Pre-feasibility study for an electric power plant based on rice straw

DANIDA contract 1711

Feasibility of renewable energy resources in Mali

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Threshing of rice in Office de Niger Mali.

Photo: Rasmus Borgstrøm

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1 Preface

Supply of affordable, reliable and environmentally friendly energy services is an important precondition for economic development of the Malian society. Currently demand for electricity is increasing by about 10 % per annum, and demand for fuel for transport is increasing at an even higher level (BAD, 2010). This brings enormous challenges to the Malian government and to national operators to reduce import of fossil fuels and to the National Electricity Utility, EDM (Energie du Mali) and to private investors in providing sufficient electricity at a reasonable price.

A large part of electricity production comes from large scale hydropower produced at the Senegal and the Niger River, but both small scale and large scale diesel generators are still providing about 20 % of the total production. While interconnections are being planned and built to meet part of the demand by electricity produced from Natural Gas in Ghana and Cote D'Ivoire, there are still good political and economic reasons to tap into abundant national renewable energy resources, such as hydro-energy, solar energy, wind energy, biomass residues from agriculture and energy crops for liquid biofuel.

Mali has since the 1980s, in cooperation with various development partners conducted a number of development projects and programs focusing on increased use of renewable energy sources, and the Ministry for Mines, Energy and Water has developed a strategy for development of renewable energy in Mali, which was adopted by the Ministerial council (Conseil des Ministres) the 26 of December 2006. (MMEE 2007). This strategy combines the efforts of reducing poverty, validation of national energy resources and ensuring long-term security and environmental sustainability of the energy supply. Given the rapid increase of prices on imported fuels, such as diesel and gasoline, it is increasingly worthwhile assessing the potential for giving renewable energy resources a central role in the future energy system: Environmentally friendly renewable energy resources are abundant in Mali and they are becoming increasingly competitive.

For the purpose of planning future investment in the renewable energy sector, the Malian energy authorities, Energie du Mali, private operators and international cooperation partners have expressed their needs for more precise assessment of the size, and the variation of renewable energy resources in Mali. The Danish National Development Association (DANIDA), has therefore provided financing for a mapping of renewable energy resources under the heading ‘Feasibility of Renewable Energy Resources in Mali, ‘Faisabilité de Resources d'Energies Renouvelables au Mali'.

A first scoping phase of the project was conducted in 2007-2008. The project report submitted in 2008 and entitled ‘Provisional mapping of Renewable Energy Resources in Mali, ‘Carte provisoire de ressources renouvelables du Mali’ was entirely based on satellite data and meteorological models.

The present project has taken the first study further by including ground measurements of wind and solar resources, and by including extensive field studies to assess the potential for using biomass waste for energy and to assess the socio economic impacts of growing cassava for biofuel production. Not all renewable energy resources are mapped, however. The most important exception is the stock of energy-resources contained in Mali’s woody vegetation, which is not easily assessed from satellite data, and which is being assessed by other on-going projects.

The present project is reported in 5 main reports:

1) Analyses of the potential for sustainable, cassava based bio-ethanol production in Mali.
2) Agricultural residues for energy production in Mali.
3) Pre-feasibility study for an electric power plant based on rice straw
4) Estimation of wind and solar resources in Mali
5) Screening of feasible applications of wind and solar in Mali: Assessment using the wind and solar maps for Mali.

The project is carried out by a group of university departments, research institutions and consultants lead by the UNEP Risø Centre (URC) at the Danish Technical University (DTU) and conducted in cooperation with Direction Nationale de l’Energie (DNE) and Centre National de l’Energie Solaire et des Energies Renouvelables (CNESOLER) in Mali. The subcontracted institutions comprise Geographic Resource Analysis & Science A/S (GRAS), Department of Geography and Geology (DGG), University of Copenhagen, Ea Energy Analyses, 3E, Ecole Nationale d’Ingénieurs Abderhamabe Baba Touré (ENI-ABT) and Mali Folkecenter Nyetaa.

The drafting of this report and the intensive study behind has been led by Felicia Fock, from Ea Energy Analysis, with input and support from the rest of the authors.

2 Summary and recommendations

The river Niger and its annual flood cycle give possibility to a variety of agricultural options in the middle/south of Mali. One option, rice production, results in by-products useful for renewable energy production: rice straw and rice hulls, which can be burned in a dedicated biomass power plant.

The country Mali

Mali in West Africa covers an area of 1.24 million km² and has a population of 14.5 million. Only the southern part of the country is suited for agricultural production.

The power system in Mali

The power supply in the interconnected area is based on hydropower (around 150 MW installed) and diesel engines (around 100 MW installed). The interconnected grid in Mali is not yet connected to any neighbouring countries. The demand exceeds the production from the hydro power plants, and the diesel engines therefore are not only operated as peak load, but generally run as base load. This is a very expensive mean of electricity production, especially with increasing oil prices. Therefore there is a need for cheaper electricity production in Mali.

Currently demand for electricity is increasing by about 10% per annum. This brings enormous challenges to the Malian government and to national operators to reduce import of fossil fuels and to the National Electricity Utility, EDM (Energie du Mali) and to private investors in providing sufficient electricity at a reasonable price. Thus, there is a need for sustainable energy production from domestic energy resources.

2.1 Selection of case

Rice production in Office du Niger

One option for domestic renewable energy resources is agricultural residuals like rice straw and rice hulls from the rice production along the Niger River. In the area Office du Niger the area cultivated with rice is expanding due to the possibility of irrigating the land. For the last 10 years the rice production has increased with an average of 5% pr. year in Office du Niger.

There are plans to expand the rice production in Mali and in Office du Niger further. With the rice production come by-products; rice straw and rice hulls. To the extent they are not used for other purposes (feeding animals, soil enrichment etc.) these by-products can be used for energy production. Therefore it’s interesting to study the option of establishing a rice husk/straw fired power plant.

Location of a power plant based on rice straw

The sustainable resource of rice straw for energy production has been estimated to about 56,000 tonnes/year from all of the Office du Niger area increasing to about 158,000 tonnes/year. This fraction of the straw is burnt in the fields today.

The town of Niono is situated in the area of Office du Niger, and the three nearby production zones of rice, Niono, N'debougou and Molodo produce currently around 167,000 tonnes of rice straw of which around 30,000 tonnes are currently burned and available for energy production.

In March 2012 the town of Niono is scheduled to be connected to the interconnected power grid by a transmission line of 63 kV.

Because of the close distance to a fairly large rice straw resource and the relatively strong connection point in the power grid (after the connection of Niono to the central interconnected power grid of Mali), Niono has been chosen as the case location for power plant based on rice straw in Mali.

2.2 Main objective of the project

The main objective is to make a first evaluation regarding if it's technically possible, economically viable, sustainable and recommendable to build a rice straw/hulls fired power plant in Niono in Mali.

2.3 Technological conclusions

Size of the power plant

Based on the available resource of rice straw and the possibilities for connecting to the grid it has been chosen to analyse a 5 MW power plant in the project.

Fuel use

For technical reasons the rice straw should be the main fuel, but rice hulls can be used for co-firing. Up to around 20% of the fuel in the plant can be rice hulls instead of rice straw.

Choice of technology

A number of different biomass power production technologies have been evaluated in the project. This includes:

- Grate fired boiler
- Bubbling fluidised bed
- Circulating fluidised bed
- Dust fired boiler
- Gasification

- Stirling engine
- Organic Rankine Cycle

Grate firing is the most relevant technology in this case, due to the fuel, the size of the power plant, the demand for electricity only and not heat, the demand for a robust and well proven technology.

For a grate fired plant a calculation of the thermodynamic process of the power plant has been carried out in order to determine the electrical efficiency of the plant. The case consists of a 5 MW grate fired power plant with steam turbines and air cooled condenser resulting in an efficiency of 24.6% at full load (20% as yearly average).

2.4 Economic conclusions

Economic evaluation

For the chosen case the different economic factors have been estimated. The key factors include:

- Investment costs
- Costs for operation and maintenance
- Costs for collecting and transporting the rice straw
- Costs for ash disposal
- Average cost of capital

Investment costs and costs for O&M have been assumed based on experience from Danish power plants but adjusted for local conditions in Mali. The costs for collecting and transporting the rice straw and for the ash disposal have been specifically estimated in this project. The average cost of capital has been estimated based on assumptions on equity, international loans and local loans/bank finance. The table below summarises the key figures for the economic calculations.

	Unit	Value
Investment	CFA	20,160
O&M	% of investment pr. year	4
Price of rice straw	CFA/kg	30
Price of ash disposal	CFA/kg	23
Average cost of capital	%	5
Efficiency (yearly average)	%	18.4
Technical life time	years	20
Availability (yearly full load hours)	hours	6,381

Table 1: Key figures for the economic calculations.

Resulting power production price

Based on the investment, the cost of O&M, fuel, ash disposal and the financial assumptions, a cash flow analysis is made in order to calculate the power price resulting in a Net Present Value (NPV) of the investment at CFA 0.

For the base case the calculated power price is CFA 125/kWh.

Sensitivity analyses have been performed, varying fuel price, investment cost, subsidy level, WACC, O&M and full load efficiency. The sensitivity analyse shows that fuel price, subsidy level and WACC are most important elements when setting the power price. There is some uncertainty associated with the determination of fuel price, subsidy level, WACC and investment cost. Before going on with the planning of a rice straw fired power plant in Niono, it would therefore be relevant to go more into detail with the pricing of these elements.

Costs of alternative power production

The marginal cost of producing electricity in the future in Mali is quite uncertain. If international interconnectors are built according to plan, the marginal power price is expected to be between 65 and 100 CFA/kWh. If not, the marginal power price might be between 100 and 120 CFA/kWh, depending on the price on crude oil.

Conclusions on economy

When calculating the cost of producing electricity from a rice straw fired power plant in Niono and comparing the price to the expected marginal power price in the interconnected power grid in Mali, is seems difficult for a rice straw fired power plant to compete. Only under good conditions (e.g. low price on rice straw and low interest rate on finance) or with investment subsidies to the plant (20-40 %), the economy for a plant would be interesting.

2.5 Recommendations

The analyses in this report have shown that it is technically feasible and under certain circumstances economically viable to establish a power plant based on rice straw in Niono. However there are a number of risks and uncertainties connected to the project that need to be further clarified before the project can be realised.

The pros and cons of erecting a power plant based on rice straw in Niono are summarised below:

- Advantages
  - Local job creation (55 full time & 800 seasonal jobs)
  - Use of national resources

  - Reducing dependency on imported diesel
  - Reduction of greenhouse gas emissions
- Disadvantages
  - Uncertainty of resulting electricity price
  - Medium to high risk investment due to uncertainties
    - First straw fired plant in the region (technical risk)
    - Uncertainty regarding straw volume and cost
    - Potential conflicts with other use of rice straw

Recommendations regarding next step

Further analyses and tests are needed before a decision on investing in the biomass plant can be taken. It is recommended that the following steps are taken:

- Practical test of straw collection in small scale. To gain experience with regard to barriers and costs
- Analyses of the connection between the local investment in a biomass power plant and the overall energy strategy for Mali. Especially plans for expansion of the power system, plans regarding international interconnectors/hydro power and plans for the use of biomass.
- Optimisation of size and location of power plant
  - Rice resources
  - Transmission capacity
  - Local power consumption
- Detailed feasibility study
  - Contact to different suppliers of biomass power plant technology
  - Visit to the site. Interview local stakeholders including rice farmers and the power company.
  - Carry out calculations of the integration of the power plant in the power system. Load flow calculations, in PSSE or Power Factory or similar tools.
- Considerations regarding ownership, i.e. private investor in combination with EDM and/or Direction National d'Énergie. Another option is collaboration with one of the sugar factories.
  - Analyses and clarification on how the project can be financed

The steps are shown in the figure below with a tentative time frame included.

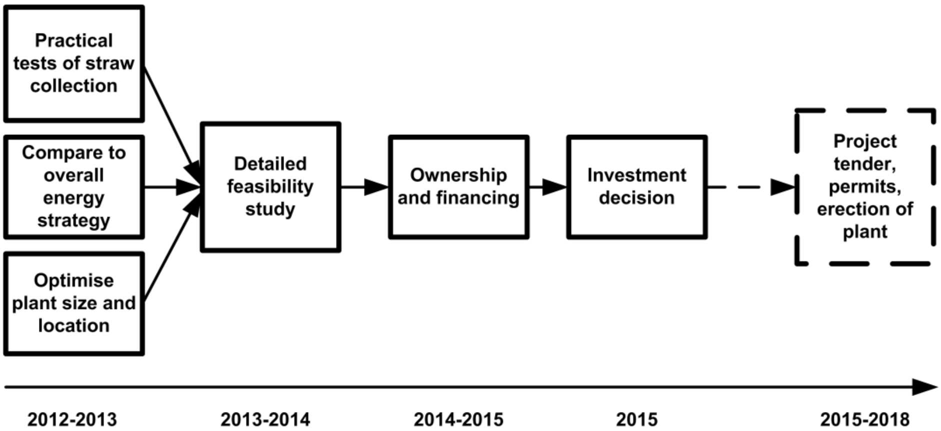


Figure 1: Next steps in the process of establishing a power plant based on rice straw in Niono.

When the steps above have been analysed and clarified an investment decision can be taken. After this decision a project tender, permits from local authorities, agreements with local farmers and establishment of the logistic chain for straw collection and transport and the erection of the power plant can be carried out.

3 Introduction

As part of the project “Faisabilité des Ressources d’Energoes Renouvelables au Mali”, supported by DANIDA (Contract no. 1711) this Pre-feasibility study has been initiated to make the first evaluation regarding establishment of a rice straw/hull fired power plant in Niono in Mali.

3.1 Objective

Main objective

The main objective is to make a first evaluation regarding if it’s economically viable, sustainable and recommendable to build a rice straw/hulls fired power plant in Niono in Mali.

Relevant technologies?

If it’s recommendable to build a rice straw fired power plant, which technologies could be most relevant?

Combination of fuel

What combination of fuel (rice straw / rice hulls) is recommendable? -With regard to environment/technology/risk/...

Recommendations to further analysis

Another purpose is to give recommendations to further analysis of the case, before a decision is taken regarding investment.

3.2 Background

Mali, situated in West Africa south of Sahara, covers an area of 1.24 million km². Mali is landlocked, bordering the seven countries; Algeria, Burkina Faso, Guinea, Cote d'Ivoire, Mauritania, Niger and Senegal. The northern part of Mali is mainly desert (Sahara). In the middle/south of Mali the river Niger (1,500 km in Mali) and its annual flood cycle give possibility to a variety of agricultural options.

Figure 2 Map of Mali

Rice production in Office du Niger

One of the agricultural options due to the Niger River is rice production. In Office du Niger the area cultivated with rice is expanding due to the possibility of irrigating the land.

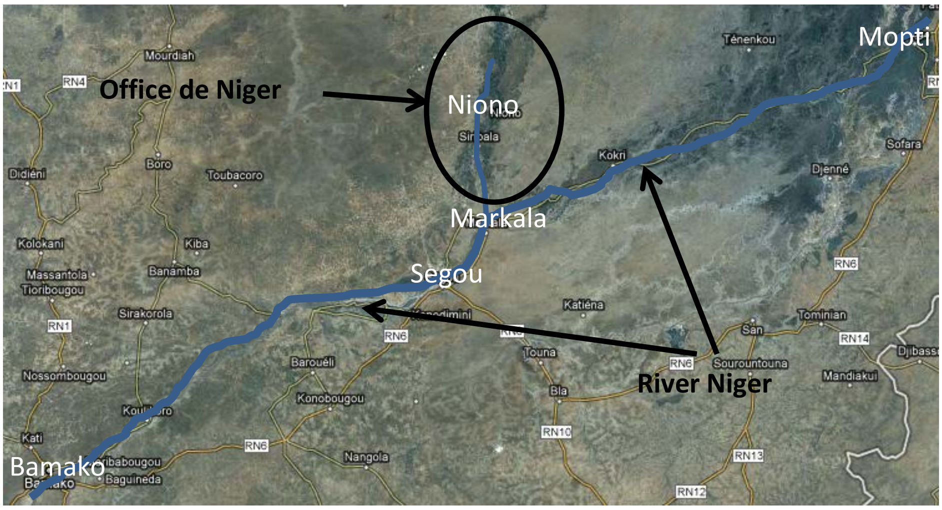


Figure 3 Location of Niono in Office du Niger, Mali

Increasing rice production

For the last 10 years the rice production has increased with an average of 5% pr. year in the area Office du Niger. The level of rice production was around 500,000 tonnes in the years 2009 to 2010. According to the Master Plan for Office du Niger (AGETIER 2004), the cultivated area is expected to more than double before 2020, which means that the production of rice within Office du Niger may reach 1.4 million tonnes of rice by 2012 (Nygaard, Bruun *et al.* 2012).

