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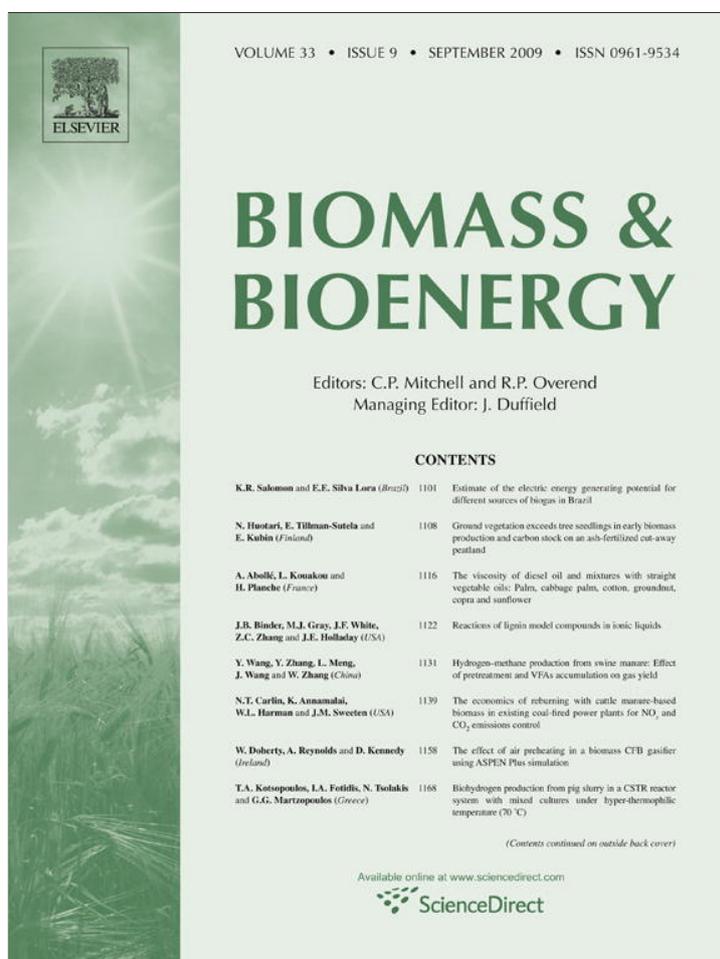
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Quantification and use of forest biomass residues in Maputo province, Mozambique

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ABSTRACT

This article describes a study on the quantification and use of forest biomass residues in Maputo province, in Mozambique. The study was performed based on information from the thematic cartography of soils of Maputo province, provided by the National Direction of Forest and Land of Mozambique, and data for the forest growth rates available in the literature. It was estimated that the total production of forest biomass residues in Maputo province is 1,233,412 ton/year, with a corresponding energy potential of 17,267,771 GJ/year. As a way of making the forest biomass residues profitable, the present work proposes the use of part of the residues as fuel in new power plants to be build in Maputo province. In this part of the study aiming at implanting power plants in Maputo province, it was taken into account the risk of forest fires, number of existing consumers of forest residues, residues availability, protected forests, transport infrastructures and existence of national electric network. It was found that the districts of Magude and Moamba are those that have the best conditions to receive the new biomass power plants. Factors such as the cost of the technology and the degree of pre-treatment of the forest residues have been taken into consideration in choosing the combustion technology for the proposed power plants. In this context, the grate burning technology appears to be the most advantageous from costs/benefits viewpoint. The proposed power plants can produce about 236,520 MWh, which is equivalent to 32% of the energy consumed in Maputo province in 2004.

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1. Introduction

The exponential growth of the world population has increased the pressure on the planet resources. Accordingly, there has been an intense debate centred on the use of energy resources in a sustainable way. In this context, the forests can play an important role since they can supply biomass residues that may constitute an important source of energy.

