costs. The share of the chipping cost of the total costs is 43 - 53% depending on the road transport distance. The road transport costs are also high, 15 - 31% of the total costs.

Harvesting costs of the new harvesting chain

Using the new mechanized harvesting chain the harvesting costs for 5 MWe power plant are 41.0 N$/MWh (4.3 Euro/MWh), for 10 MWe power plant 44.0 N$/MWh (4.6 Euro/MWh) and for 20 MWe 47.0 N$/MWh (4.9 Euro/MWh). The road transport distance for a 5 MWe plant is 20 km, 30 km for a 10 MWe plant and 40 km for a 20 MWe power plant.

The harvesting costs of the new mechanized harvesting chain are 24% lower than with the CCF semi-mechanized harvesting chain. However, the felling and compiling costs of the new harvesting chain are higher (19 – 41%), but the chipping costs are about 50% smaller than in the CCF semi-mechanized chain. The road transport costs are also about 28% smaller than in the new harvesting chain.

Harvesting 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 cots from Okahandja are 70.4 N$/MWh (7.4 Euro/MWh) and from Otijiwarongo 90.9 N$/MWh (9.5 Euro/MWh) using the CCF semi-mechanized harvesting method. The wood chip supply costs to Van Eck are lower with the new mechanized harvesting method. The wood chips supply costs from Okahandja are 55.5 N$/MWh (5.8 Euro/MWh) and from Otijiwarongo 76.0 N$/MWh (7.9 Euro/MWh) using the new mechanized harvesting method. In these figures the wood chips are transported to Windhoedk by truck trailers. The loading and unloading costs are not calculated in the road transport cost.

Labour force and investments for the fuel supply

The annual demand of wood chips is 32 000 wet tons (20 w-%) for a 5 MWe power plant, 64 000 wet tons (20 w-%) for a 10 MWe power plant and 128 000 wet tons for a 20 MWe power plant. The annual total harvesting area is 4 800 ha in the case of a 5 MW_e power plant,

9 600 ha for a 10 MW_e and 19 200 ha for 20 MW_e power plant if the yield is 6.7 wet tons per ha. With 10 years rotation the total harvesting area is 10 times higher.

Production of wood chips with the current harvesting chain requires 231 men all year round for a 5 MWe plant, 458 men for a 10 MWe plant and 912 men for a 20 MWe power plant. It is very difficult to control a high number of workers in wood chip production. With the new harvesting chain it labour need for production of wood chips is only 29 men for 5 MWe, 60 men for 10 MWe and 127 men for 20 MWe power plant. The labour demand in the new harvesting chain is only about 14% of the labour demand in the old harvesting chain.

The investments for the machines in the CCF semi-mechanized harvesting chain to produce the demand of wood chips for 5 MWe power plant is 8.5 mill. N$ (0.9 mill. Euro), 19.6 mill. N$ (2.1 mill. Euro) for 10 MWe power plant and 44.0 mill. N$ (4.6 mill. Euro) for 20 MWe. The investments in the new mechanized harvesting chain are a little bit higher: 10.1 mill. N$ (1.1 mill. Euro) for 5 MWe, 21.0 mill. N$ (2.2 mill. Euro) and for 20 MWe 45.7 mill. N$ (4.8 mill. Euro).

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

- Ø 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-%.
- Ø The CCF semi-mechanized harvesting chain works well.
- Ø The main disadvantages in the semi-mechanized harvesting chain are the low chipping capacity and the high number of workers.
- Ø 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.
- Ø The most effective felling device is a skid steer with rotator saw.
- Ø A new mechanized harvesting chain was designed.
- Ø With the new mechanized harvesting chain the harvesting cost are lower than those of the CCF semi-mechanized harvesting chain.
- Ø The number of workers with the new mechanized harvesting chain is much more lower than in the CCF semi-mechanized harvesting chain.
- Ø The investments for the harvesting machinery in the new harvesting chain area little higher than in the CCF semi-mechanized chain.

- There is a need to test the new mechanized harvesting chain in practice.

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Appendixes

Appendix 1. The coefficients and abbreviations used in the study.

Appendix 2. Results from the harvesting tests at CCF.

Appendix 3. The results from the cost analysis for the current harvesting chain.

Appendix 4. The results from the cost analysis for the new harvesting chain.

Appendix 1

Table 1. The coefficients used in the study.

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

Table 2.Abbreviations used in the study.