With the rice production come by-products; rice straw and rice hulls. To the extent they are not used for other purposes (feeding animals, soil enrichment etc.) these by-products can be used for energy production.

Energy system

The interconnected electricity grid in Mali only reaches a limited area in the central/southern part of Mali (see the full lines in the circle in the map below). The rest of Mali has no electricity supply or have small generation plants (mainly diesel engines) supplying electricity to the isolated grids. Detailed information on the existing and planned electricity system is provided in the report "Screening of feasible applications of wind and solar in Mali" (Nygaard, Nørgård *et al.* 2012). This section provides an extract of this information.

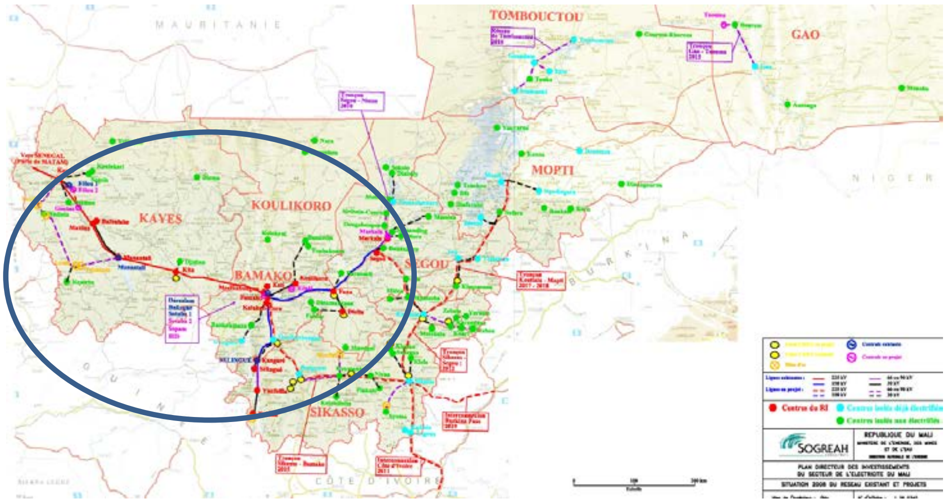


Figure 4 Interconnected power grid in Mali and planned future connections.

Existing generation capacity in interconnected grid

The power supply in the interconnected area is based on hydropower produced at the Senegal and the Niger River (around 150 MW installed) and diesel engines (around 100 MW installed). The interconnected grid in Mali is not yet connected to any neighbouring countries. The demand exceeds the production from the hydro power plants, and the diesel engines therefore are not only operated as peak load, but generally run as base load. This is a very expensive mean of electricity production, especially with increasing oil prices. Therefore there is a need for cheaper electricity production in Mali.

Increasing demand

The electricity demand is increasing, and is expected to increase further. In the interconnected area the electricity demand is expected to rise with an average of 10% pr. year. This is including increased demand due to grid extensions.

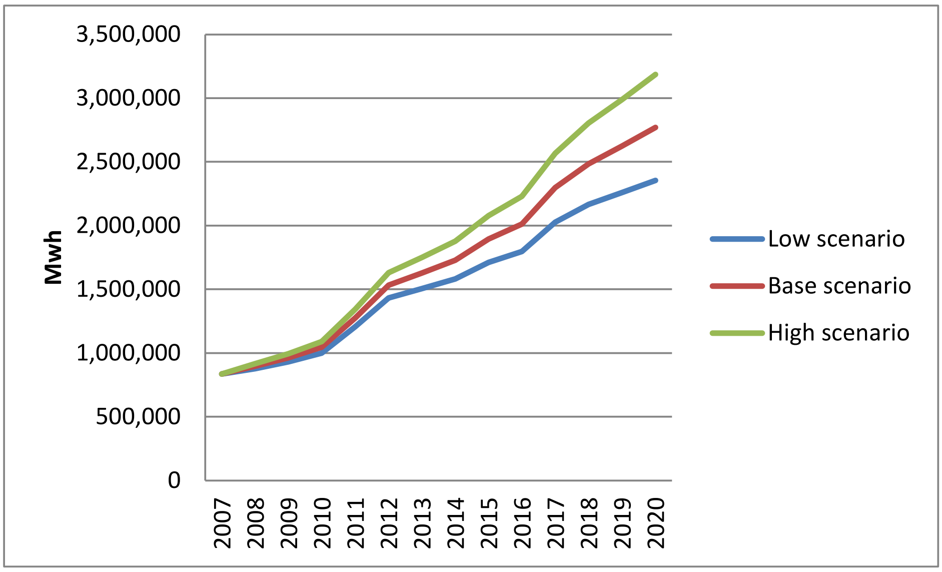


Figure 5 Expected electricity consumption in the interconnected grid in Mali (SOGREAH 2008).

Planned new generation capacity

To meet the rapidly increasing power consumption, there are plans to install new capacity in the interconnected grid and there are also plans to establish interconnectors to neighbouring countries.

The first plans for 2012 include more thermal generation based on heavy fuel oil (110 MW) and an interconnector to the Ivory Coast (100-200 MW). After this there are several plans concerning hydro power (total of 200 MW in 2013-18) and an interconnector to Guinea (200 MW in 2021).

With the rapidly increasing power consumption and a substantial part of the power supply being based on oil products, there is a need for this very poor country to find cheap domestic sustainable power supply.

3.3 Scope of the analysis

The scope of this analysis is to perform a pre-feasibility study for a rice straw/hull fired power plant in Niono in Mali.

Economic calculations for one case

Economic calculations, risk assessment and positive side effects will be performed for one case. The case consists of a 5 MW grate fired power plant with steam turbines and air cooled condenser resulting in an efficiency of 24.6% at full load (20% as yearly average). The plant will be a base load unit using 80% rice straw and 20% rice hulls and be located close to the town Niono in Office du Niger in Mali.

Sensitivity analysis will be performed to investigate the consequences of other fuel prices, changing power prices, different levels of investment costs, a smaller plant (3 MW instead of 5 MW) etc.

Different possible technologies will be discussed, but only grate firing will be used for calculating economy.

Many of the analyses will be based on experiences from Denmark. This is due to the fact that Denmark has gained unique experiences with using straw for power production in small power plants (Skøtt 2011; Nicolaisen, Nielsen *et al.* 1998). No other country has such a high share of power production from straw-only power plants.

4 Description of case

4.1 Location

Niono is a central town in Office du Niger. Office du Niger is the largest irrigated area in Mali, currently comprising about 77,000 ha of irrigated rice during the rainy season and a production of rice and vegetables in the dry season. A Master plan for the extension of the irrigated area in Office du Niger was approved by the Malian government in 2008 (AGETIER 2004). According to the Master plan the irrigated area is expected to increase to 220,000 ha before 2020. Existing and planned areas for rice production is shown in Figure 6.

4.2 Available resources

Detailed information on the development of the agricultural sector in and around Office du Niger and the technical and sustainable resources of straw for energy purposes in Office du Niger is provided in the report 'Agricultural residues for Energy production in Mali' (Nygaard, Bruun *et al.* 2012). This section presents an extract of the main results from this report.

Straw currently available in Office du Niger

The resources of straw currently available in Office du Niger are presented in Table 2. The table shows the average harvest of rice paddy in 2009 and 2010, and the potential and the sustainable resources of straw related to this harvest. The potential resource is defined as the amount of straw harvested. The sustainable resource is defined as the amount of straw which is currently burned in the field. The sustainable resource is on an average 15 % of the potential resource.

Zone	**Macina**	**Bewani**	**Niono**	**Molodo**	**Kourou-mari**	**N'debou-gou**	**Total**
Harvest (rice paddy)	105,455	70,153	85,640	52,081	104,699	85,522	503,549
Straw to grain ratio	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Potential resource	**79,091**	**52,614**	**64,230**	**39,060**	**78,524**	**64,141**	**377,661**
Share being burned	2%	18%	22%	12%	18%	19%	15%
Sustainable resource	**1,582**	**9,471**	**14,131**	**4,687**	**14,134**	**12,187**	**56,191**

Table 2 Rice harvest and potential and sustainable resources of straw in Office du Niger (tonnes/year)

Sustainable straw resources available near Niono

The three zones, Niono, N'debougou and Molodo are situated next to the town of Niono. The sustainable resource in the three zones is currently around 30,000 tonnes/year out of a total amount of around 56,000 tonnes in Office du Niger.

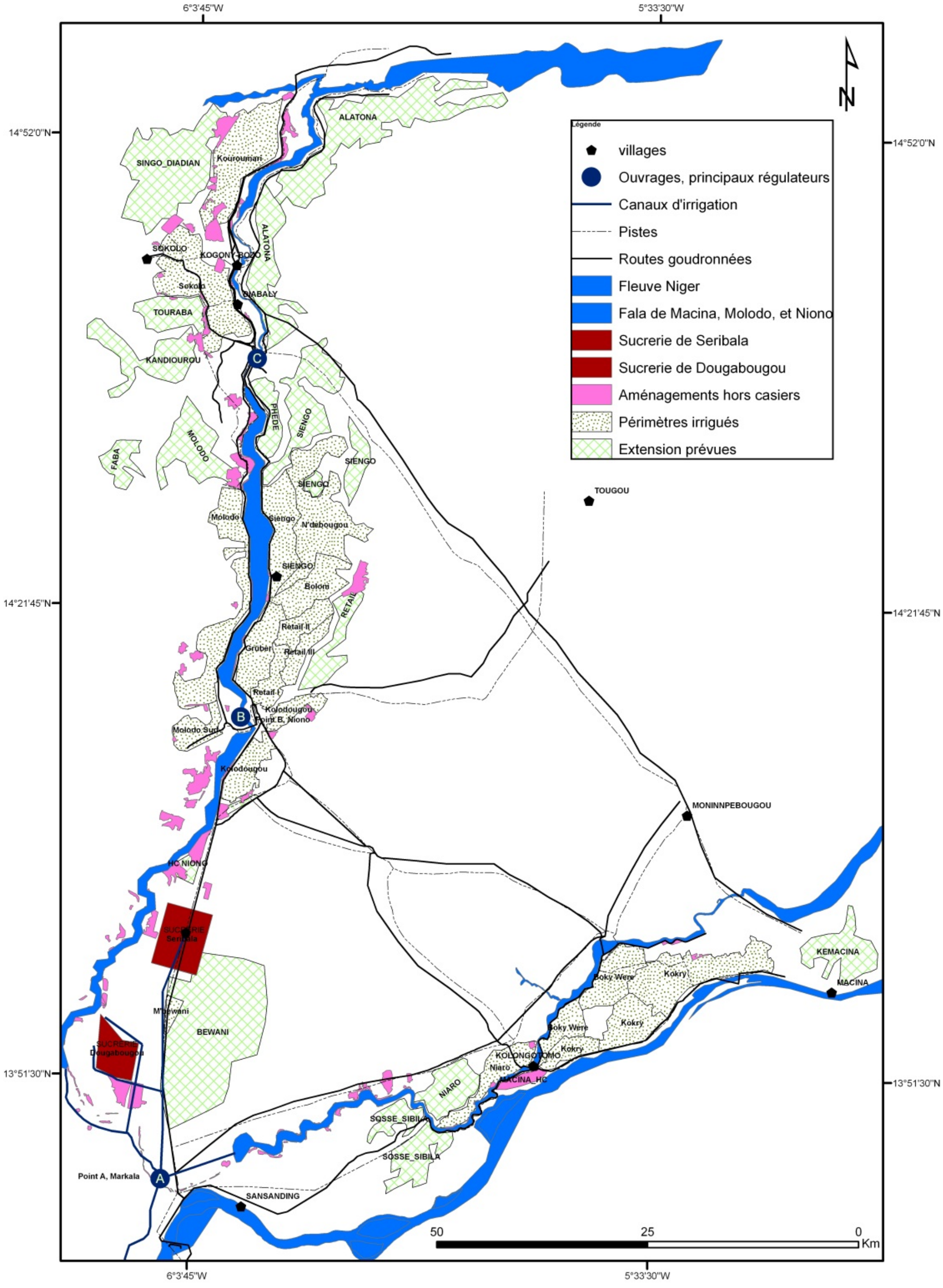


Figure 6 Map of Office du Niger showing cultivated areas in 2004 and planned extension before 2020. Niono is situated at the signature B (AGETIER 2004)

Increasing straw potential due to extension of cultivated area

As illustrated in the map in Figure 6 the cultivated area is extended both north and south of Niono. Given that the cultivated areas will be extended as planned and that yield, straw to grain ratio and percentage burned will remain unchanged, the sustainable potential of rice straw will be 158,000 tonnes/year in 2020.

Figure 7 Surplus rice straw

Rice hulls available for energy production in Office du Niger

The technical resource potential of rice hulls (or husks) for energy in office du Niger is estimated to be around 100,000 tonnes at the moment, potentially increasing to 280,000 tonnes by 2020.

The portable rice hullers which are currently used in the Office du Niger produces a mixture of broken rice, hulls and bran (USAID 2005). According to a recent study by USAID (2009) investigating the rice value chain, the portable hullers are quite inefficient and operate with a 50-60 % net yield. The relatively high amount of broken rice in the residue, means that it has a relatively high nutrient value for cattle, compared to 'pure' rice hulls, and according to USAID (2005) this fraction is currently returned to the farmers as animal feed. Nevertheless, as the picture in Figure 8 shows, there are substantive amounts of this residue, which is actually stored in big piles close to the huller and which is partly burned and partly left for rotting.

In order to reduce the losses and improve the quality of processed rice, mini rice mills are gradually established in Office du Niger. USAID (2005) refers to 10 such mini rice mills operating at Seriwali, only about 7 km from Niono, and refers to plans of establishing another 10 rice mills in the area. According to the same source the mini rice mills are of the rubber roll sheller/steel polisher type mills, and are capable of producing a better quality of milled rice (less brokens), while at the same time producing two by products – hulls (husk) and bran. The 10 mini rice mills produces about 15,000 tonnes of rice husk per year, which will be available for energy purposes, as pure hulls due to its high silica content is not suited for cattle feed.

To the extent that mini rice mills will take over the rice hulling market in Office du Niger, the sustainable potential of rice husk will equal the technical potential mentioned above.

Figure 8 Surplus rice hulls

Characteristics of rice straw and hulls for energy use

High ash content in rice straw

The ash content is very high in rice straw (and rice hulls) compared to wheat straw and especially compared to wood. This influences the heating value in a negative direction and it also complicates ash handling at the plant and afterwards in the ash disposal.

		Rice straw	Rice hulls	Wheat straw	Wood
Ash content	%	15-20	15-20	8,5	1
Typical moisture content	%	15-30	9-11	7-15	5-15
Heating value (wet basis)	GJ/tonne	14	13	16	16,2

Table 3 Ash content, typical moisture content and lower heating value for selected biomass.[1]

Ash composition

There are also differences in the composition of the ash, when comparing ash from rice straw with ash from wheat straw or wood. According to Baxter (1993) there is a higher silica content in ash from rice straw (75%) compared to in ash from wheat (55%). This has an influence on the wear on the boiler. On the other hand the alkali content is lower in ash from rice straw (15%)

[1] http://www.biofuelsb2b.com/useful_info.php?page=Typic

compared to in ash from wheat (25%). This means relative lower corrosion level for the same amount of ash, but with higher ash content, the corrosion problems related to rice straw utilisation, should not be expected to be lower than for wheat straw.

Especially the high ash content, but also the high silica content in the ash makes rice straw and rice hulls a less attractive fuel. The advantage of rice straw and rice hulls is mainly in its availability as a rather cheap agricultural by-product.

4.3 Size of the plant

The plant in the case study is dimensioned with regard to available straw in the area, reasonable transportation distance for the straw to the plant, reasonable size of the plant and the size of power interconnector.

Available rice straw and rice hulls in the area

As mentioned above the rice production in Office de Niger has since 2000 been 350-500,000 tonnes/year. With a straw to grain ratio of 0.75, this results in a straw production of around 260-375,000 tonnes of straw per year (Nygaard, Bruun *et al.* 2012).

Available rice straw

Today most of the straw is used for feeding the cattle, but around 15% is burned in the fields or left in the fields (Nygaard, Bruun *et al.* 2012). This fraction (around 40-55,000 tonnes/year) can be used for other purposes, for instance in a power plant.

Figure 9. Burning of rice straw in the fields

This amount would just be enough for a 5 MW plant only based on rice straw.