Mozambique is a country that has considerable forest resources. These resources are of special importance for the country given its social, economic and environmental

impacts. In Mozambique about 70% of the population depends on the energy coming from the forest [1]. The uncontrolled forest fires constitute one of the main causes of forest degradation, with estimates indicating that between 6 and 10 million hectares of forest are annually burnt in Mozambique. About 90% of the forest fires are due to the human activity being the remaining 10% consequence of natural causes. It is well known that both the agriculture and the hunting are the activities that most contribute to the forest fires in rural zones. Against this background, the exploitation of forest residues for energy purposes must be faced not only as a powerful way

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to avoid forest fires and to reduce greenhouse gas emissions, but also as a positive factor that can generate businesses and thereby favour the economic development and the creation of jobs in rural zones.

At present, Maputo province has two power plants: the hydro-electric power station of Corumana located in the district of Moamba, and the thermo-electric power station Luis Cabral located in the district of Maputo city. The power station of Corumana has a nominal capacity of 14 MW, and the power station Luis Cabral has a nominal capacity of 52 MW. Table 1 presents the energy availability in Maputo province in 2004 [2]. The table reveals that most of the electric energy consumed in the province was imported from South Africa. In light of this, it can be anticipated with reasonable justification that biomass-based electrical energy systems may have an important role in Maputo province and, therefore, it is important to examine the feasibility of installing such systems there, as it is considered in this work. There are very few studies that have concentrated on the utilization of forest biomass residues for production of electricity in Mozambique. The present work is intended to help to redress this problem. Maputo province has been chosen mainly because it is the most industrialized region of the country, presents the highest population density, the largest energy needs, but possesses few hydro energy resources, depending, to a large extent, of the imported electricity from South Africa.

In this context, the main objective of the present work is to quantify the forest residues in an important region of Mozambique (Maputo province) and, subsequently, to examine its energetic potential and to investigate solutions for power generation. In regard to earlier studies centred on the bioenergy potential of Mozambique, the works of Pereira et al. [1] and Batidzirai et al. [3] must be mentioned. Pereira et al. [1] provided an overview of the charcoal production potential for Maputo province that has considered the players, the supply areas, the impact of charcoal production and its role on the overall rural development and economy. Batidzirai et al. [3] investigated the potential, economic and logistic options for Mozambique to produce biomass and biofuels for the export market. These authors concluded that Mozambique has the potential to produce up to 6.7 EJ annually of biomass energy using surplus land under moderate agricultural technological inputs, with biomass production costs ranging from 0.6 to 1.2 Euro/GJ. These costs, however, represent solely a small part of the final fuel costs, with both the inland transport and the pre-treatment costs being more important.

Other important studies aimed at quantifying the potential of forest biomass residues for energy production included those of Voivontas et al. [4], Berndes et al. [5], Balat [6], Rosa and Vieira [7], Smeets and Faaij [8] and Smeets et al. [9], among

others. Voivontas et al. [4] used a Geographic Information System (GIS) based method to estimate the power production potential from agriculture residues in the island of Crete (Greece). These authors concluded that this island has a significant biomass potential that could be economically and competitively harvested. Berndes et al. [5] presented a very interesting article in which they discussed the contribution of biomass in the future global energy supply. The discussion was based on a review of 17 earlier studies on the subject that have arrived at widely different conclusions about the possible biomass contribution, e.g., from below 100 EJ/year to above 400 EJ/year in 2050. In the article, Berndes et al. [5] discussed the diverging conclusions about the future contribution of biomass energy by analyzing the underlying assumptions and methodologies that were used in these 17 previous studies. Balat [6] analyzed the potential of various biomass energy sources in Turkey, concluding that the total biomass potential of Turkey was around 117,000,000 ton/year, being the potential amount of usable biomass around half of this value. Rosa and Vieira [7] evaluated the biomass potential in the island of Madeira (Portugal). These authors included in their study both forest and agricultural residues as well as residues from the timber industry. Using a GIS-based method, they estimated a total biomass potential of 135,390 ton/year in the island of Madeira. More recently, Smeets and Faaij [8] and Smeets et al. [9] described in detail how net availability of forest resources can be quantified and what factors should be taken into account. Smeets and Faaij [8] evaluated the global energy production potential of woody biomass from forestry for the year 2050 using a bottom-up analysis of key factors, such as the demand for industrial roundwood and woodfuel, the plantation establishment rates, and the various theoretical, technical, economical, and ecological limitations related to the supply of wood from forests. Based on a medium demand and medium plantation scenario, the global theoretical potential of the surplus wood supply (i.e., after the demand for woodfuel and industrial roundwood is met) in 2050 was calculated to be 71 EJ. Smeets and Faaij [8] concluded that forests can, in theory, become a major source of bioenergy, and that the use of this bioenergy can, in theory, be realized without endangering the supply of industrial roundwood and woodfuel and without further deforestation.