Abbreviation	Meaning
h	Hour
a	Year
m	Month, metre
w	Week
w-%	Moisture content in wet basis
m^3	Cubic meter
l	Litre
kg	Kilogram
ha	Hectare
MWh	Energy content unit

Appendix 2

Results from harvesting tests at CCF during 12.2.-23.2.2007

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

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

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

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

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

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

Table 4. The measured data on bush felling and compiling in harvesting tests at CCF in 12.2-23.2.2007.

Plot	Area ha	Cutting type	Number of workers	Cutting start	Cutting stop	Total cutting time, manh	Compiling start	Compiling stop	Total compiling time, manh	Average moisture, w-%	Total yield wet ton, 20 w-%	Total yield dry ton
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	6.39	5.11
3	0,7	Brush cutter	1	We 20.2	Fr 22.2	14.25	*	*	*	15.10	4.23	3.38
4	1	Chainsaw	1	Th 15.2	We 20.2	15.5	*	*	*	15.40	6.09	4.87
6	1	Manual crew 1	4	Tu 13.2	We14.2	44.5	Th 22.2	Th 22.2	30	14.65	9.53	7.62
7	1	Manual crew 2	4	We 14.2	Th 15.2	50	*	*	*	11.50	5.11	4.09
8	1	Lawn mover	2	We 14.2	Th 15.2	24.5	*	*	*	12.88	6.98	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 harvesting tests at CCF in 12.2.-23.2.2007. Productivity in wet tons per man day is presented in original moisture content. Mand means man day and manh means man hour.

Plot	Area	Cutting	Yield	Yield	Total cutting	Cutting produc-	Cutting productivity		Total transfer	Transfer produc-	Transfer productivity	
	ha	method	dry ton	wet ton, 20-w-%	time, manh	tivity, ha/mand	wet ton/mand 20 w-%	Dry ton/mand	time, manh	tivity, ha/mand	wet ton/mand 20 w-%	dry ton/mand
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	5.11	6.39	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	4.87	6.06	15.5	0.52	3.13	2.51	30.00	0.27	1.62	1.30
6	1	Manual crew 1	7.62	9.53	45	0.18	1.69	1.35	*	*	*	*
7	1	Manualcrew 2	4.09	5.11	50	0.16	0.82	0.65	*	*	*	*
8	1	Lawn mover	5.58	6.98	24.5	0.32	2.28	1.82	*	*	*	*
9	1	Manualcrew 1	17.61	22.01	94	0.09	1.87	1.50	*	*	*	*

*Table 6. The measured data on chipping and road transport in harvesting tests at CCF in 12.2-23.2.2007. Weight in wet tons is presented in original moisture content. Mark * means that moisture content evaluated.*

Plot	Load	Date	Chipping		Number of People	Transport		Offloading		Number of People	Weight, wet ton	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	”
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	”
6	5	Mo 26.207	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	9:42	7					2	2.37	“

Table 7. The calculated data in chipping at CCF in 12.2 -23.2.2007. Macd means machine day.

Plot	Load	Chipping time Mach	Load weight		Chipping productivity	
			Dry	Wet – 20 w-%	Wet ton/macd, 20 w-%	Dry ton/macd
1	1	1.50	3.26	4.08	21.76	17.37
1	2	1.58	3.16	3.95	20.00	16.00
1+2	3	1.50	3.15	3.94	21.01	16.80
2 + 6	4	3.33	3.27	4.09	9.83	7.86
6	5	2.00	3.09	3.86	15.44	12.36
6	6	2.33	3.71	4.64	15.93	12.74
7	7	2.88	4.09	5.11	14.19	11.36
8	8		2.16	2.70		
8	9	2.13	3.42	4.28	16.08	12.85
3	10	0.68	3.38	4.23	49.76	39.76
4	11	1.87	2.86	3.58	15.32	12.23
9	12	1.50	3.07	3.84	20.48	16.37
9	13	1.67	3.25	4.0	19.16	15.57
9	14	1.12	2.62	3.28	23.43	18.71
9	15	1.22	2.98	3.73	24.46	19.54
9	16	1.88	3.67	4.59	19.53	15.61
4+9	17	2.55	4.04	5.05	12.67	15.84
Average			**3.25**	**4.06**	**20.14**	**16.11**

Table 8. The calculated data on road transport at CCF farm in 12.2.-23.2.007. Macd means machine days and mach means machine hour.