In addition to the rice straw, some of the rice hulls can be used for energy production as well.

Available rice hulls

With a rice hull to grain ratio of 0.2 (Nygaard, Bruun *et al.* 2012) and a production of 350-500,000 tonnes of rice per year, there will be around 70-100,000 tonnes of rice hulls per year. As described above the rice hull to grain ratio depends on the technology used.

Usage of rice hulls in the power plant

For technical reasons the rice straw should be the main fuel, but rice hulls can be used for co-firing. Up to around 20% of the fuel in the plant can be rice hulls instead of rice straw (based on mass fraction).

Enough straw and hulls for a 6 MW plant

With somewhat similar ash content and heating value, 20% of the fuel can be rice hulls, based on energy. This means that the plant can be up to 6 MW based on available fuel (straw and hulls).

It should be taken into consideration that some straw and hulls will not be collected. Therefore the plant should not be bigger than 4-5 MW. 4-5 MW is perhaps too big considering the available straw and hulls today. If a 4-5 MW plant is planned, other backup fuels must be considered unless there are very confident plans for expanding the rice production.

Reasonable transportation distance for the straw to the plant

Straw within reasonable distance

Considering using straw from all of the Office de Niger area, the longest transport distance to a power plant placed in Niono will be around 50-80 km. This is a long, but still realistic distance to transport the straw.

Typical size of a power plant of this type

Reasonable size for a first plant in Mali

When looking at the straw fired power plants erected in Denmark, the first 3 plants from 1989 and 1990 are in the sizes 2.3 MW, 5 MW and 11 MW. A 5 MW plant for Niono is therefore a reasonable size for a first small plant in Mali.

Size of power interconnector

Interconnection

As shown below Niono will be connected to the central interconnected power grid in Mali. The line will be able to support transmission of 10-15 MW power, which is more than enough for a power plant of 5 MW.

4.4 Connection to power grid

Transmission line to Niono

In March 2012 the town of Niono is scheduled to be connected to the interconnected power grid by a transmission line of 63 kV. The line will have a length of over 100 km and will use an Almelec cable 148 mm ². This line will able to support 10 to 15 MW

Connection point for a power plant

Technical decisions must be taken regarding the connection point for a power plant. These decisions, amongst other, depend on the distance from the power plant to the transmission line.

For connecting a 5 MW power plant to the grid, there are basically two options for the connection.

1) The power plant can be connected at 15 kV if the distance separating the 33 kV/15 kV step-down substation does not exceed 1 km. This means that the power plant will be connected directly to the 15 kV busbar of the interconnected system.

2) If the distance between the 33 kV/15 kV step-down substation and the power plant is greater than 1 km, the plant should be connected at the busbar of the 63 kV / 33 kV step-down substation to the 63 kV line from the interconnected network at Segou. This will mean that a sub-station 15 kV / 33 kV (2x5 MVA) is required at the plant.

4.5 Operation

Base load

For a straw fired power plant in Niono, it will be optimal if the plant can operate as base load. The investment costs are high for a straw fired power plant compared to oil based plants, which due to low investment costs and high fuel costs, are more suitable for peak load operation.

The operation and maintenance of the plant will also benefit from base load operation as opposed to peak load. Experiences from Denmark show that it’s possible to change to part load or to start/stop the plant quite often. This is due to experiences from many years of operating grate fired power plants in Denmark. For a first plant in Mali, with no previous experience in operating and maintaining grate fired power plants, it’s not recommendable to plan with too many part load hours or start/stops.

Availability

For the Danish plants the average availability is 90%. As this being the first plant in Mali, a lower availability should be expected, perhaps as low as 70-75%.

Fuel supply

The fuel (rice straw) will naturally be available seasonal. But in order to make the economy in the plant attractive, it’s necessary to store the fuel to maintain a stable fuel supply for the whole year. Most of this fuel should be stored in the fields or next to the fields in smaller distributed storages. There might be a difference in fuel price over the year, due to the storage possibilities and the supply of fuel. This might affect the operational profile a little, but it will still be considered base load operation.

Power demand/price

It's assumed that the marginal cost of power production will be high enough almost every hour of the year for a rice straw fired power plant to stay in operation. Short periods of lower power production cost are not expected to make it worthwhile stopping or downloading the power plant. Therefore power prices are not expected to affect the operational profile.

4.6 Sugar factories in the area

SUKALA

Existing factories

Close to Niono in Markala there is production of sugar from sugar cane at two small sugar factories at Dougabougou at Siribala. The factories are owned by a joint venture between the Malian Government and a Chinese company under the name of SUKALA (or N'SUKALA). The two plants are currently producing around 39,000 tonnes of sugar a year (SUKALA 2010). As typical for a sugar factory they have their own power plant run on bagasse. The existing power plant has a capacity of around 5 MW, and all power is used at the sugar factory.

New factory

According to an article on Mali Web September 2011 a new factory was expected to be in operation early 2012. The annual production is estimated to 100,000 tonnes of sugar per year and 9.6 Million liters of alcohol. (Mali Web 2011). This involves a new 15 MW power plant for own consumption.

SoSuMar

Another project, SOciete SUcriére de MARkala (SoSuMAR) has been under development for some years and according to an interview with the management in February 2012 (SOSUMAR 2012), the company was at the time in the phase of concluding financial agreements and expected that the first sugar would be produced in 2015. Full production would be achieved in 2018. The main shareholder in the company is the largest sugar company in Africa, Illova Holding in a public private partnership with the government of Mali (6 %).

In combination with this factory, it's planned also to have:

- 14,000 ha for sugar cane (60% owned by the company, 40% owned by local farmers)
- a 30 MW power production unit using bagasse and leaves and other waste from sugar cane
- a bioethanol plant : Production of 15 million litre bioethanol per year (50 tonnes/day) from residues from sugar production

Also producing power to the grid

In contrary to SUKALA, SoSuMAR will not only produce power to the factory, but also some for the grid (around 10% of the production).

A signed power purchase/sales agreement has been made with EDM. This is the first one for biomass power production in Mali.

Fuel for the power plant

The power plant will primarily use bagasse as fuel, but also leaves and other waste from the sugar cane will be used. Of the total amount of potential waste from the sugar canes, only 30% are used in the power plant. This is due to 70% of the sugar canes will be harvested manually, where the fields are burned before the sugar canes are collected. This harvesting method leaves no waste. The remaining 30% of the sugar canes will be harvested mechanically, leaving the waste for the power production.

Manual harvesting creates more jobs

The reason for harvesting 70% of the sugar canes manually is that the sugar cane production is a part of a labour project. According to the interview with management, mechanical harvesting is more efficient, but does not create job to as many as manually harvesting.

Options for cooperation with the sugar factories

There are some similarities between the planned bagasse/sugar cane waste fired power plant and a potential rice straw fired power plant. Both power plants will use agricultural residues, which must be collected, transported and stored. Both must use rather robust technology due to the aggressive and irregular fuel.

Fuel exchange

It seems obvious that cooperation should be considered. This could either be fuel exchange between two potential plants, when there are variations in fuel supply or it could even be one common multi fuel power plant. The latter is probably not realistic for this case, since the sugar factories are too far in their planning to add an extra fuel and increase the capacity.

Potential for extra fuel reducing the risk	If the 70% of the sugar canes planned to be harvested manually at the SoSuMar project, sometime in the future instead will be harvested mechanically, and the additional waste was utilised in a power plant, this is estimated to potentially increase the power capacity by 4 MW. That is a considerable amount in addition to the amount of rice straw. If a 5 MW rice straw fired power plant is erected, the potential extra fuel resource from sugar farms could reduce the risk of varying fuel resources.
Exchange know how and skilled workers	With potentially 2 new power plants in the same area, also using difficult agricultural residues, there are possibilities for exchanging know how, establishing an environment with specialists and skilled workers maintaining all the power plants and perhaps coordinated maintenance planning etc. This will reduce the technical risk significant for a small "one of a kind" straw fired power plant in Niono.

5 Technologies

Different technologies are applied when using biomass for power production. Common technologies are grate firing, bubbling fluidised bed, circulating fluidised bed or dust firing. These technologies are mainly used for woody biomasses, residues from pulp and paper industry, residues from sugar industry, peat, and in some cases for straw.

Straw for power production

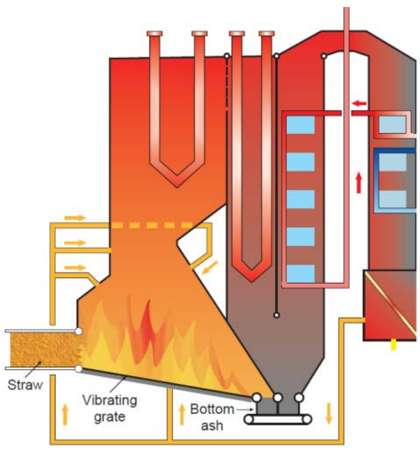
The international experiences with power production using straw as a fuel are limited. In Denmark there is 20 years of experiences, mainly using grate firing technology or dust firing in co-combustion with coal or wood pellets.

In the following section it will be discussed which technologies are recommendable for a 5 MW power plant located in Niono, Mali using rice straw as fuel.

5.1 Grate fired boiler

Advantages

The grate firing technology is old, well proven, relatively cheap and used wide spread in different countries and using a great variety of fuels, also difficult fuels like wheat straw. In Denmark many grate fired boilers are used for power production using either wood, household waste or straw. A grate fired boiler is very robust when it comes to variation in fuel size, moisture content, ash composition etc. Grate fired boilers are built in the size range 3-50 MW_{power}.



Disadvantages

Some of the disadvantages for grate firing boilers are moderate efficiency and relatively high operational and maintenance expenses.

5.2 Bubbling Fluidised Bed (BFB)

In a BFB boiler, a sand bed bubbles in the lower part of the furnace. The combustion zone retains all fuel heat, which makes BFB combustion well suited for biomass.

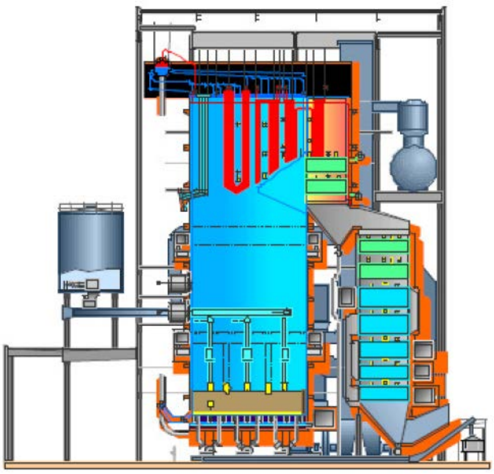
The BFB boiler technology is also widespread for small biomass power plants. Especially in Sweden and Finland the BFB boiler is used in the pulp and paper industry, but BFB boilers for biomass can be found worldwide.

Advantages

Compared to the grate firing technology, BFB can obtain slightly higher efficiencies and lower operational and maintenance expenses. BFB boilers are mainly used in timber and paper industry using woody residuals as fuel. BFB boilers can be built a little bigger than grate firing boilers; from very small up to approximately 100 MW_{power}.

Disadvantages

BFB boilers require certain moisture content in the fuel to keep the temperature at an acceptable level. The BFB boiler is therefore not recommendable for a dry fuel like straw. In addition the alkali content in straw will cause problem in a BFB boiler.



There is no documentation on positive experiences using straw in a BFB boiler, whereas it's not recommendable to look more into BFB technology for this case.

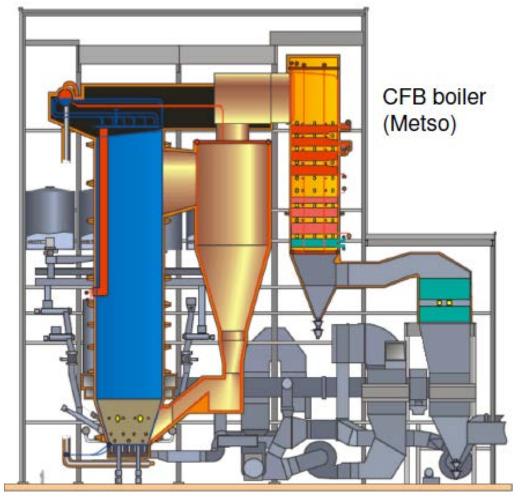
5.3 Circulating Fluidised Bed (CFB)

In a CFB boiler, the bed material flows together with flue gas through the furnace, after which it is separated from gas by cyclones and returned to the lower part of the furnace.

The CFB technology is also used in Swedish and Finnish pulp and paper industry, but mainly for bigger plants compared to the BFB technology. CFB plants using coal and to some extend also wood are erected all over the world.

Advantages

In a circulating fluidised bed fuel of different sizes and moisture content can be used. The CFB boiler can be built bigger than grate fired and BFB boilers (up to 3-400 MW_{power}). By building it bigger, it's also possible/feasible to go for a higher efficiency.



Disadvantages

The nitrous emission is higher from CFB boilers than from other boilers. The own consumption of electricity is about 1 % point higher from CFB boilers than from grate fired boilers (2-3 % for grate fired boilers and 3-4 % for BFB/CFB boilers according to Evald and Witt (2006)). CFB boilers are sensitive to alkali content in the fuel, and therefore not recommendable for straw.

Due to the alkali content in the fuel, it's not recommendable to look more into CFB technology for this case.

5.4 Dust firing

Dust firing boilers are widely used for coal. A few coal power plants have been retrofitted to use wood pellets, but it's expected that more will follow.

Advantages

A dust fired boiler can be built large scale and with high electrical efficiency.

Disadvantages

In a dust firing boiler only very fine material can be used. For biomass this means pellets, saw dust or pulverized straw. Pulverizing straw is costly, and only interesting when looking at a big power plant, where high efficiency is a high priority.

For a small plant it's far from feasible to build a dust firing boiler with straw pulverizing.

5.5 Other technologies for biomass power plants

Stirling engines

Stirling engines have been developed for biomass including straw. The technology is immature with regards to using straw, but the technology is working.

Advantages

The advantage is that the engine is very robust even when using straw, and the fact that very small units can be built.

Disadvantages

The main disadvantages are:

- low electrical efficiency
- that it's not well proven technology
- that it until now only has been built in very small sizes

When this technology becomes more mature it may be interesting for smaller installations for production of electricity.

Gasification

Gasification is not a new technology, but it's new to use more complicated fuels like straw in a gasifier. Potentially a gasifier in combination with a gas engine could supply a high efficiency even for a small plant using biomass. Until now no gasifiers have successfully been run on straw for a longer period.

Organic Rankine Cycle (ORC)

ORC is a very robust technology for biomass power plants. The disadvantage is a very low electrical efficiency. The technology is therefore only interesting if the main demand is heat and electricity is a side product.

5.6 Chosen technology

Grate firing is the most relevant technology in this case, due to the fuel, the size, the demand for electricity only and not heat and the demand for a robust and well proven technology. Grate firing technology is also the only one with substantial positive references when using straw.

5.7 Technical recommendations for the power plant

Fuel handling from field to plant

Handling of straw from the field to the power plant is described in Annexe A. This section will cover the handling of straw at the power plant

Description of plant

The rice straw must be delivered to the power plant in big bales (500 kg each).

Storage at power plant

At the power plant the big bales will be stored in a closed storage, which can contain straw for 2 days of production.

Decentralised storage

The remaining straw must be stored decentralised closer to the fields. This will reduce risk for fire at the power plant and reduce investments costs. In the decentralised storage some of the rice straw can be stored outdoor.

Fuel handling at power plant

From the storage the straw is taken with a crane to the reception conveyer. On the straw conveyer the straw is weight and seals make sure there is no back burning from boiler to straw storage. The strings around the bales are removed automatically and the bales are torn apart before the screw pushes the straw into the boiler.

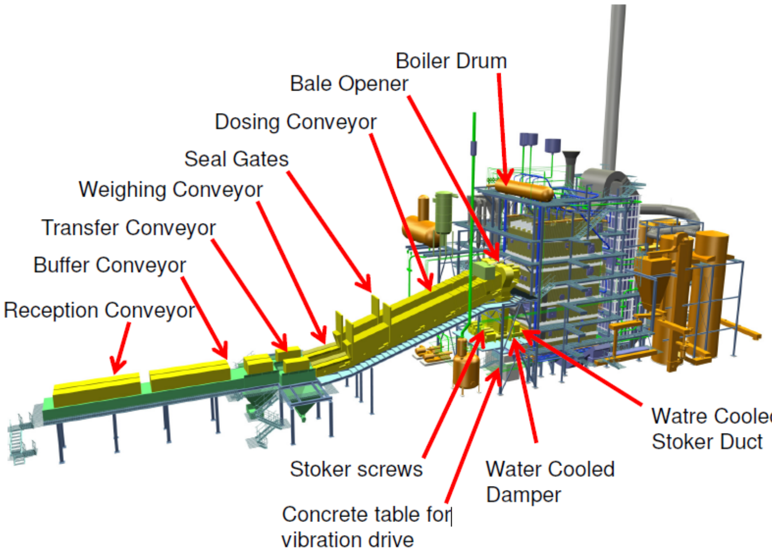


Figure 10 Example of fuel handling and boiler at a (wheat) straw fired power plant in Germany. Double size of the case in Niono (Petersen 2012).