The remaining of this article is organized as follows: section 2 presents a general characterization of Mozambique and Maputo province, section 3 provides a forest characterization of Maputo province, section 4 evaluates the forest residues potential in Maputo province, section 5 considers briefly the economics of forest residues production, section 6 analyses the sustainability of biomass power plants in Maputo province and, finally, section 7 summarises the main conclusions of this study.

2. Characterization of Mozambique and Maputo province

Figure 1 shows the geographical location of Mozambique in Africa and of Maputo province in Mozambique as well as the geographical distribution of the nine districts and of the main roads in Maputo province. Mozambique is situated on the east

Table 1 – Energy availability in Maputo province in 2004 [2].

Energy (MWh)	
Electricity produced in Maputo province	10,720
Electricity imported from South Africa	1,364,980
Electricity consumed in Maputo province	739,806

coast of Southern Africa. It has a total area of 799,380 km², of which about 786,380 km² is covered by firm earth and 13,000 km² by superficial waters. Mozambique is bordered by South Africa to the south, Tanzania to the north and has inland borders with Malawi, Zambia, Zimbabwe and Swaziland. Maputo province is situated in south of Mozambique (Fig. 1) and has a total area of 23,622 km². In 2006, the population of Maputo province was 2,316,313 inhabitants – about 11% of the population of Mozambique – of which about 6% lived in Maputo city, and the remaining 5% in the other eight districts (Fig. 1).

Maputo province has a very heterogeneous population density. Specifically, data from 2005 indicate that Maputo city, with an area of 347 km², had a population density of 3172 inhabitants/km², while the remaining eight districts presented an average population density of 312 inhabitants/km².

The energy demand, in particular the demand of electricity, is growing rapidly as a result of social and economic development. The main indigenous energy resource is the hydro, mainly in the western part of Maputo province [2]. The economic activity in Mozambique is supported by the solid performance of the extractive and manufacturing industries. Sectors such as the sugar and tobacco ones have registered a fast growth during the last few years. From energy viewpoint, the country depends on the import of fossil fuels – at the present time there is evidence that the consumption of crude-derived fuels is growing.

3. Forest characterization of Maputo province

The vegetation of Maputo province is one of the most diversified of Africa and falls within the Savanna biome being a mosaic of sand forests, scrub forests, evergreen and semi-evergreen bush-land and thicket, in a matrix with secondary and wooded grasslands [1]. The closed south forests can grow up to 6 m in height, while the northern variant of these forests may reach up to 9 m in height being generally widely spaced.

In regard to the vegetable coverage, Maputo province is divided in three different groups: forests, other woody formations and remaining areas, including the grasslands and the agriculture, among others [10]. Table 2 shows the total area occupied by vegetation type in Maputo province [10]. As can be seen in the table, the forests occupy 34.7% of the area of Maputo province, that is, an area of 820,400 ha.

Table 3 shows the importance value index (IVI) for the most important species in the deciduous forests of Maputo province. It can be observed that the *Azelia Quanzensis* is the species that present the higher IVI value in the deciduous forests of Maputo province.