Plot number	Load number	Load weight wet ton, 20 w-%	Chipping time, mach	Transport time to factory, mach	Transport speed, km/h	Unloading time, mach	Total road transport time, mach	Transport productivity	
								wet ton/macd	dry ton/macd
1	1	4.07	1.50	1.58	31.65	0.83	5.49	5.93	4.74
1	2	3.95	1.91	0.75	66.67	0.83	4.24	7.45	5.96
1+2	3	3.93	1.50	-	-	-	-	-	-
2+6	4	4.09	3.33	1.27	39.37	-	-	-	-
6	5	3.87	2.00	0.50	100.00	1.00	4.00	7.74	6.19
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	9.16	7,33
3	10	4.22	0.68	0.62	80.64	1.17	3.09	10.93	8.74
4	11	3.57	1.87	0.90	55.56	-	-	-	-
9	12	3.83	1.50	0.50	100.00	0.58	3.08	9.95	7.96
9	13	4.06	1.67	1.55	32.25	0.58	5.35	6.07	4.,86
9	14	3.27	1.12	0.80	62.50	0.50	3.22	8,12	6.50
9	15	3.76	1.22	1.20	41.67	0.33	3.95	7.62	6,09
9	16	4.58	1.88	2.67	18.73	0.62	7.84	4,67	3.74
4+9	17	5.04	2.55	1.08	46.30	0.43	5.14	7,84	6.28
Average		**4.06**	**1.88**	**1.04**	**60.83**	**0.75**	**4.65**	**7.64**	**6.11**

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
Plot 1	1	19.0	8 - 9
Plot 1	2	19.0	9 - 10
Plot 1-2	3	19.0	-
Plot 2	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 4	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 current wood harvesting chain

Table 1. The cost break down of Morbark Tornado Model 13 drum chipper + tarctor -chipping unit.

Manufacturer	Product	Make/model	Price, €	Other	Price, N$
Morbark Inc., Michigan	Brush Chipper	Tornado15			460 000
Massey Ferguson	Tractor	80 hp, 2 wd			225 217
Price, total			**71 901**		**685 217**

1. Basic information	**Chipper**			**Tractor**
Utilization rate (=operating time/time at site)	81,45 %			61 %
Total production, ton/year	32 000,00			
Average productivity, ton/h (20 w-%)	2,52			
Operating hours, h/d	7,00			5,5
Time at site, h/year	1 915,00			
Operating time, h/year	1 559,77			

2. Costs per year (VAT excluded)				
Price of chipper N$	460 000,00	N$		225 217,00
Price of the whole unit	685 217,00	N$	71 901,05	
Serviceable life, yrs	7,00			
Operating hours during servieable life	10 918,39	h		
Depreciation %	25,00 %			20,00 %
Depreciation value	61 402,59		6 443,08	24 182,49
Interest rate	8,00	%		8,00 %
Insurances	2 300,00	N$/year	241,34	1 126,09
CHIPPER				TRACTOR
Fuel price	5,64	N$/liter	0,59	6,14
Fuel consumption	13,30	l/operating hour		5,00
Fuel cost/ operating hour	75,01	N$/operating h	7,87	30,70
Hydraulic oil	11,40	N$/liter	1,20	26,00
Consumption of hydraulic oil	0,05	l/operating hour		0,00
Cost of hydraulic oil	0,57	N$/operating h	0,06	0,00
Price of motor oil	11,40	N$/liter	1,20	11,40
Consumption of motor oil	0,05	l/h		0,10
Cost of motor oil	0,57	N$/h	0,06	1,14
Repair and maintenance % of depreciation (parts and maintenance equipment included)	35,00 %			25,00 %
Moving costs	1,50	N$/km	0,16	
Moving distance	500,00	km/y		0,00

FIXED COSTS			
	N$/year	€	
Capital depreciation	56 942,49		20 103,45
Interest costs	23 133,80		10 780,12
Total	**80 076,29**		**30 883,57**
N$/operating hour	51,34	5,39	24,19

OVERHEADS			
Administration and maintenance	4 600,00		2 252,17
Movings of chipper	750,00		0,00
Insurance	2 300,00		1 126,09
Margin	0,00		0,00
Total	**7 650,00**		**3 378,26**
N$/operating hour	4,90	0,51	2,65

WAGES	N$/year		
Total	**111 503,73**		**14 577,38**
N$/operating hour	71,49	7,50	11,42