Boiler/grate

In the boiler the straw lands on the grate. It can either be a traveling grate, a vibration grate or a step grate. On e.g. a vibration grate the fuel is moving a little down the sloping grate every time the grate vibrates.

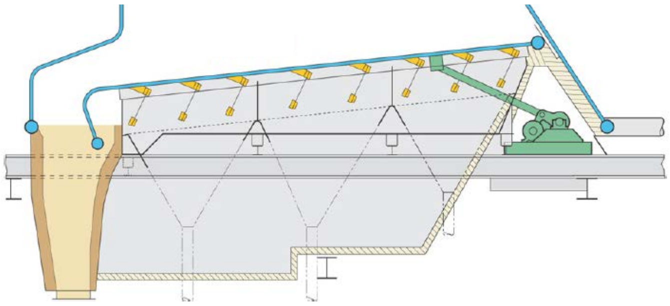


Figure 11 Example of vibration grate

When the fuel reaches the end of the grate it's completely burned out, and only the bottom ash is left, which falls down into a slag container filled with water. From the slag container the ash can be transported back to the fields and used as fertiliser.

Flue gas path

The flue gas passes through the superheaters and economisers heating up the water/steam for the turbine. Afterwards the flue gas is cleaned from particles in a bag filter or an electrostatic precipitator, and the flue gas is clean enough to go to the stack.

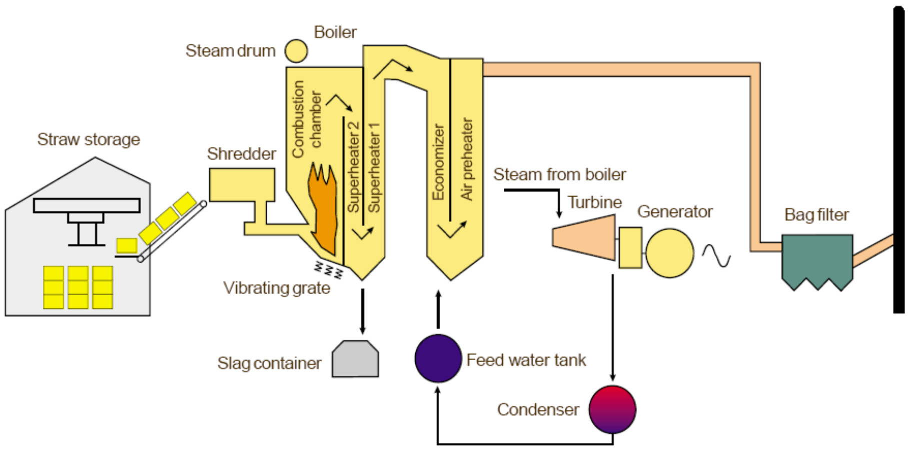


Figure 12 Principle sketch of grate fired power plant using straw

Steam circle

The superheated steam is lead from the superheaters to the steam turbine. The turbine is running the generator to produce electricity. After the turbine the steam must be condensed in the condenser before the feed water pump increases the pressure of the water. The high pressure water is send it back into the economisers and superheaters in the boiler for evaporation.

Cooling the steam in the condenser

The steam from the turbine must be cooled in order to condensate into water. This can be done in different types of condensers. If sufficient cold water is available, a water cooled condenser is usually preferred, because the heat transfer is better and the unit hereby can be smaller and cheaper.

Water cooled condenser

Choosing a water cooled condenser will result in the lowest investment costs, due to the better heat transfer. At the same time it will give the highest efficiency for the power plant due to the ability to cool down to a lower temperature.

The problem is the amount of water needed for a water cooled condenser. With a boiler efficiency of 90% and an electrical efficiency of around 20% there will be a need of around 2,500-3,000 m^3/h (0.75 m^3/s) cooling water, if the water may be heated with 5 °C. That amount of water is not expected to be available for a power plant in this location.

Water cooled condenser with cooling tower

A water cooled condenser can be combined with a cooling tower if not enough cold water is available. A cooling tower can either be a dry cooling tower or a wet cooling tower, where the energy for evaporation is used to cool down the water in the water cooled condenser. A wet cooling tower for a plant like the one in this case, would use in the area of 30-50 m^3/h of clan water.

Air cooled condenser

The simplest solution for a plant in an area where clean or cold water is a scarce resource is an air cooled condenser. The investment cost is a little higher and the efficiency a little lower, but the challenge to get enough water and to maintain the condenser is reduced significant.

It’s recommended to use an air cooled condenser for this specific case.

Efficiency calculations

To estimate the electrical efficiency of the power plant, a heat balance calculation has been made. The components used in the heat balance calculations are: Boiler, high pressure valves, turbine (with steam extraction at

4 different pressure levels), gear, generator, condenser, 2 preheaters and feed water tank. The overall schematic of the process can be seen in Figure 13.

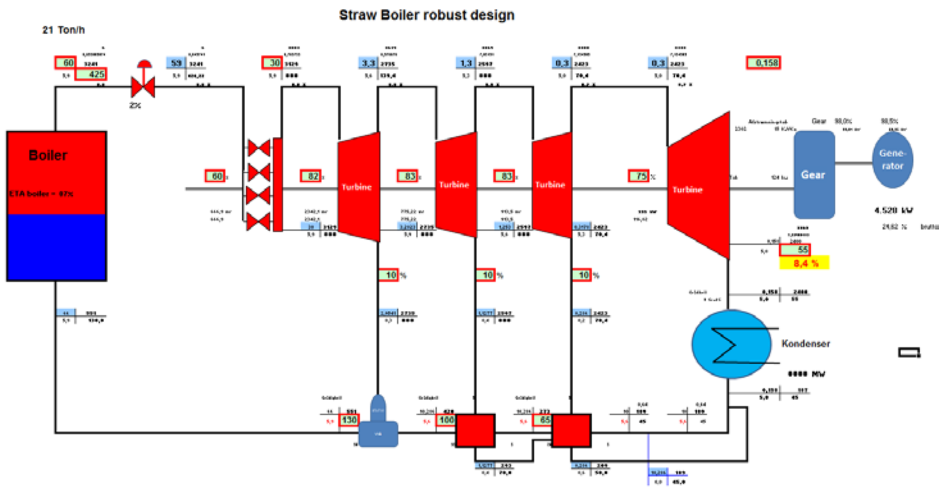


Figure 13 Power plant process model (heat balance calculations).

For each component heat balances, mass balances and thermodynamic equations are calculated. The pressure levels for each turbine extraction point are optimised to obtain as high efficiency as possible.

Component efficiencies

Some component efficiencies are estimated:

- Boiler efficiency: 87 %
- Valve loss: 2 %
- Isentropic efficiency for turbine stages: 75-83 %
- Gear efficiency: 98 %
- Generator efficiency: 98.5 %

Pressures and temperatures

Pressures and temperatures the most important places are:

- After boiler: 60 bar and 425 C
- After turbine: 0,16 bar and 55 C
- At turbine extraction 1: 3,3 bar and 139 C
- At turbine extraction 2: 1,3 bar and 106 C
- At turbine extraction 1: 0,3 bar and 70,4 C
- In feed water tank/before boiler: 66 bar and 130 C

Efficiency

The total electrical efficiency for the modelled power plant is calculated to be 24.6 % gross and 22.7 % net. The major energy flows and losses are shown in Figure 14.

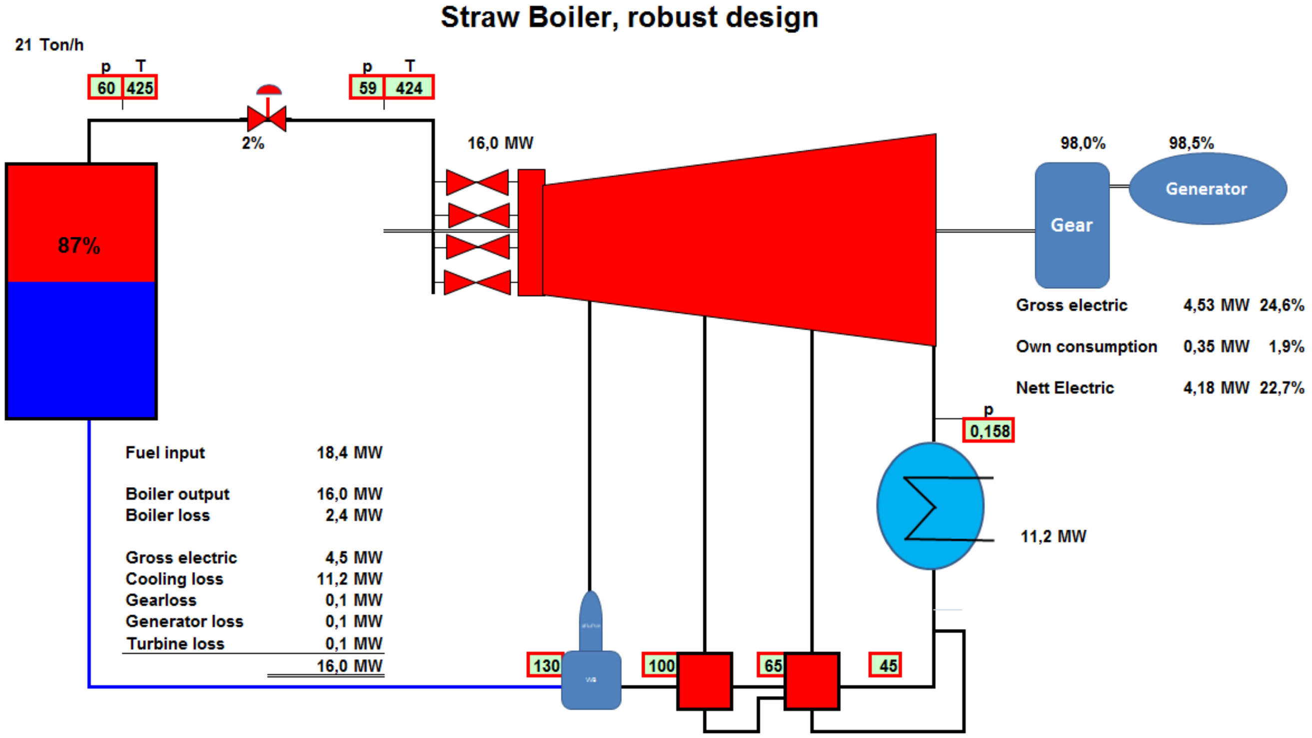


Figure 14 Overview of power plant process model

Recommendation

If a power plant of the size 4-5 MW is to be erected in Niono, the process could look like the one described above. It could be recommended to have the above described components and pressure and temperature levels.

Further along in the decision process, more detailed process calculations and optimisations should be made.

6 Economic evaluation

For the economic evaluation of the erection and operation of the rice straw fired power plant, the most important parameters are investment cost (including investment in connecting to the grid), cost of O&M, cost of the fuel (straw), cost of ash disposal and possible subsidies for the plant.

Based on these parameters, and the assumption that the internal rate of return (IRR) for the project calculated for a period of 23 years (3 years for erection plus 20 years of operation) must be 5%, the minimum accepted average power price can be calculated.

6.1 Investment costs

Power plant

In Denmark many similar plants have been erected over the last 25 years using wheat straw as a fuel. Therefore it's reasonable to look at Danish specific prices for this type of plant in order to estimate the investment cost in Mali. In DEA (2010) average specific ratios for this type of plants has been calculated, based on experiences from many plants of different sizes over the years. This average specific investment is used as a base in these calculations, giving in a specific investment cost of CFA 3,556 million per MW_{power} for a power plant similar to Danish straw fired power plants.

Comparison with investment costs for 7 Danish straw fired power plants

For 7 straw fired power plants the specific investment has been investigated, to see if the CFA 3,556 million per MW_{power} is representative for a new plant with the same size as the plant suggested for Niono. The data for the 7 plants are found in Nicolaisen, Nielsen *et al.* (1998).

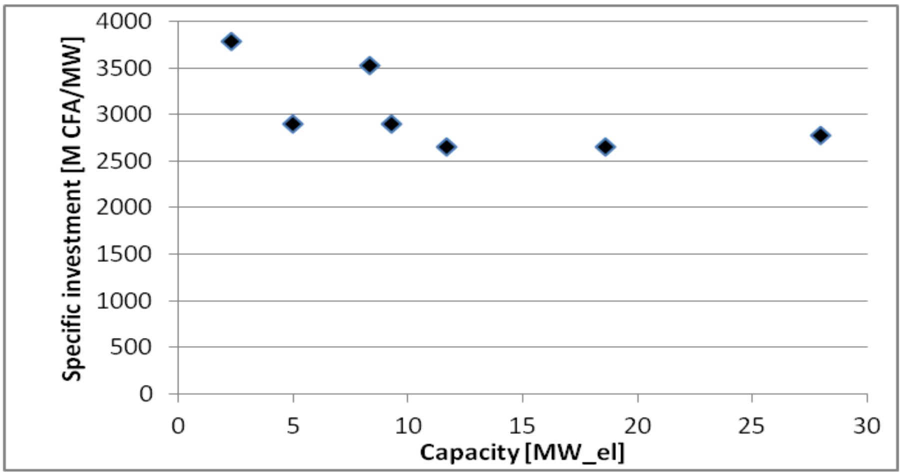


Figure 15 Specific investment for 7 different straw fired combined heat and power plants in Denmark with installed capacity between 2.3 to 18.6 MW_{power}. In million CFA/MW.

In Figure 15 it can be seen that the specific costs for the small units (2-10 MW_{power}) is in the range CFA 3-4,000 million per MW_{power}. The CFA 3,556 million per MW_{power} seems therefore reasonable.

The 7 plants from Denmark in this evaluation have been installed between 1989 and 2000.

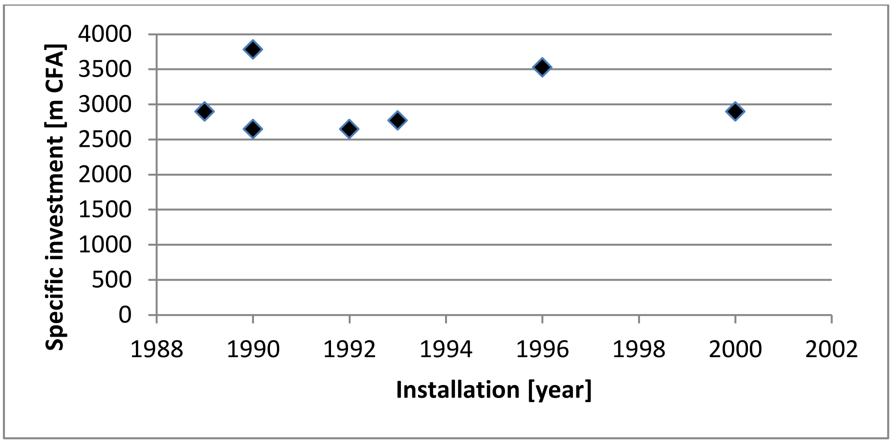


Figure 16 Specific investment for 7 different straw fired combined heat and power plants in Denmark. Installed between 1989 and 2000. In million CFA/MW.

As can be seen from Figure 16, there has not been any significant change in investment costs over the years.

Condensing/CHP

All the biomass power plants in Denmark produce power in combination with heat for district heating of houses. For a power plant in Niono there is no need for the heat, and the plant should therefore be a condensing power plant. The specific investment of CFA 3,556 million per MW_{power} is valid for combined heat and power plants (CHP), which have a lower electrical efficiency than a condensing power plant. Therefore the specific investment must be adjusted according to the efficiency ratio with a factor of 22.07/24.5 (ratio between efficiency for a CHP and for a condensing power plant). For a 5 MW plant, this will result in an investment of CFA 15,940 million.

In addition to this adjustment, the investment cost is adjusted according to the technical differences for the actual plant and according to the location.