Fig. 2 shows the map of the vegetable coverage of Maputo province. As can be seen, the semi-deciduous open forests expand up throughout Maputo province. It is also seen that

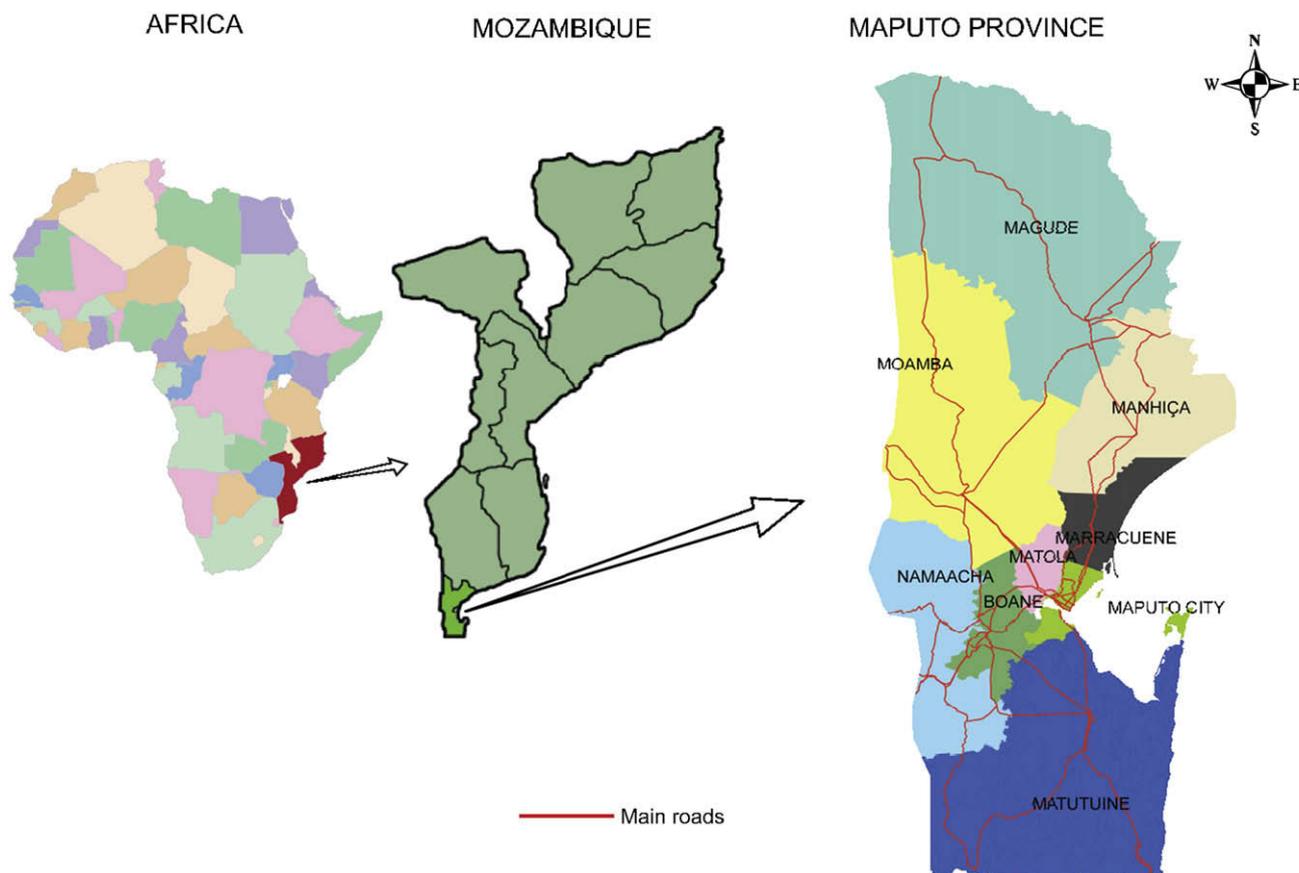


Fig. 1 – Geographical location of Mozambique in Africa and of Maputo province in Mozambique as well as the geographical distribution of the nine districts and of the main roads in Maputo province.

the grasslands is the type of vegetation that occupies the larger area, covering all Maputo province.

4. Evaluation of the forest residues potential in Maputo province

In the present study, the quantification of the forest biomass residues in Maputo province was performed with the aid of a GIS. The study was based on information gathered from the thematic cartography of soils of Maputo province, provided by the National Direction of Forest and Land of Mozambique (NDFLM), and data for the forest growth rates available in the literature.