VARIABLE COSTS	N$/year			
Fuel	121 872,00			39 190,09
Repair and maintenance	19 929,87	0,13		5 025,86
Hydraulic oil	926,08	0,57		0,00
Motor oil	926,08	0,57		1 455,27
Travel allowance	0,00	6,73		0,00
Total	**143 654,03**			**45 671,21**
N$/operating hour	92,10		9,66	35,78

SUMMARY, CHIPPER				**94 510,42**	**Total tractor**	
Grand total of cost of chipper	**342 884,05**	N$/year				
Cost/operating h	219,83	N$/h	23,07	74,04		
Cost/ton	87,23	N$/ton	9,15			
Cost/MWh	21,36	N$/MWh	2,24			
	5,93	N$/GJ	0,62	14,7	GJ/ton	3,6 GJ/MWh
				4,08	MWh/ton	

SUMMARY, WHOLE UNIT (chipper + tractor)			**€**
Grand total of cost of chipper unit	**437 394,46**	N$/year	
Cost/h	**293,87**	N$/h	30,84
Cost/ton	**116,61**	N$/ton	12,24
Cost/MWh	**28,56**	N$/MWh	3,00

Table 2. Breakdown of costs of tractor & trailer -unit. Road transport one-way distance is 20 km.

Manufacturer	Product	Make/Model	Price, €	Other	Price, N$	
Massey & Ferguson	Tractor	2-wheel drive, 100 hp			294 783	
	Trailer			two trailers	164 000	two trailers for transportation
	Trailer			two trailers	164 000	and two for chipping
Price total:			**65 350**		**622 783**	

1. Basic information

Utilization rate (=operating time/time at site)	82,28 %	%				
Total production, ton/year	32 000,00	ton	h	km	ton/h	
Average productivity, ton/h	3,27	6,2	1,896	40	3,27	
Operating hours, h/d	7,00					
Time at site, h/year	1 915,00					
Operating time, h/year	1 576,00					

2. Costs per year (VAT excluded)	**N$**		**€**
Price of the unit	622 783,00	N$	65 349,74
Serviceable life	10		
Operating hours during servieable life	15 760,00	h	
Depreciation %	20,00 %		
Depreciation value	66 870,82		7 016,87
Interest rate	8,00 %		
Insurances	1 473,92	N$/year	154,66
Administration and maintenance	6 227,83	N$/year	653,50
TRACTOR TRAILER -UNIT			
Fuel price	6,14	N$/liter	0,64
Fuel consumption	5,00	l/operating hour	
Fuel cost/ operating hour	30,70	N$/operating h	3,22
Price of hydraulic oil	11,40	N$/liter	1,20
Consumption of hydraulic oil	0,05	l/operating hour	
Cost of hydraulic oil	0,57	N$/operating h	0,06
Price of motor oil	11,40	N$/liter	1,20
Consumption of motor oil	0,10	l/h	
Cost of motor oil	1,14	N$/h	0,12
Repair and maintenance % of depreciation (parts and maintenance equipment included)	25,00 %		
Moving costs	1,50	N$/km	0,16
Moving distance	0,00	km/y	
FIXED COSTS	N$/year		
Capital depreciation	55 591,22		
Interest costs	29 809,80		
Total	**85 401,02**		
N$/operating hour	54,19		5,69
OVERHEADS			
Administration and maintenance	6 227,83		
Movings of unit	0,00		
Insurance	1 473,92		
Margin	0,00		
Total	**7 701,75**		
N$/operating hour	4,89		0,51
WAGES	N$/year		
Total	**13 862,39**		
N$/operating hour	8,80		0,92
VARIABLE COSTS	N$/year		
Fuel	49 878,29		
Repair and maintenance	13 897,80		0,09
Hydraulic oil	926,08		0,57
Motor oil	1 852,16		1,14
Travel allowance	0,00		6,66
Total	**66 554,33**		
N$/operating hour	42,23		4,43

SUMMARY						
Grand total of cost	**173 519,49**	N$/year	**€**			
Cost/h	110,10	N$/h	11,55			
Cost/ton	33,67	N$/ton	3,53	14,7	GJ/ton	3,6
Cost/MWh	8,25	N$/MWh	0,87	4,08	MWh/ton	

Appendix 4

The results from the cost analysis for the new harvesting chain

Table 1. Breakdown of felling costs by skid steer and rotator saw -unit.