Means of condensing	Since the plant is a condensing power plant, and not a CHP, the plant must be cooled in another way than by means of district heating. Technically speaking this means that instead of a district heating heat exchanger, the plant must be equipped with a bigger turbine and a condenser. Since there is not much water available, it's assumed that the condenser must be an air cooled condenser. Compared to a water cooled condenser, this will result in a lower efficiency and a little higher investment cost. The bigger turbine plus the air cooled condenser means extra investment cost of around 10% in addition to the CFA 15,940 million.
Storage facilities	In addition to the power plant itself, the building site has to be prepared and storage facilities must be added. This increases the specific investment with around 5% in addition to the CFA 15,940 million.
Erection in Mali	Finally the equipment and the knowhow for building this type of biomass power plant is not present in Mali, since it will be the first of its kind here. Therefore additional cost will be added due to long transportation of equipment and the necessity of importing experts and special skilled workers for the erection project and for the commissioning. This is expected to add 10% extra to the total investment cost.
Total investment cost	The estimated investment cost for at 5 MW rice straw fired power plant in Niono is CFA 20,164 million in 2012 prices.
Life time	The technical lifetime of a rice straw fired power plant of this investment, is 20 years. If the plant should stay in operation after 20 years, some additional investments, besides from the extraordinary maintenance, will be needed. This will not be included in these calculations.
Erection time	The erection time for a straw fired power plant will usually be 2-3 years. Due to longer transportation time for equipment and the necessity to transport

experts to Mali for the erection period, for this case 3 years of erection time is expected. For the economic calculations the investment will be spread over the 3 years with 10% of the investment in the first year and 45% of the investment in the following two years.

Transmission lines

It's assumed that the electrification of Niono scheduled for March 2012 has resulted in transmission lines with a sufficient capacity for a 5 MW power plant to be connected to the grid (Nygaard, Nørgård *et al*. 2012). Therefore no extra investment costs are added for expansions in the transmission system.

6.2 Cost of O&M

The expenses for operation and maintenance (O&M) of the plant is assessed, according to the investments cost, based on key ratios from DEA (2010). For small scale straw fired power plants, the yearly O&M is on average 4% of the investment costs. This figure is used in these economic calculations.

Use of local labour or foreign labour

It could be discussed to what extent maintenance can be handled by local people. It's assumed that the daily operation and the ordinary maintenance is handled by local specialised workers, but the extraordinary maintenance must be handled by specialists, which it's not expected to find locally, since a plant in Niono will be the first of its kind in Mali. The salary of the local specialised workers is considerably lower than for equivalent workers in Denmark. This would imply the O&M to be lower than in Denmark. On the other hand, when extraordinary maintenance is needed, the price will be considerably higher than in Denmark, due to the fact that both spare parts and people must be imported to Mali, most likely from Europe. Since it will be the first biomass power plant in Mali, it's also expected that more O&M will be needed compared to an average plant in Denmark.

All this taken into consideration, the cost of O&M is expected to be 10% higher than in Denmark, just like the investment cost. This means that the O&M in Mali is also expected to be 4% of the investment cost.

6.3 Power plant efficiency and availability

The power plant efficiency and the total number of hours of full load are important for the calculation of the fuel consumption.

Efficiency at full load

The electrical efficiency for a straw fired power plant in Niono is calculated to be 24.6% gross and 22.7% net (see 5.7 Technical recommendations for heat balance calculations), which is a little lower than the average efficiency

(24.4%) for the 7 Danish straw fired power plants described in Nicolaisen, Nielsen *et al.* (1998). For the 7 plants there is not a significant correlation between size of the plant and efficiency. There is a tendency for slightly increasing electrical efficiency over the years, as can be seen in Figure 17.

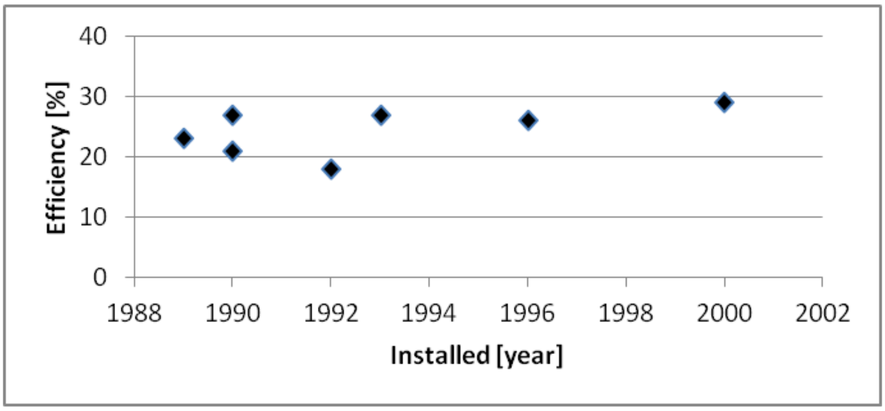


Figure 17 Electrical efficiency for 7 different straw fired combined heat and power plants in Denmark. Installed between 1989 and 2000.

Since a straw fired power plant in Niono would be the first of its kind in Mali, the efficiency could not be expected to be as high as the newest plants in Denmark.

Correlation between yearly average efficiency and the efficiency at full load

A power plant does not reach the same efficiency at part load as at full load. Furthermore additional fuel is used during load changes and during start up. Therefore the yearly average efficiency is not as high as the full load efficiency. For the 7 Danish straw fired power plants the full load efficiency, the yearly fuel consumption and the power production is measured (Nicolaisen, Nielsen *et al.* 1998). The ratio between the yearly average efficiency and the full load efficiency for the 7 plants is between 0.74 and 0.9 with a mean value at 0.81. This mean value is used for a plant in Niono, resulting in an estimated yearly average efficiency of 18.4%.

Number of full load operation hours per year / availability

The availability of a straw fired power plant in Denmark is on average 91% (DEA 2010). It's estimated that the full load operation will be 80% of that, partly due to lower availability in Mali with longer waiting time for spare parts and experts and partly due to other variations in fuel access, power demand etc. This results in an estimation of 6,381 full load equivalent hours a year. For a 5 MW plant, this will result in a yearly power production of 32,000 MWh.

6.4 Cost of fuel

Amount of fuel used

The yearly amount of fuel used in the power plant, is calculated based on:

- Yearly average efficiency
- Number of full load operation hours per year
- Fraction of rice hulls co-fired with the rice straw
- Heating value for rice hulls and rice straw / moisture content in rice hulls and rice straw

Fraction of rice hulls co-fired with the rice straw

It's possible to co-fire some rice hulls together with the rice straw. The amount is limited due to the grate in the boiler. If too high amount of rice hulls are added, they will fall through the grate and the air distribution and hereby the combustion and temperature will be uneven. It's estimated that at least 20% co-firing of rice hulls is acceptable.

Heating value and moisture content for rice hulls and rice straw

A heating value for the mixed fuel (80% rice straw and 20% rice hulls) is calculated to 13.4 GJ/tonne using the moisture content and the lower heating values for rice hulls and rice straw found in www.biofuelsb2b.com[2].

Yearly fuel consumption in tonnes/year

Based on the size of the plant (5 MW), the yearly average efficiency (18.4%) and the number of full load equivalent hours a year (6,381h), the fuel consumption in energy will be 174,000 MWh/year.

With 20% co-firing with rice hulls, the fuel consumption in tonnes will be 46,800 tonnes/year (37,400 tonnes of rice straw/year and 9,400 tonnes of rice hulls/year).

Price on rice straw

Cost of handling, transporting and storing straw

The cost of handling and transportation of straw to the power plant is analysed in Annexe A "Handling of straw from field to power plant". The costs are split up in the following processes:

- Transport from field to local storage
- Baling and storing
- Local storage facilities
- Transport local storage to plant

And the costs are split in capital cost, O&M and staff. The results from the analyses are summarised in the table below.

[2] http://www.biofuelsb2b.com/useful_info.php?page=Typic

	Capital cost	O&M	Staff	Total
Transport from field to local storage	0.8	0.1	5.5	**6.4**
Baling and storing	5.1	4.9	0.3	**10.3**
Local storage facilities	4.0	0.6	1.1	**5.7**
Transport local storage to plant	1.2	1.4	0.1	**2.8**
Total	**11.1**	**7.0**	**7.1**	**25.2**

Table 4 Overall cost in CFA/kg straw for collection, transport and storage of straw.

There is some uncertainty on the transport distance from the local storages to plant, since this depends on which areas around Niono will deliver straw to the plant. The cost of transportation to the plant is only 6 % of the total cost, and therefore longer transport distance is not considered to be crucial for the cost of straw.

Price on straw

In the following calculations it's assumed that straw is sold by the farmers for 5 CFA/kg in piles in the fields, and that either farmers or local entrepreneurs transport the straw from the piles in the fields to the local storage. In case the farmers choose to do this transport, it will be an additional income for the farmers. In Annexe A, the cost of collecting, transporting, handling and storing straw is estimated to be 25.2 CFA/kg straw. The straw price, including the sales price of 5 CFA, is therefore estimated to be 30.2 CFA/kg.

Price on rice hulls

Cost of rice hulls

The cost of collecting, transporting and storing the rice hulls is roughly estimated based on the calculations for rice straw in Annexe A .

It's assumed that the cost of transportation of rice hulls from the field to a local storage is comparable to the cost for rice straw. It might be possible to transport more rice hulls at a time, since the density is higher, but there is a limit to how much weight a donkey can pull in a small cart on a dyke. Therefore the cost of transportation of rice hulls from the field to a local storage is set a little lower than for straw. The cost is estimated to be 5 CFA/kg (compared to 6.4 CFA/kg for straw).

The cost of baling of the rice straw is not relevant for rice hulls. The rice hulls can be put into a pile or a silo at the local storage. The cost of handling the rice hulls at the local storage is estimated to be 2 CFA/kg.

The cost of local storage facilities for the rice hulls is estimated to be similar or lower than for rice straw. The cost of storage facilities is estimated to be 5 CFA/kg.

The cost of transport from the local storages to the power plant is expected to be similar to the costs for straw. The cost for transportation to the plant is estimated to be 2.8 CFA/kg.

The total cost of transporting, handling and storing the rice hulls is estimated to be 14.8 CFA/kg.

Price on rice hulls

As for rice straw, it's assumed in the following calculations that a sales price of 5 CFA/kg is included in the rice hull price. The cost of transporting, handling and storing rice hulls is estimated to be 14.8 CFA/kg, and the price is therefore estimated to be 19.8 CFA/kg.

Total cost of fuel

With yearly straw consumption of 37,400 tonnes/year and a straw price of CFA 30.2/kg the yearly cost of collecting, storing and transporting the straw will be CFA 1,130 million/year.

With yearly rice hull consumption of 9,400 tonnes/year and a rice hull price of CFA 19.8/kg the yearly cost of collecting, storing and transporting the rice hulls will be CFA 185 million/year.

The total yearly fuel cost for the power plant will be CFA 1,300 million/year.

6.5 Cost of ash disposal

Rice straw and rice hulls contain a high percentage of ash. The ash can be dispersed on the rice fields as fertilizer, but there is a cost related to the logistics of transporting the ash back to the fields and it takes many man hours to disperse the ash.

Ash production per year

Based on[3] and (Jenkins et al. 1998) the ash concentration in both rice hulls and rice straw is estimated to be around 17%. With a fuel consumption of 46,800 tonnes/year and an average moisture content of straw and hull mixture of 20%, the ash production will be 6,400 tonnes/year

[3] http://www.biofuelsb2b.com/useful_info.php?page=Typic

Bottom ash / fly ash	When using straw in a grate fired power plant, approximately 80% of the ash will come out as bottom ash and 20% as fly ash. The bottom ash will come out wet under the grate. From here it will be transported to a transportable container. The fly ash can be collected in a bag filter or an electrostatic precipitator. The fly ash will be dry. All the bottom ash can be returned to the fields as soil fertiliser. Depending on the cadmium content and the regulations for cadmium in Mali part of or all the fly ash can be mixed with the bottom ash, and returned to the fields as well. In this study it's assumed that all of the fly ash can be returned to the fields.

Cost of ash disposal

It's assumed that the dispersion of the ash has a little positive effect on the soil, but not enough for the farmers to be willing to pay for the ash. The cost for ash disposal therefore consists of cost for transportation to the local storages, storage costs, transportation to the fields and payment to the farmer for dispersing the ash.

The cost of transporting, storing and dispersing the ash is roughly estimated based on the calculations for rice straw in Annexe A and the calculations for rice hulls.

Storage at power plant	The cost of storing the ash at the power plant is included in the investment costs and the cost of handling the ash at the power plant is included in the O&M costs.
Transportation from the power plant to the local storages	The cost of transporting ash from the power plant to the local storages is expected to be similar to the costs for straw/hulls. The cost for transportation from the plant to a local storage is estimated to be 2.8 CFA/kg.
Handling the ash	The ash can be put into a silo at the local storage. The cost of handling the ash at the local storage is estimated to be 2 CFA/kg.
Local storage	The cost of local storage facilities for the ash (silo) is estimated to be similar to storage costs for rice hulls. The cost of storage facilities is estimated to be 5 CFA/kg.
Transportation from a local storage to the field	It's assumed that the cost of transportation of ash from a local storage to the field is similar to the cost for rice hulls. The cost is estimated to be 5 CFA/kg.

Dispersing the ash on the fields	The cost of dispersing the ash on the fields is estimated to be 3 CFA/kg. This estimation is based on the expected time consumption for dispersing compared with the time consumption for local transportation.
Total cost of ash disposal	The total cost of transporting, handling, storing, transporting and dispersing the ash is estimated to be 17.8 CFA/kg.
Price on ash disposal	In addition to the handling costs a profit of 5 CFA/kg is included in the handling of ash. The total price on ash disposal is therefore estimated to be 22.8 CFA/kg.
Total cost of dispersing the ash	With a specific price of CFA 22.8 /kg for ash disposal, and an annual ash production of 6,400 tonnes/year, the yearly cost for ash disposal will be CFA 145 million.

6.6 Subsidies

The base calculations are made without any subsidies. For the sensitivity analysis different subsidy levels are investigated where the subsidy level is 20, 40 or 60% of the investment costs.

6.7 Financing assumptions

For the calculation of the economy of a biomass power plant, some financing assumptions are made.

Fixed 2012 CFA	The calculations are made using fixed prices, the unit is 2012 CFA. All prices for renewable energy systems are without tax
Investment decision	It's assumed that an investment decision can be made in the beginning of 2014, for the investment and erection to take place in 2014-16.
Financing expenses	In addition to the technical investment cost, 1.5 % of the investment is added for financing costs and 1.5 % of the investment is added to cover expenses for lawyers, financing consultancies etc.
WACC	A Weighted Average Cost of Capital (WACC) is calculated based on the fraction of the investment covered by: • Equity • International loans (e.g. from the World Bank) • Local loans / bank finance

For each fraction of the financing, the Interest Rate (IR) or the Internal Rate of Return (IRR) (for equity) is stated. Hereby the WACC can be calculated as:

Fraction_equity*IRR + Fraction_international*IR_int + Fraction_local*IR_local

An example:

20% of the investment is covered with equity, 60% is covered with international loans and 20% is covered with local loans. The expected Internal Rate of Return on equity is 10%, the interest rate on international loans is 2.5 % and the interest rate on local loans is 8%. This will result in a Weighted Average Cost of Capital of:
WACC = 20%*10% + 60%*2.5% + 20%*8% = 5.1%

For the base calculation a WACC of 5 % is used. In the sensitivity analysis the WACC is varied between 2.5 to 10 %.

6.8 Calculated power prices

Produced power

As stated above the yearly average efficiency of a 5 MW plant is expected to be 18.4%. With 6,381 full load equivalent hours, the yearly power production will be 31,900 MWh/year.

Power price

Based on the investment, the cost of O&M, fuel, ash disposal and the financial assumptions, a cash flow analysis is made in order to calculate the power price resulting in a Net Present Value (NPV) of the investment at zero.

For the base case the calculated power price is CFA 125/kWh.

6.9 Sensitivity analyses

There is some uncertainty on many of the input to the economic calculations. Therefore sensitivity analyses are performed to see the robustness on the calculated power price. The most uncertain input data, which also have a significant impact on the calculated power price, are: Fuel price (including remuneration to the farmers), investment cost (including impact from down scaling the plant size), subsidy level, WACC, O&M and full load efficiency.

Fuel price

The fuel price can vary depending on how big an area the straw must be collected from, the salary level, the sales price of straw in the field, etc. In this sensitivity analyses the fuel price is varied from 20 to 36 CFA/kg. The 20

CFA/kg corresponds to a sales price of zero, 20 % shorter transport distance and 20 % lower wages. The 36 CFA/kg corresponds to double sales price (10 CFA/kg), 20 % longer transport distance and 20 % higher wages, or just normal sales price and wages, but 5 times longer transport distance.