Manufacturer	Product	Make/Model	Price, €	Other	Price, N$
John Deere	Skid steer	332			240 000
Grace Manufacturing Inc.	Rotary saw		3150		30 020
Price total:			**28 334**		**270 020**

1. Basic information

Utilization rate (=operating time/time at site)	84,85 %				
Total production, ton/year	32 000,00				
Average productivity, ton/h	2,10				
Operating hours, h/d	7,00				
Time at site, h/year	1 914,70				
Operating time, h/year	1 624,70				

2. Costs per year (VAT excluded)	N$		€		
Price of the unit	270 019,50	N$	28 333,63		
Serviceable life	10				
Operating hours during serviceable life	16 247,00	h			
Depreciation %	20,00 %				
Depreciation value	29 688,95		3 115,31		
Interest rate	8,00 %				
Insurances	1 200,00	N$/year	125,92		
Administration and maintenance	5 530,00	N$/year	580,27		
TRACTOR TRAILER -UNIT					
Fuel price	6,14	N$/liter	0,64	consumption	
Fuel consumption	7,00	l/operating hour		7 l / h	
Fuel cost/ operating hour	42,98	N$/operating ho	4,51		
Price of hydraulic oil	11,40	N$/liter	1,20		
Consumption of hydraulic oil	0,20	l/operating hour			
Cost of hydraulic oil	2,28	N$/operating ho	0,24		
Price of motor oil	11,40	N$/liter	1,20		
Consumption of motor oil	0,20	l/h			
Cost of motor oil	2,28	N$/h	0,24		
Repair and maintenance % of depreciation (parts and maintenance equipment included)	25,00 %				
Moving costs	1,50	N$/km	0,16		
Moving distance	0,00	km/y			
FIXED COSTS	N$/year				
Capital depreciation	24 681,09				
Interest costs	13 234,80				
Total	**37 915,89**				
N$/operating hour	23,34		2,45		
OVERHEADS					
Administration	5 530,00				
Movings of unit	0,00				
Insurance	1 200,00				
Margin	0,00				
Total	**6 730,00**				
N$/operating hour	4,14		0,43		
WAGES	N$/year	1 in crew			
Total	**13 192,28**				
N$/operating hour	8,12		0,85		
VARIABLE COSTS	N$/year				
Fuel	69 829,61				
Repair and maintenance	6 170,27	0,04			
Hydraulic oil	3 704,32	2,28			
Motor oil	3 704,32	2,28			
Travel allowance	0,00	6,46			
Total	**83 408,51**				
N$/operating hour	51,34		5,39		

SUMMARY					
Grand total of cost	**141 246,69**	N$/year			
Cost/h	86,94	N$/h	9,12		
Cost/ton	41,40	N$/ton	4,34	14,7 GJ/ton	3,6 GJ/MWh
Cost/MWh	10,14	N$/MWh	1,06	4,08 MWh/ton	

Table 2. Breakdown of compiling costs by a grapple fork in skid steer.

Manufacturer	Product	Make/Model	Price, €	Other	Price, N$
John Deere	Skid steer	332			240 000
Grace Manufacturing Inc.	Rotary saw				30 000
Price total:			**28 332**		**270 000**

1. Basic information

Utilization rate (=operating time/time at site)	84,85 %				
Total production, ton/year	32 000,00				
Average productivity, ton/h	2,10				
Operating hours, h/d	7,00				
Time at site, h/year	1 914,70				
Operating time, h/year	1 624,70				