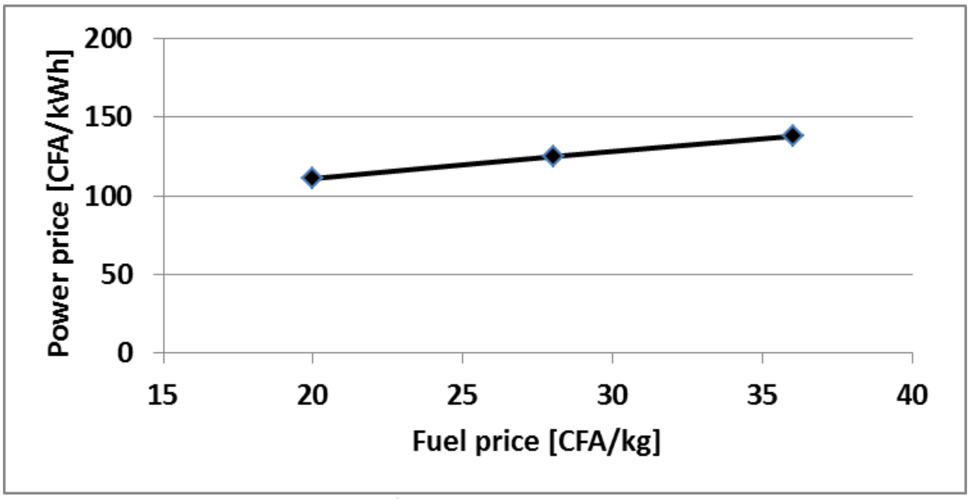


Figure 18 Calculated power price in CFA/kWh with varying fuel price. Fuel price in base case is 28.2 CFA/kg.

With high fuel prices the calculated power price increase from 125 to 136 CFA/kg, which is a 10 % increase.

Investment cost

If a smaller plant is build, the specific investment price will probably increase. To show the effect of this and other uncertainties on the investment costs, the investment price is varied with +/- 20 % compared to base case.

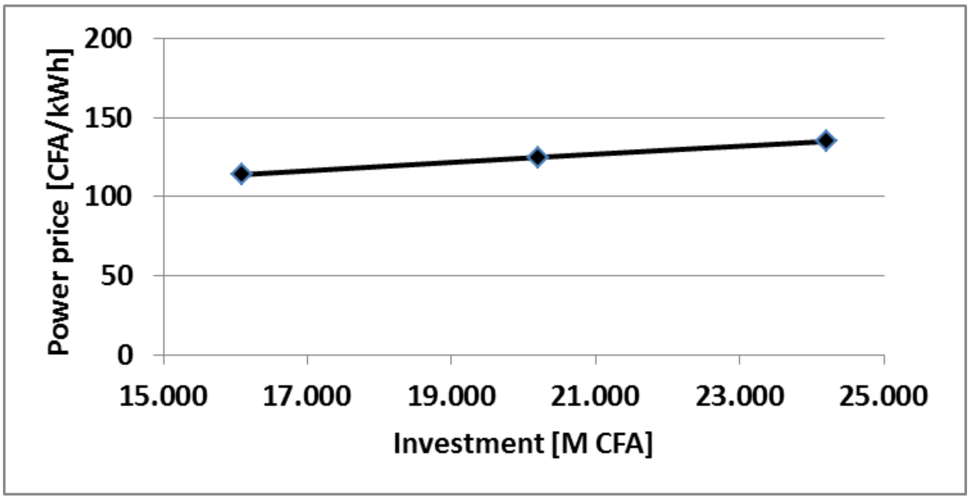


Figure 19 Calculated power price in CFA/kWh with varying investment costs. Investment cost in base case is 20,200 MCFA.

With a 20 % increase in investment, the power price is only increased with 8 %. Up- or down scaling the size of the power plant (influencing the specific investment costs and the fuel cost due to longer transport distance) will not have a significant effect on the power price.

Subsidy level

The calculated power price in the base case is barely competitive to fossil fuel produced electricity, and it's not likely that the project will be implemented, if no subsidies are granted. The resulting power price is calculated for different subsidy levels, if subsidies are given to the investment (20, 40 and 60 % of investment).

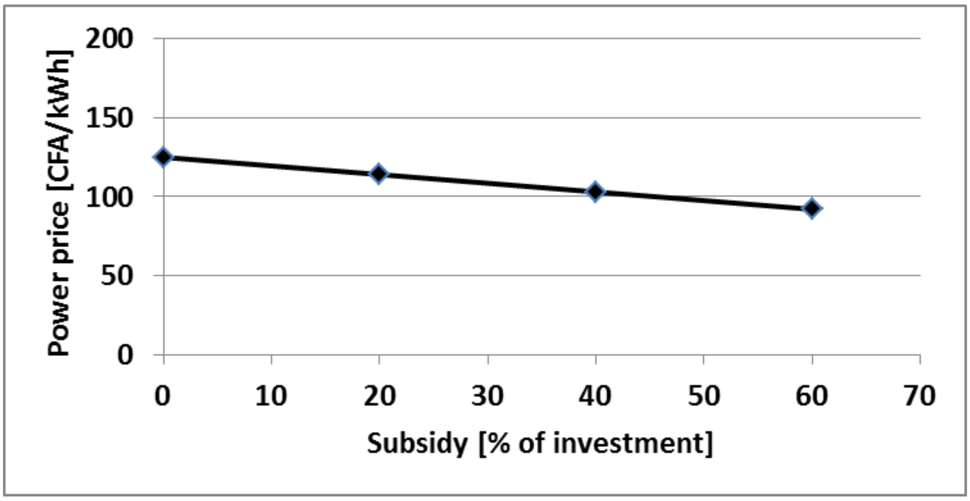


Figure 20 Calculated power price in CFA/kWh with varying subsidy level. In the base case calculations no subsidies are included.

For each 10 % of subsidy to the investment, the power price is decreasing with 5 CFA/kWh. Other solutions to improve the economy for the plant could be to subsidize the power sold from the plant or the fuel bought to the plant.

WACC

As described above, the Weighted Average Cost of Capital (WACC) is calculated based on the fraction of the investment covered by:

- Equity
- International loans
- Local loans

If loans with low interest can be raised for the project, a lower WACC can be obtained.

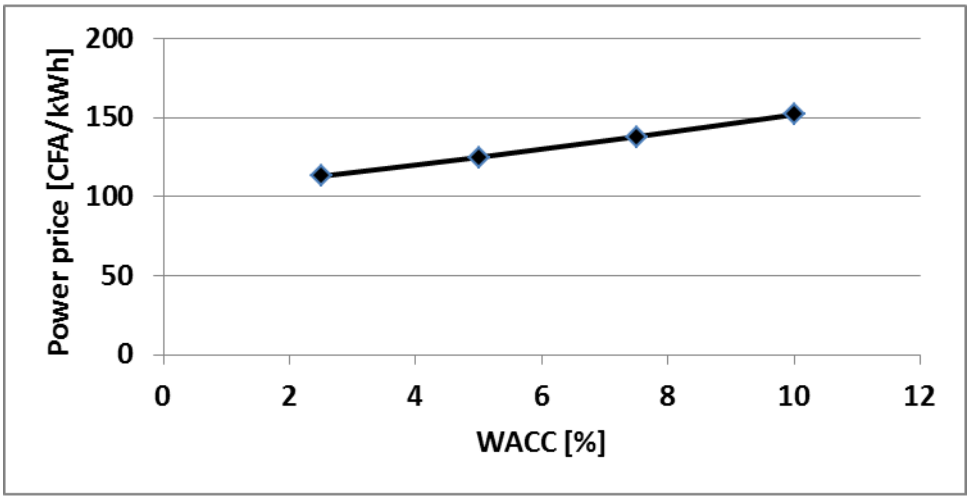


Figure 21 Calculated power price in CFA/kWh with varying WACC. In the base case calculations WACC is set to 5 %.

Lowering the WACC has a significant influence on the power price. By reducing the WACC with 2.5 %points (from 5 to 2.5 %) the power price is reduced with 10 %. To improve the economy for the plant it's also an option to offer loans with low interest.

O&M

The expenses for operation and maintenance are varied from 500 to 1100.

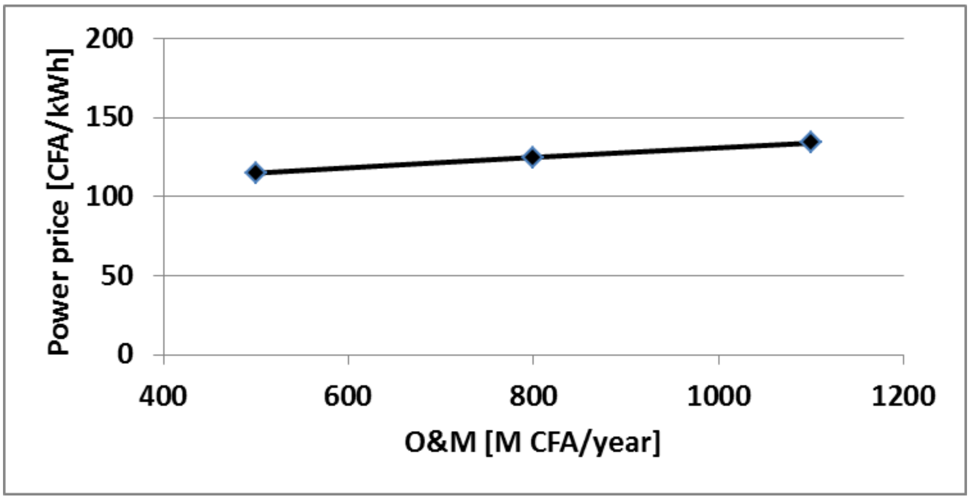


Figure 22 Calculated power price in CFA/kWh with varying O&M costs. O&M costs in the base case is 802 M CFA/year.

As can be seen from the graph above, the calculated power price does not vary significantly even with high variation in the O&M costs. When O&M is increased with 37 % the power price only increases with 7 %.

Full load efficiency

The power plant efficiency can be affected e.g. by choice of technology or by level of O&M. Higher power plant efficiency will result in lower fuel consumption, and hereby lower cost and lower calculated power price. The power plant efficiency is varied from 17 to 28.

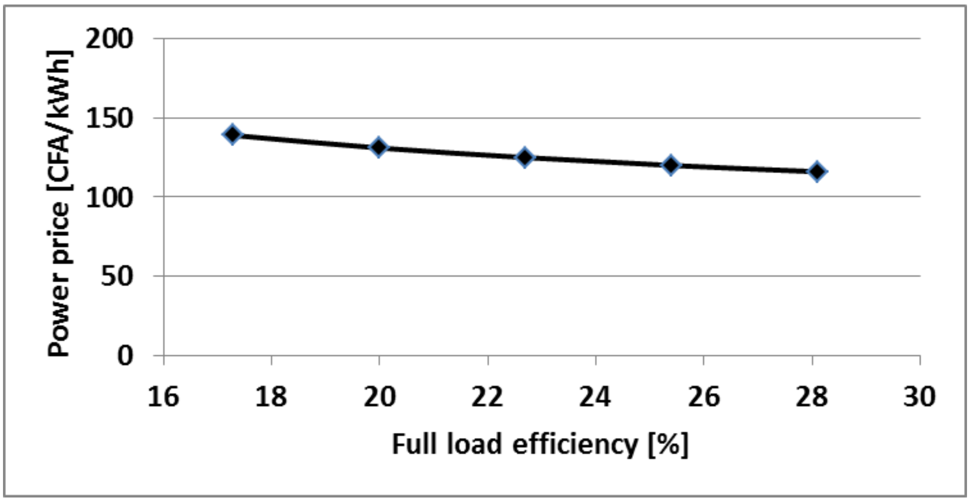


Figure 23 Calculated power price in CFA/kWh with varying full load efficiency. The full load efficiency in the base case is 22,7 %.

Even when varying the power plant efficiency rather much, the calculated power price does not change significantly.

6.10 Expected power prices (avoided costs)

The marginal cost of producing electricity in the future in Mali has been calculated in (Nygaard, Nørgård *et al.* 2012). If planned interconnectors to neighbouring countries are established according to plan, the marginal cost of power production will be set by the price on imported power. The marginal cost of power production is in that case expected to be between 65 and 100 CFA/kWh depending on the outcome of the negotiations regarding the Ghana – Burkina Faso – Mali interconnector.

If the planned interconnectors and hydropower schemes are delayed and the power consumption in Mali increases as expected then the marginal cost of power production will be set by the thermal power plants. The marginal cost of power production is in that case expected to be between 100 and 120 CFA/kWh (if crude oil prices are 100 or 125 USD/barrel)

With a calculated power price for a rice fired power plant in Niono of 125 CFA/kWh, it seems unrealistic to compete with imported electricity. Only if interconnectors are delayed or not build at all, a rice fired power plant in

Niono might have a chance to compete with electricity from thermal plants, if crude oil prices are high and straw prices are kept relative low.

7 Effects on climate and local environment

The straw fired power plant in Niono will have effects on climate gas emissions as well as local pollution because the electricity production from other power plants will be reduced. In addition to this, the straw fired power plant will have some local environmental effects due to transportation of the straw, ash disposal etc.

7.1 Influence on climate

The use of biomass for fuel is regarded as CO_2 neutral.

As described in section 6.10 the new biomass fired power plant will either substitute power production from diesel engines or imported power, probably from natural gas.

CO_2 emission if substituting diesel engines

If the new biomass fired power plant will substitute power production from engines using fuel oil, this will result in reduced CO_2 emission amounting to 25,000 tonnes CO_2/year. This is based on:

- A power production of 32,000 MWh/year from existing fuel oil plants in Mali, which could be substituted by the electricity production from the rice fired power plant. (The electricity produced from the rice fired power plant is calculated in chapter 6.3)
- A fuel consumption at existing plants of 200-300 g fuel oil pr. produced kWh electricity (average 245 g/kWh), which corresponds to an electrical efficiency of 30-40 % (35 in average). (EDM, 2010)
- CO2 emission from fuel oil is 2.65 kg CO2/L
- Density of fuel oil is 0.85 kg/L

CO_2 emission if substituting imported power

If the new biomass fired power plant will substitute imported power, this will mainly be substitution of natural gas based power, either in direct cycle or combined cycle plants (Nygaard, Nørgård *et al.* 2012). This will result in reduced CO_2 emission amounting to 10-20,000 tonnes CO_2/year depending on technology and efficiency of natural gas power plants. This is based on:

- A power production of 32,000 MWh/year from existing natural gas plants in neighbouring countries, which could be substituted by the electricity production from the rice fired power plant. (The electricity produced from the rice fired power plant is calculated in chapter 6.3)
- An estimated electrical efficiency of 35 % for direct cycle and 55 % for combined cycle power plants (DEA 2010).

- CO2 emission from natural gas is 56.8 kg CO2/GJ

7.2 Influence on local environment

Reduction of local emissions from diesel power plants

If the power from the rice fired power plant is substituting power from diesel engines the decrease in power production on diesels plants will have other environmental benefits to the local environment at the diesel power plants in addition to the reduced CO_2-emissions. This includes reduced emission of NO_x, SO_2 and particles.

Local environmental effects of the biomass plant

The biomass plant will also have an impact on the local environment. This encompasses the transportation of the fuel, local emissions to the air and waste water from the plant as well as ash disposal.

Transporting the fuel and the ash

The environmental impact of transporting the fuel and the ash has not been evaluated in detail in this project. However, different studies, e.g. Nielsen (2001) show that the energy used for collecting and transporting the fuel is very low compared to the energy content of the straw.

Air pollution

Combustion of the rice straw in a power plant will give emissions of SO_2, NO_x and particles. However, a large quantity of the straw is already burnt in the fields today resulting in air pollution. In a straw fired power plant the combustion can be controlled in order to reduce the emissions of SO_2, NO_x and particles. Therefore the emission level from a rice straw fired power plant will be lower than the emission from burning the rice straw in the fields.

Furthermore the air pollution from diesel plants will be reduced, if power production from a straw fired power plant can substitute power production from existing diesel power plants.

Ash disposal

Assuming the fly ash from the plant does not contain too much cadmium, the ash can be used as fertiliser in the fields. Hereby the nutrients from the rice straw can be recycled back to the soil. If the cadmium content is too high, the ash must be deposited, which will be a major economic disadvantage and an environmental challenge.

8 Risk assessment

The previous chapters of this report have shown that erection of a straw fired power plant in Niono is technically feasible and that the power production price might be competitive under certain circumstances. However, a number of risks associated with the project have been identified:

- Conflicts related to use of rice straw
- Operation and maintenance
- Technical risk
- Security
- Local political circumstances
- Change of power prices
- Change in the quantity of available fuel

Conflicts related to use of rice straw

Today most of the straw is used for feeding the cattle, but around 15% is burned in the fields. It is assumed that this fraction of the straw could be collected and used for combustion in a power plant in the future. However, other uses of the rice straw might compete with the use for energy production and therefore might reduce the fraction available for the power plant or increase the price of straw.

The fraction used for feeding cattle (own cattle and other cattle e.g. owned by transhumant herders) differs a lot from area to area and from farmer to farmer. This fraction might change if it's more attractive to owe cattle or if other feedstock for cattle becomes scarce. To the extent that straw used for power production is seen as a threat for the availability of feedstock to transhumant cattle this could induce conflicts between farmers and transhumant herders.

Operation and maintenance

It's assumed that the daily operation and the ordinary maintenance is handled by local specialised workers, but the extraordinary maintenance must be handled by specialists, which it's not expected to find locally, since a plant in Niono will be the first of its kind in Mali. It is a significant project risk that the specialised workers will not be available for the project or that their lack of experience will make it difficult to run the plant without regular breakdowns.

Technical risk

Since this plant would be the first of its kind in Mali, and there is no great tradition for thermal power plants using other solid fuels (coal, wood etc.) in Mali, there is a risk of experiencing technical challenges not solvable by local technicians and experts. This could result in high expenses for commissioning the plant and for solving special problems during the subsequent maintenance. In worst case the plant will be out of operation for longer periods or even taken out of operation if commissioning or special maintenance becomes too costly due to the need of foreign experts.

Security	The security situation in Mali has recently been significantly worsened. If this situation continues it will be very difficult to get experts to the area to build the plant and later to assist with operation and maintenance of the plant. With the current situation it is not feasible to invest in a biomass power plant.
Local political circumstances	A prerequisite for erection of a biomass power plant is that all needed permits regarding environment, building etc. can be obtained from the local authorities. There is a risk that this process can be difficult and time consuming. Furthermore, backup from local authorities and politicians can contribute to the acceptance of the project whereas resistance from local authorities can be a serious impediment for the project.
Change of power prices	The price of power production is in the same order of magnitude as the marginal power production price in the power system. Thus, a decrease in power prices in the power system implies that the biomass power plant is not economically feasible. This could be the case if oil prices drop, if the power system in Mali is rapidly expanded with cheaper production (hydro power or maybe even solar power if prices continue to go down) or if cheaper power from neighbouring countries becomes available through new interconnectors. However, this seems unlikely as power consumption is expected to increase by 10 % pr. year and the investments in the power system are progressing slowly.
Change in available fuel quantities	It has been assumed that the land use is unchanged in the operation period of the biomass power plant. There is a risk that the use of agricultural land can change leaving less straw for energy production. Climate changes can also reduce the land used for rice production and therefore reduce the available quantity of straw.

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Annexe A: Handling of straw from field to power plant

Authors : Ivan Nygaard, Aliou Maiga, Bouréma Kone

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1 Introduction

There is long time experience with large scale handling of straw for power plants in developed countries. In Denmark more than 2 million tonnes of straw is currently collected and transported to large power plants for electricity production. Detailed historical information on handling and storage of straw in Denmark is available in Nielsen (2003) and special information on handling of straw for energy is available in Nicolaisen, Nielsen *et al.* (1998) and Skøtt (2011).

It is the objective of this assessment to transfer the experiences with handling of straw from highly mechanised agriculture in Denmark to the actual context in Office du Niger.

This work is the result of consultations with various stakeholders in Mali during the project period. The process started at a workshop held at Mali Folkecenter in December 2010, with participant from CNESOLER, Mali Folkecenter and the consultant from IER. The current work is the joint work of the three authors

2 Defining the systems

Various system configurations have been considered during initial stages of this work. Here we have chosen to describe a base case system and to discuss the advantages and disadvantages of other systems. This chapter first describes the base case system, and hereafter it brings the discussion of alternative system configurations.

2.1 The base case system

The base case system has been selected as the most simple and the best proved system. The system is visualised in Figure 2.1.

In the base system the straw is transported loose by donkey cart from the piles in the fields close to the dikes to local storage facilities, where it is unloaded. The straw is pressed into 500 kg bales at the local storage facility by baling equipment, which circulates among 2-3 storage facilities along with a telescope loader to stack the bales. The bales are transported from the local storage to the power plant by tractor with trailer and loaded and unloaded by separate telescope loaders.

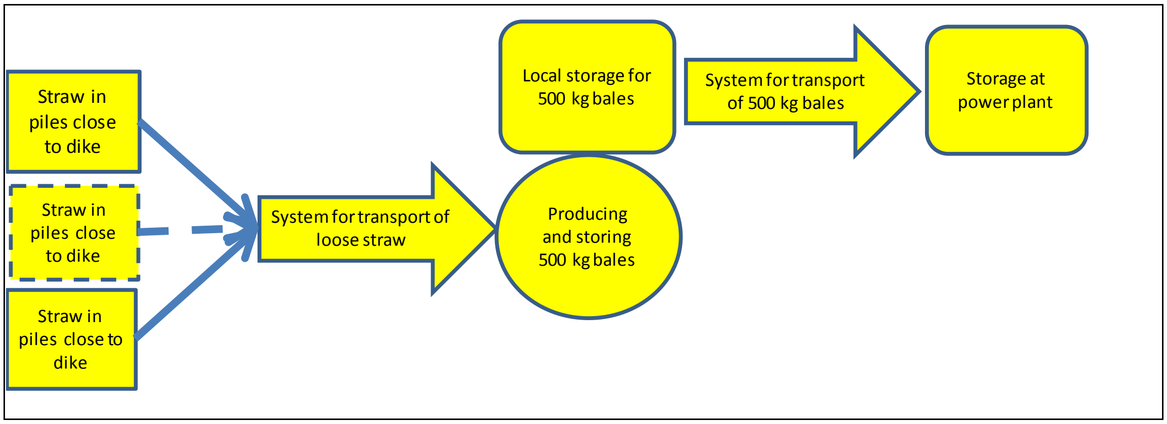

Figure 2.1. Base case system for handling straw from field to power plant

The base case system is described more in details below.

2.1.1 Transport from field to local storage

Figure 2.2. Straw is threshed close to the dikes and left in piles, Niono 2010 (Photo: Rasmus Borgstrøm, Ivan Nygaard)

Straw is left in piles close to the dikes after threshing as shown in Figure 2.2. Transport from the field to local storage will be carried out by donkey charts. Straw is transported loose. It is anticipated that load will be 100 kg. The loading time will be half an hour and the unloading will be 15 minutes. Transport speed is set to 3 km/hour.

Figure 2.3. Transport with donkey carts in Niono in 2010 (Photo: Ivan Nygaard, Koldo Salinas)

2.1.2 Local storage

Straw will be stored in 18 local storage facilities, each containing about 2400 bales or 1200 tonnes of straw. Examples of storage of bales in Denmark are shown in Figure 2.4. The pictures show an open storage, which can be covered by a tarpaulin, and a closed storage. In the base case the storage facilities will be open buildings with only a roof for protection against rain. The floor will be of concrete. The area will be 1150 m^2 and the volume about 9000 m^3, as bales are stacked six bales on top of each other (6 times 1.3 meter). The shape of the storage facility can vary according to the local circumstances, but it could e.g. be 24 meters wide and 46 meter long. The storage facility should comprise an area of another 2000 m^2 for reception and storage of loose straw from the farmers, and for compressing the straw into bales.

Figure 2.4. Examples of open and semi closed storage facilities in Denmark (Skøtt 2011, Nielsen 2003)

The storage and reception facility should be surrounded by a fence, to protect against cattle and to protect against fire or other damage. The facility should be surveyed 24 hours by a watchman to avoid fire or damage by e.g. herders seeking feed for the cattle.

2.1.3 Compressing and storage

The bales are pressed using a tractor (100 Hp) and a baler (Hesston 4900 or similar) as shown in Figure 2.5. The baler will automatically pick up the loose straw, which is stored in rows on the open storage facility. The pressing capacity at field operations in Denmark is about 15 tonnes/hour. In this case picking up straw from a pile, the capacity is considered to be substantial lower, at about 7.5 tonnes/hour.

The tractor and baler will service 3 local storages per day. Half an hour is estimated to be used to move to the next local storage. The tractor and baler will be followed by a telescope loader, which can stack the bales (two at a time) at a height of 6 bales. A total of 6 tractors, balers and loaders will be needed to handle the 36 000 tonnes in 90 days.

Besides the operator of the tractor and the loader, two manual workers are following the baling equipment to manually assist when needed.

Figure 2.5. Hesston 4900 baler in operation in a field in Denmark (Skøtt 2011)

2.1.4 Transport from local storage to power plant

Transport from the storage to the plant will be carried out by two tractors (100 Hp) with trailers each loading 20 bales (10 tonnes). Examples of tractor transport with varying loads (8 and 14 tonnes) are shown in Figure 2.6. The two tractors will serve one local storage facility at the time. A telescope loader will follow the two tractors to load bales at the local storage. The tractor drivers will operate the loader at the storage. Loading capacity is set to 20 tonnes/hour. Transport speed is set to 20 km/hour.

Another telescope loader will be available at the power plant for unloading the two and for loading the power plant. Unloading capacity is set to 20 tonnes/hour.

Figure 2.6. Transport with tractor and trailer (www.skovulbjerg.dk; Nielsen 2003)

2.2 Alternative systems

A number of alternative systems have been considered at initial phases of this study. They are presented here with a short comment on advantages and disadvantages.

a) Same as the base system, but using small Chinese rice tractors, *motoculteurs* instead of donkey carts.

Figure 2.7. Roads on dikes used for transport of loose straw. Rice tractor (Photo: Oumar Traoré)

The advantage of this option is higher load (200 kg instead of 100 kg), and higher transport speed (5 km/hour instead of 3 km/hour). This should be counterbalanced by higher investment and maintenance costs, increased fuel costs and lower employment benefit. This option is expected to have similar costs or maybe even slightly lower cost than the base case.

b) Producing 12 kg bales by tractor and mobile baler circulating at the dikes. Transport and local storage of 12 kg bales. Transport of 12 kg bales to plant. Storage at plant and feeding of plant by 12 kg bales.

Figure 2.8. Light machinery for producing small bales of 12 kg (Nielsen 2003)

This option has the advantage that all machinery is lighter, cheaper and more adapted to Malian conditions. This option will also increase the need for manual labour. The disadvantage is especially that it is difficult to transport and store the large amounts in 12 kg bales, as they have about half the density of 500 kg bales (90 kg/m^3 vs. 140 kg/m^3 per bale and 68 kg/m^3 vs. 120 kg/m^3 in storage) (VHF 1998). This will not least be a problem at the power plant, where there is a need of 240 tonnes of storage to ensure continued operation. A consumption of 120 tonnes/day implies a flow of 10000 bales per day, 420 bales an hour, or 7 bales per minutes. In this case several storages- and unloading stations will be needed close to the plant in order to provide sufficient space for access of transport to the storage and for loading the plant manually.

c) Producing 12 kg bales by tractor and baler circulating at the dikes. Transport to local storage by donkey cart or *motoculteur*. Unloading and pressing of new 500 kg bales at the central storage as in the base case. Storage and further transport as in the base case.

   This option has the advantage that transport from the dikes to the local storage is more efficient as the density is higher. It implies on the other hand an extra baling process at the dikes and it might in practice create some technical problems to take the bales apart at the storage and make them into 500 kg bales.

d) Producing 15-20 kg bales (Type CAFON)[1] by tractor and baler circulating at the dikes. Transport and local storage of 15-20 kg bales. Transport of 15-20 kg bales to plant. Storage at plant and feeding of plant by 15-20 kg bales.

   This option is similar to option c) and has the advantage that all machinery is lighter, cheaper, locally produced and more adapted to Malian conditions, and as c) it will increase the need for manual labour. The disadvantage, as for option c) is that it is difficult to transport and store the large amounts in 15-20 kg bales, as they have a lower density than 500 kg bales. This will not least be a problem at the power plant.

e) Transport of loose straw from the field to the plant.
   This option is not practically feasible for the large amount of straw in question

f) Manual pressing of 12 kg bales by the manual baler from CAFON.
   This option is not considered applicable for the large amounts of straw in question

2.3 Conclusion

Alternative a) seems very relevant, and may result in the same cost or even slightly lower cost than the base case. Alternatives b), c) and d) could be considered, but for the economic calculations, there are no reasons to expect that handling costs by alternative b), c) or d) will be considerably lower. Alternative e) and f) are considered not to be applicable in large scale.

1 CAFON is producing manually operated balers (10-13 kg) and motorized balers (15-20 kg).

3 Capacity assessment

The base case described in section 2.1 is the result of a number of considerations, which will be described in the following.

3.1 Local storage capacity and transport distances

A simple model has been developed in order to get a first estimation of the transport distances and the number and size of local storage facilities. The model is shown in Figure 3.2.

The sustainable resource of straw in the area is about 1 tonne/ha.[2]. This means that if the straw is equally distributed around the power plant, the collection area will be about 36.000 ha. This is a square of 19*19 km.

There is an economy of scale with respect to locale storage facilities. Storage facilities on the other hand should be limited in size to reduce the transport distance with loose straw by donkey carts, but also to reduce the risk for large scale fires. In this case a size of 1200 tonnes has been considered.

Figure 3.1. Illustration of the major roads and roads on the dikes in Molodo

2 The sustainable resource in the area is about 1 tonne of straw per ha. (see Nygaard, Bruun *et al.* 2012)

Total comsumption	36,000	tonnes	Residues per ha	1	ton
Collection area	36,000	ha	No of local storages	18	Units
Collection area	360	km2	Collection area local storage	20.0	km2
Diameter collection area	19	km	Diameter local collection area	4.5	km
Theoretical average distance for a circular area				0.66	radius
Faktor taking into account extra distance due to roads				1.5	
Result					
Average transport distance between local storage and power plant (round trip)				18.8	km
Average transport distance between field and local storage (round trip)				4.4	km

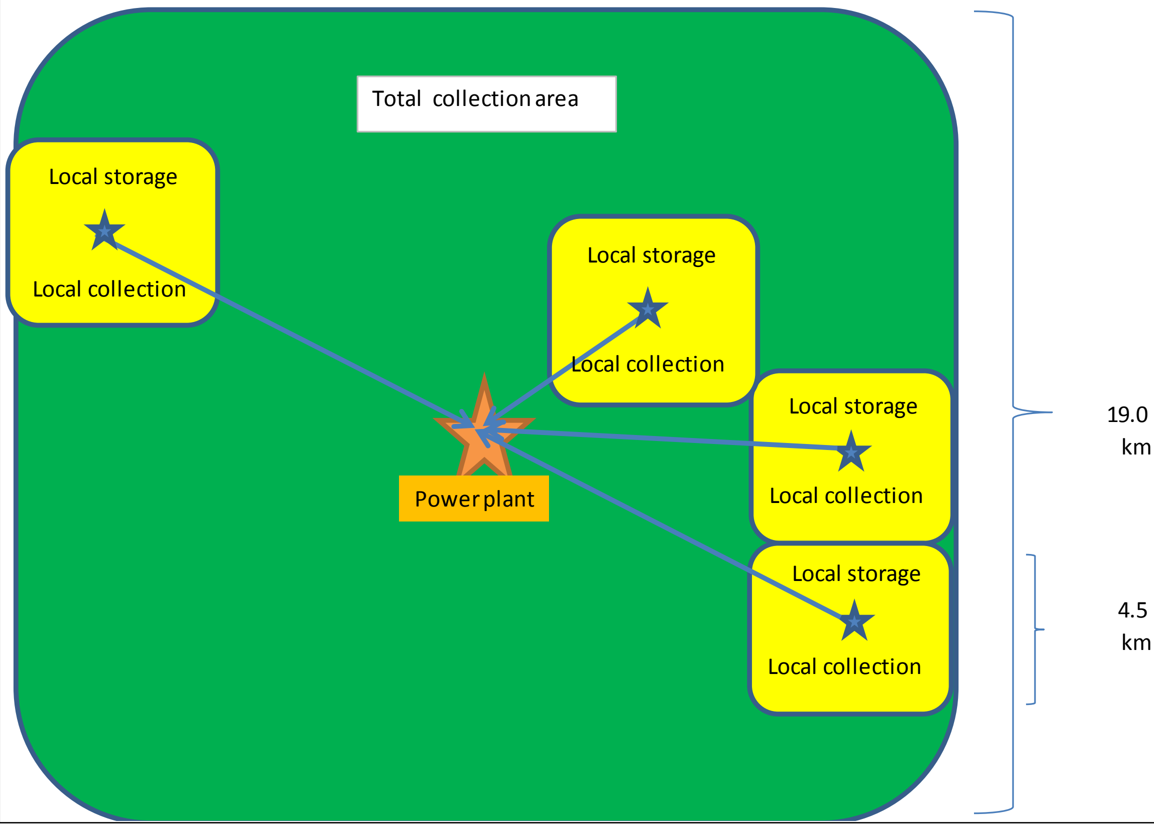

Figure 3.2. Model for calculation of average transport distance for a certain amount of straw

Straw is transported from the piles at the dikes in four months from December to April. The power plant is estimated to work on average for 6381 full load hours or 265 days of full load. In this calculation the storage capacity is based on 300 days of full load, taking into consideration annual variations of full load hours. This means that there is a need for storage of 300-120=180 days of consumption, which is 21600 tonnes. With the storage size of 1200 tonnes, this equals 18 storage facilities.