2. Costs per year (VAT excluded)	**N$**		**€**		
Price of the unit	270 000,00	N$	28 331,58		
Serviceable life	10				
Operating hours during serviceable life	16 247,00	h			
Depreciation %	20,00 %				
Depreciation value	29 688,95		3 115,31		
Interest rate	8,00 %				
Insurances	1 200,00	N$/year	125,92		
Administration and maintenance	5 530,00	N$/year	580,27		
TRACTOR TRAILER -UNIT					
Fuel price	6,14	N$/liter	0,64	consumption	
Fuel consumption	7,00	l/operating hour		7 l / h	
Fuel cost/ operating hour	42,98	N$/operating hour	4,51		
Price of hydraulic oil	11,40	N$/liter	1,20		
Consumption of hydraulic oil	0,20	l/operating hour			
Cost of hydraulic oil	2,28	N$/operating hour	0,24		
Price of motor oil	11,40	N$/liter	1,20		
Consumption of motor oil	0,20	l/h			
Cost of motor oil	2,28	N$/h	0,24		
Repair and maintenance % of depreciation (parts and maintenance equipment included)	25,00 %				
Moving costs	1,50	N$/km	0,16		
Moving distance	0,00	km/y			
FIXED COSTS	N$/year				
Capital depreciation	24 681,09				
Interest costs	13 234,80				
Total	**37 915,89**				
N$/operating hour	23,34		2,45		
OVERHEADS					
Administration	5 530,00				
Movings of unit	0,00				
Insurance	1 200,00				
Margin	0,00				
Total	**6 730,00**				
N$/operating hour	4,14		0,43		
WAGES	N$/year	1 in crew			
Total	**13 192,28**				
N$/operating hour	8,12		0,85		
VARIABLE COSTS	N$/year				
Fuel	69 829,61				
Repair and maintenance	6 170,27	0,04			
Hydraulic oil	3 704,32	2,28			
Motor oil	3 704,32	2,28			
Travel allowance	0,00	6,46			
Total	**83 408,51**				
N$/operating hour	51,34		5,39		

SUMMARY					
Grand total of cost	**141 246,69**	N$/year			
Cost/h	86,94	N$/h	9,12		
Cost/ton	41,40	N$/ton	4,34	14,7 GJ/ton	3,6 GJ/MWh
Cost/MWh	10,14	N$/MWh	1,06	4,08 MWh/ton	
	2,82	N$/GJ	0,30		

Table 3. Breakdown of chipping costs by Morbark Hurricane -chipper unit.

Manufacturer	Product	Make/model	Price, €		Other	Price, N$
Morbark Inc., Michigan	Brush Chipper with loader	Hurricane	75 000	€		714 750
Massey Ferguson	Tractor	100 hp, 2 wd	30 932	€		294 783
Price, total			**105 932**			**1 009 533**

1. Basic information	**Chipper**		**Tractor**	
Utilization rate (=operating time/time at site)	83,55	%	61	%
Total production, ton/year	32 000,00			wet ton/day
Average productivity, ton/h (20 w-%)	7,55			61,2
Operating hours, h/d	7,00		5	
Time at site, h/year	1 915,00			
Operating time, h/year	1 600,00			

2. Costs per year (VAT excluded)	**Chipper**			**Tractor**	
	N$		**€**	**N$**	
Price of chipper	714 750,00	N$	75 000,00	294 783,00	
Price of the whole unit	1 009 533,00	N$	105 932,11		
Serviceable life, yrs	7,00				
Operating hours during servieable life	11 200,00	h			
Depreciation %	25,00	%		20,00	%
Depreciation value	95 407,61		10 011,29	31 652,08	
Interest rate	8,00	%		8,00	%
Insurances	3 573,75	N$/year	375,00	1 473,92	
CHIPPER				TRACTOR	
Fuel price	5,64	N$/liter	0,59	6,14	
Fuel consumption	39,00	l/operating hour		5,00	
Fuel cost/ operating hour	219,96	N$/operating hou	23,08	30,70	
Hydraulic oil	11,40	N$/liter	1,20	26,00	
Consumption of hydraulic oil	0,10	l/operating hour		0,00	
Cost of hydraulic oil	1,14	N$/operating hou	0,12	0,00	
Price of motor oil	11,40	N$/liter	1,20	11,40	
Consumption of motor oil	0,10	l/h		0,10	
Cost of motor oil	1,14	N$/h	0,12	1,14	
Repair and maintenance % of depreciation (parts and maintenance equipment included)	35,00	%		25,00	%
Moving costs	1,50	N$/km	0,16		
Moving distance	500,00	km/y		0,00	
FIXED COSTS					
	N$/year				
Capital depreciation	88 477,48			26 313,09	
Interest costs	35 945,40			14 109,93	
Total	**124 422,89**			**40 423,02**	
N$/operating hour	77,76		8,16	34,83	
OVERHEADS					
Administration and maintenance	7 147,50			5 895,66	
Movings of chipper	750,00			0,00	
Insurance	3 573,75			1 473,92	
Margin	0,00			0,00	calculated for the whole chain
Total	**11 471,25**			**7 369,58**	
N$/operating hour	7,17		0,75	6,35	
WAGES	N$/year				
Total	**29 082,18**			**13 163,35**	
N$/operating hour	18,18		1,91	11,34	
VARIABLE COSTS	N$/year				
Fuel	357 369,01			35 627,35	
Repair and maintenance	30 967,12		0,19	6 578,27	
Hydraulic oil	1 852,16		1,14	0,00	
Motor oil	1 852,16		1,14	1 322,97	
Travel allowance	0,00		6,56	0,00	
Total	**392 040,45**			**43 528,59**	
N$/operating hour	245,03		25,71	37,51	

							MJ/kg	
Calorific value	19*0,8-0,02441*	14,7118						
20% moist								

SUMMARY, CHIPPER				**104 484,53**	**Total tractor**		
Grand total of cost of chipper	**557 016,77**	N$/year					
Cost/h	348,14	N$/h	36,53	90,03			
Cost/ton	46,11	N$/ton	4,84				
Cost/MWh	11,29	N$/MWh	1,18				
				14,7	GJ/ton	3,6	GJ/MWh
	3,14	N$/GJ	0,33	4,08	MWh/ton		

SUMMARY, WHOLE UNIT (chipper + tractor)			**€**
Grand total of cost of chipper unit	**661 501,30**	N$/year	
Cost/h	**438,17**	N$/h	45,98
Cost/ton	**58,04**	N$/ton	6,09
Cost/MWh	**14,21**	N$/MWh	1,49

Table 4. Breakdown of roadtransport costss by tractor and Junkkari-trailer -unit. Road transport distance is 20 km.

Manufacturer	Product	Make/Model	Price, €	Other	Price, N$
Massey & Ferguson	Tractor	2-wheel drive, 100 hp			294 783
Junkkari	Trailer	J 18	25000		238 250
Price total:			**55 932**		**533 033**

1. Basic information

Utilization rate (=operating time/time at site)	84,85 %				
Total production, ton/year	32 000,00	ton	h	km	ton/h
Average productivity, ton/h	4,01	7,6	1,896	40	4,01
Operating hours, h/d	7,00				
Time at site, h/year	1 914,70				
Operating time, h/year	1 624,70				

2. Costs per year (VAT excluded)	**N$**		**€**
Price of the unit	533 033,00	N$	55 932,11
Serviceable life	10		
Operating hours during servieable life	16 247,00	h	
Depreciation %	20,00 %		
Depreciation value	57 233,98		6 005,66
Interest rate	8,00 %		
Insurances	1 473,92	N$/year	154,66
Administration and maintenance	5 330,33	N$/year	559,32
TRACTOR TRAILER -UNIT			
Fuel price	6,14	N$/liter	0,64
Fuel consumption	5,00	l/operating hour	
Fuel cost/ operating hour	30,70	N$/operating	3,22
Price of hydraulic oil	11,40	N$/liter	1,20
Consumption of hydraulic oil	0,05	l/operating hour	
Cost of hydraulic oil	0,57	N$/operating	0,06
Price of motor oil	11,40	N$/liter	1,20
Consumption of motor oil	0,10	l/h	
Cost of motor oil	1,14	N$/h	0,12
Repair and maintenance % of depreciation (parts and maintenance equipment included)	25,00 %		
Moving costs	1,50	N$/km	0,16
Moving distance	0,00	km/y	
FIXED COSTS	N$/year		
Capital depreciation	47 579,90		
Interest costs	25 513,88		
Total	**73 093,78**		
N$/operating hour	44,99		4,72
OVERHEADS			
Administration and maintenance	5 330,33		
Movings of unit	0,00		
Insurance	1 473,92		
Margin	0,00		
Total	**6 804,25**		
N$/operating hour	4,19		0,44
WAGES	N$/year	1 in crew	
Total	**13 192,28**		
N$/operating hour	8,12		0,85
VARIABLE COSTS	N$/year		
Fuel	49 878,29		
Repair and maintenance	11 894,98	0,07	
Hydraulic oil	926,08	0,57	
Motor oil	1 852,16	1,14	
Travel allowance	0,00	6,46	
Total	**64 551,50**		
N$/operating hour	39,73		4,17

SUMMARY					
Grand total of cost	**157 641,81**	N$/year	€		
Cost/h	97,03	N$/h	10,18		
Cost/ton	24,21	N$/ton	2,54	14,7 GJ/ton	3,6 GJ/MWh
Cost/MWh	5,93	N$/MWh	0,62	4,08 MWh/ton	