With these inputs the model calculates an average travel distance between the local storage and the power plant of 18.8 km (return trip) and an average travel distance between the fields and the local storage of 4.4 km (return trip).

For the economic calculations at this stage the precision of this level is sufficient. The next step in a feasibility study would be to precisely locate the plant and the local storage facilities and do a proper calculation based on a GIS map of the area.

3.2 Capacity assessment for the system

The capacities of the base case system elements are assessed as illustrated in Figure 3.3.

The capacities are calculated based on handling of 36,000 tonnes per year, a storage capacity of 21600 tonnes and 18 local storage facilities. Input fields in the model are marked by yellow.

Transport by donky cart

Working days per year	120	days
Daily capacity	300	tonnes

Load	100	kg
Loading	200	kg/hour
Transport speed	3.0	km/hour
Transport distance (roundtrip)	4.4	km
Unloading	400	kg/hour
Loading	0.5	hour
Transport time	1.5	hour
Unloading	0.3	hour
Roundtrip	**2.2**	**hour**
Capacity per hour	45.1	kg/hour
Working hours	8.0	
Capacity per day	0.4	ton/day

Resources:		
Carts	831	carts
Staff	831	persons

Operation hours	Annual hours	
Donkey cart	960	hour

Pressing loose straw to 500 kg bales

Working days per year	120	days
Daily capacity	300	tonnes
Number of bales	600	bales/day
Incoming straw per storage	16.7	t./day

Amount pressed per storage	16.7	t./day
Baling capacity	7.5	t/hour
Baling time per storage	2.2	hours
Transport time per storage	0.5	hours
Number of storage per day	3.0	
Transport time per day	1.5	hours
Baling time per day	6.7	hours
Total hours per day (output)	8.2	hours
Total capacity per day per work group	50.0	t./day

Resources:				
Tractor			6.0	units
Baler			6.0	units
Loader			6.0	units
Staff	tractor		6.0	persons
Staff	loader		6.0	persons
Staff	manual	2	12.0	persons
Staff	Storage	3	54	persons

Operation hours	Annual hours
Tractor	980
Baler	800
Loader (half of tractor time)	490

Transport from local storage to plant

Working days per year	300	days
Daily capacity	120	tonnes
Number of bales	240	bales/day

Load	10	tonne
Loading decentralised	20	t/hour
Transport speed	20	km/hour
Transport distance (roundtrip)	18.8	km
Unloading final storage	20	t/hour
Loading	0.5	hours
Transport time	0.9	hours
Unloading	0.5	hours
Roundtrip	**1.9**	hours
Capacity per hour	5.2	t/hour
Working hours	8.0	hours
Capacity per day	41.2	t/day

Resources:		
Tractors	2.9	units
Trailers	2.9	units
Mobile loader final storage	1.5	units
Mobile loader decenralized storage	1.5	units
Staff, tractor + loader	2.9	persons

Operation hours	Daily hours	Annual hours
Tractor	3.9	1,163
Trailer	3.9	1,163
Loader final storage	4.1	1,237
Loader decetralised storage	4.1	1,237

Figure 3.3. Assessment of capacities of the three main system elements

4 Cost assessment

The cost assessment in this section is based on calculated costs including a 5 % interest rate on capital. Capital costs are calculated as a fixed yearly payment on a loan for the depreciation period. Scrap value is set to 0. Fuel cost is set to 800 CFA/litre. In the cost assessment no profit is included to a potential operator. Remuneration to the farmers for the straw is not included in this assessment and will be dealt with separately. The reader should be aware that this is a model calculation using the transport of 36000 tonnes of straw as an example. For the model to produce scalable results, the model is operating with fractions of equipment, such as 1.5 tractors. This makes perfect sense in this calculation of handling costs per kg of straw. In a feasibility study for a concrete investment, equipment would need to be included in real numbers.

4.1 Summary of handling costs

The total handling costs for straw from the field to the plant is estimated to 25.2 CFA/kg. The breakdown of costs is summarized in Figure 4.1.

Handling costs for straw	Capital cost	O&M	Staff	Total
Transport from field to local storage	0.8	0.1	5.5	6.4
Baling and storing	5.1	4.9	0.3	10.3
Local storage facilities	4.0	0.6	1.1	5.7
Transport local storage to plant	1.2	1.4	0.1	2.8
Total	11.1	7.0	7.1	25.2

Figure 4.1. Overall cost in CFA/kg straw for collection, transport and storage of straw.

The employment effects in terms of seasonal and full year employments are presented in Figure 4.2. The calculation is based on capacity assessment in Figure 3.3. Seasonal employment is in this case a 4 month employment from December to April.

Process	Activity	Seasonal		Full year	
		Unskilled	Skilled	Unskilled	Skilled
Transport	Donkye cart	831			
Baling and storage	Baler		6		
	Loader		6		
	Manual assistance	12			
Storage	Watchman			54	
Transport	Tractor				3
Total		843	12	54	3

Figure 4.2. Employment effects of collection, transport and handling of straw for the power plant

Income generation effects are shown in Figure 4.3. The income generation is based on a salary of 2000 CFA/day for unskilled workers and 5000 CFA/day for skilled workers (machine operators). About 30 % of the cost for handling of straw is cost of local labour, - see Figure 4.1.

Annual income generation (CFA)		Seasonal		Full year		Total annual
Process	Activity	Unskilled	Skilled	Unskilled	Skilled	income
Transport	Donkye cart	199,500,000				199,500,000
Baling and storage	Baler		3,600,000			3,600,000
	Loader		3,600,000			3,600,000
	Manual assistance	2,880,000				2,880,000
Storage	Watchman			39,420,000		39,420,000
Transport	Tractor				5,238,000	5,238,000
Total		202,380,000	7,200,000	39,420,000	5,238,000	254,238,000

Figure 4.3. Income generation effects (CFA/year) for collecting, storing and handling of straw

4.2 Handling costs per system element

4.2.1 Transport from field to local storage

The cost is estimated to 6.4 CFA/kg for transport of loose straw by donkey cart over an average distance of 4.4 km (round trip). The investment in a donkey and donkey cart is 150,000 CFA. Maintenance cost is set to 3% covering feeding of the animal and maintenance of the cart. Daily salary for a four month period from December to April is set to 2000 CFA. The capacity assessment in Figure 3.3 estimates the capacity need to about 830 donkeys and carts. The assessment is shown in Figure 4.4.

Equipment	Units	Investment per unit (FCA)	Total investment (FCA)	Depreciation (years)	Annual capital cost (CFA)	Cost per kg (CFA)
Donkey and cart	831	150,000	124,687,500	5	28,799,670	0.8

Staff	Persons	Working days	Daily Salary (CFA)		Annual staff cost (CFA)	Cost per kg (CFA)
Cart driver	831	120	2,000		199,500,000	5.5

Operation and maintenance	Units			Maintenance (% of invest.)	Annual cost (CFA)	Cost per kg (CFA)
Donkey	831			3.0%	3,740,625	0.1

Total transport from field to local storage	6.4

Figure 4.4. Cost assessment for transport from field to local storage

4.2.2 Baling and storing at local storage facilities

The cost of the baling and storing system is estimated to be around 5.1 CFA/kg. The details of the assessment are shown in Figure 4.5. The costs are based on import prices in Denmark. The cost of a 100 HP tractor is 58.6 MCFA. The baler is a Hesston 4900 baler which costs around 66.7 MCFA. The loader is telescope loader, a Manitou LMT 735, which costs around 58600 CFA

Equipment	Units	Investment per unit (FCA)	Total investment (FCA)	Depreciation (years)	Annual operation hours	Annual capital cost (CFA)	Cost per kg (CFA)
Tractor 100 HP	6.0	58,600,000	351,600,000	10	980	45,533,809	1.3
Baler	6.0	66,700,000	400,200,000	5	800	92,436,114	2.6
Loader	6.0	58,600,000	351,600,000	10	490	45,533,809	1.3

Staff	Persons	Working days	Daily Salary (CFA)			Annual staff cost (CFA)	Cost per kg (CFA)
Tractor	6.0	120	5,000			3,600,000	0.1
Loader	6.0	120	5,000			3,600,000	0.1
Manual w.	12.0	120	2,000			2,880,000	0.1

Operation and maintenance	Units	Fuel: l/hour	Fuel cost (CFA) /string cost	Maintenance (% of invest.)	Maintenance (CFA)	Annual cost (CFA)	Cost per kg (CFA)
Tractor 100 HP	6.0	10	47,040,000	3.0%	10,548,000	57,588,000	1.6
Baler	6.0	String (2 cfa/kg	72,000,000	6.0%	24,012,000	96,012,000	2.7
Loader	6.0	5	11,760,000	3.0%	10,548,000	22,308,000	0.6

Total Baling and storing	10.3

Figure 4.5. Cost assessment for bailing and storing straw at local storage facilities.

Depreciation is set to 10 years for tractor and loader and 5 year for the baler. Maintenance is set to 3 % of investment cost for tractor and loader and to 6 % for the baler. Fuel consumption is set to 10 litre per hour for the tractor (hour of operation) and 5 litre/hour for the loader. Strings for the bales are set to 2 CFA/kg, based on costs in a Danish context.

4.2.3 Storage

Storage costs are estimated to 5.7 CFA/tonne. This cost is divided by the total amount of straw although only 21600 tonnes of 36000 tonnes is actually stored. This means that storage costs per tonne straw actually stored is higher. Details are presented in Figure 4.6.

According to (Hinge and Maegaard 2005) the price of the storage facility in DK would be around 1.4 million DKK (123 MCFA). Due to lower costs in Mali, the same cost has been used to also including the 2000 m^2 consolidated area for reception of loose straw, and the fence around the 3200 m^2 facility.

Maintenance cost for the storage is set to 1 % and depreciation is set to 30 years.

Equipment	Units	Investment per unit (FCA)	Total investment (FCA)	Depreciation (years)	Annual capital cost (CFA)	Cost per kg (CFA)
Storage	18	123,000,000	2,214,000,000	30	144,023,877	4.0

Staff	Persons	Working days	Daily Salary (CFA)		Annual staff cost (CFA)	Cost per kg (CFA)
Watchman	54	365	2,000		39,420,000	1.1

Operation and maintenance				Maintenance (% of invest.)	Annual cost (CFA)	Cost per kg (CFA)
Storage				1.0%	22,140,000	0.6

Total Storage	5.7

Figure 4.6. Assessment of storage costs for straw in local storage facilities

4.2.4 Transport from local storage to power plant

The transport cost from local storage to power plant is estimated to 2.6 CFA/kg. Details of the cost assessment are shown in Figure 4.7.

The cost of tractor and loader is the same as in the section above. As described in section 2.1.4, two tractors with trailers and a loader will work together as a team on the same local storage. In Figure 3.3 and in the calculation below the demand is 2.9 tractors and trailers and 1.5 loader. This can be fulfilled (at approximately the same costs) with two tractors with trailers and a loader working together plus 1 loader with trailer working alone.

Equipment	Units	Investment per unit (FCA)	Total investment (FCA)	Depreciation (years)	Annual operation hours	Annual capital cost (CFA)	Cost per kg (CFA)
Tractor	2.9	58,600,000	170,526,000	10	1,163	22,083,897	0.6
Trailer	2.9	3,636,364	10,581,818	10	1,163	1,370,394	0.0
Loader local st.	1.5	50,869,565	74,015,217	10	1,237	9,585,309	0.3
Loader power pl	1.5	50,869,565	74,015,217	10	1,237	9,585,309	0.3

Staff	Persons	Working days	Daily Salary (CFA)			Annual staff cost (CFA)	Cost per kg (CFA)
Tractor	2.9	360	5,000			5,238,000	0.1

Operation and maintenance	Units	Fuel: l/hour	Fuel cost (CFA)	Maintenance (% of invest.)	Maintenance (CFA)	Annual cost (CFA)	Cost per kg (CFA)
Tractor	2.9	10	27,072,000	3.0%	5,115,780	32,187,780	0.9
Trailer	2.9			3.0%	317,455	317,455	0.0
Loader local st.	1.5	5	7,200,000	3.0%	2,220,457	9,420,457	0.3
Loader power pl	1.5	5	7,200,000	3.0%	2,220,457	9,420,457	0.3

Total transport from local storage to plant	2.8

Figure 4.7. Assessment of costs of transport from local storage to power plant

5 Sensitivity analysis

A sensitivity analysis is carried out on two main parameters. The effect of varying pressing capacity is shown in Figure 5.1 and the effect of varying transport distance is shown in Figure 5.2. The pressing capacity in the field in Denmark is about 15 tonnes/hour. In this model study the capacity is set to 7.5 tonnes/hour as the baler is working on unloaded loose straw in rows at the local storage facility, which may reduce the capacity. The pressing capacity is seen to be a quite sensitive parameter. The cost on the other hand is not very sensitive to variation in transport distance. In the base case distances are 4.4 km and 18.8

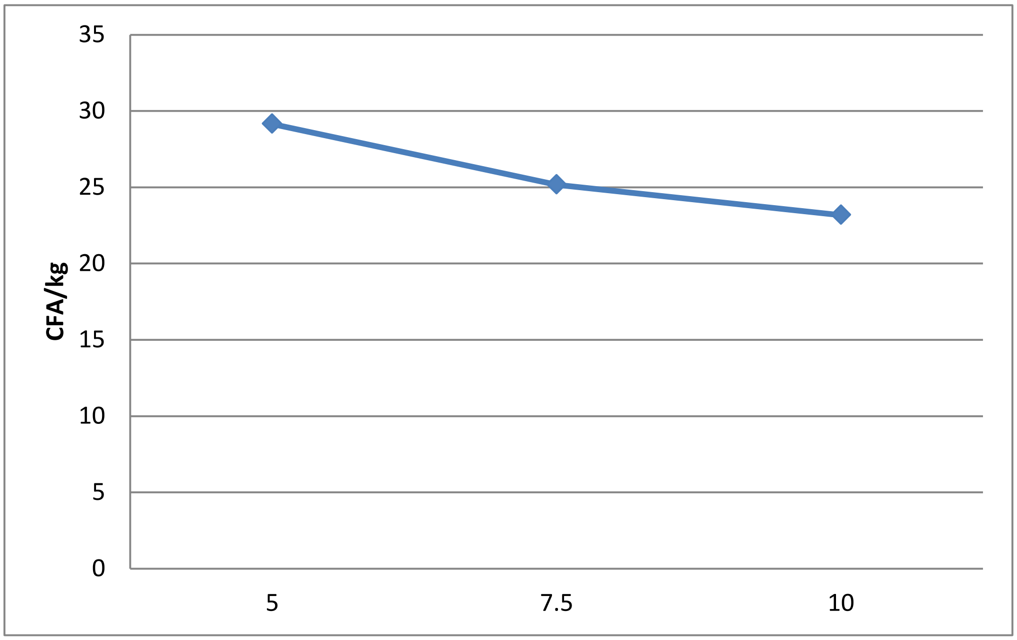

Figure 5.1. Total handling costs as a function of pressing capacity in tonne/hour

Sensitivity analysis		Transport distance from storage to plant			
Base cost	25.2	10.0	20.0	30.0	40.0
Transport	2.0	22.1	22.9	23.8	24.6
from	3.0	23.1	23.9	24.7	25.5
field to	4.0	24.1	24.9	25.7	26.5
storage	5.0	25.0	25.9	26.7	27.5

Figure 5.2. Sensitivity analysis of total handling costs (CFA/kg) as a function of transport distance in km (return trip)

6 References

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