The thematic cartography of soils of Maputo province was developed by Jansen et al. [11] based on the methodology proposed by Di Gregorio and Jansen [12]. Jansen et al. [11] produced a land cover map based on the interpretation of satellite images (LANDSAT 5 TM of year 2004–2005). Map validation was carried out with ground truthing or high resolution images. Using statistical methods, Jansen et al. [11] estimated that the accuracy of the map was 86–88% for the main classes and 90% for the forest classes.

As for forest growth rates the data available in the literature is very scarce. Clement [13] presented a model to estimate forest productivities for countries in Africa. Following the work of Clement [13], a number of authors [e.g., 1] estimated forest growth rates between 0.1 and 2.5 m³/ha/year or 0.072 and 1.8 ton/ha/year for countries in Southern Africa.

Table 4 shows the total area occupied, biomass growth rates, forest residues and energy potential by forest type in Maputo province. The growth rates have been taken from Pereira et al. [1], varying between 0.7 and 1.16 ton/ha/year in Maputo province.

Table 5 shows the energy potential by district in Maputo province. The total production of forest biomass residues

Table 2 – Total area occupied by vegetation type in Maputo province [10].

Type of vegetation	Occupied area (ha)	Percentage (%)
Dense forest	268,000	11.3
Open forest	516,400	21.9
Mangrove	5400	0.2
Aquatic and regularly flooded open forest	30,600	1.3
Sub-total of forests	820,400	34.7
Thickets	58,800	2.5
Shrublands	285,400	12.1
Forested with shifting cultivation	94,900	4.0
Sub-total of other woody formations	439,100	18.6
Grasslands	699,600	29.6
Cultivation	309,300	13.1
Bare areas	50,200	2.1
Water	43,500	1.8
Total	2,362,100	100

Table 3 – The importance value index (IVI)^a for the most important species in the deciduous forests of Maputo province [10].

Species name	Abundance	Dominance	Frequency	IVI
<i>Azelia Quanzensis</i>	10.4	15.9	0.5	26.8
<i>Dialium Schlechteri</i>	13.7	9.8	0.7	24.2
<i>Spirostachys Africana</i>	3.8	4.8	0.2	8.8
<i>Albizia Versicolor</i>	3.9	4.3	0.3	8.5

a IVI = Abundance + dominance + frequency.

estimated for Maputo province is 1,233,412 ton/year, with a corresponding energy potential of 17,267,771 GJ/year, assuming an average low heating value for the dry residues of 20 MJ/kg [14] and an energy efficiency of 70% [7]. Fig. 3 shows a map with the distribution of the forest residues in Maputo province. The map reveals that the districts that present higher energy potential are those of Magude, Matituíne and Moamba, having thereby good conditions to receive power plants from this viewpoint.

5. Economics of forest residues production

In this work it was considered as forest residues the tops and the branches of the tree species existing in the forests of Maputo province. Besides the forest biomass residues, additional biomass potential also exists from other sources such as timber-processing activities and agricultural waste. The 19 Mha of land in Mozambique considered to be productive forests has a potential sustainable extraction of about 500,000 m³ cut per year [3]. According with Batidzirai et al. [3], the potential biomass from forest logging residues is estimated to be about 850 TJ while 1.9 PJ of biomass is potentially available from waste in timber-processing industries, giving a combined residue potential of about 2.7 PJ.

In general, the harvested biomass is stored in the field for up to six weeks to facilitate natural and low-cost drying. The costs of open-air storage in the field would be equivalent to the land costs or opportunity cost of land. For Mozambique, these costs are small and hence ignored [3]. Thus, the only costs associated with the collection of forest biomass will be the transport of the residues from the forests to the main roads by tractors and, subsequently, from the main roads to the power plant. An excellent discussion on biomass costs for energy purposes in Mozambique may be found in Batidzirai et al. [3].

6. Sustainability of biomass power plants in Maputo province

6.1. Possible locations of the biomass power plants

In order to select the best locations for the installation of the biomass power plants, the following aspects have been considered:

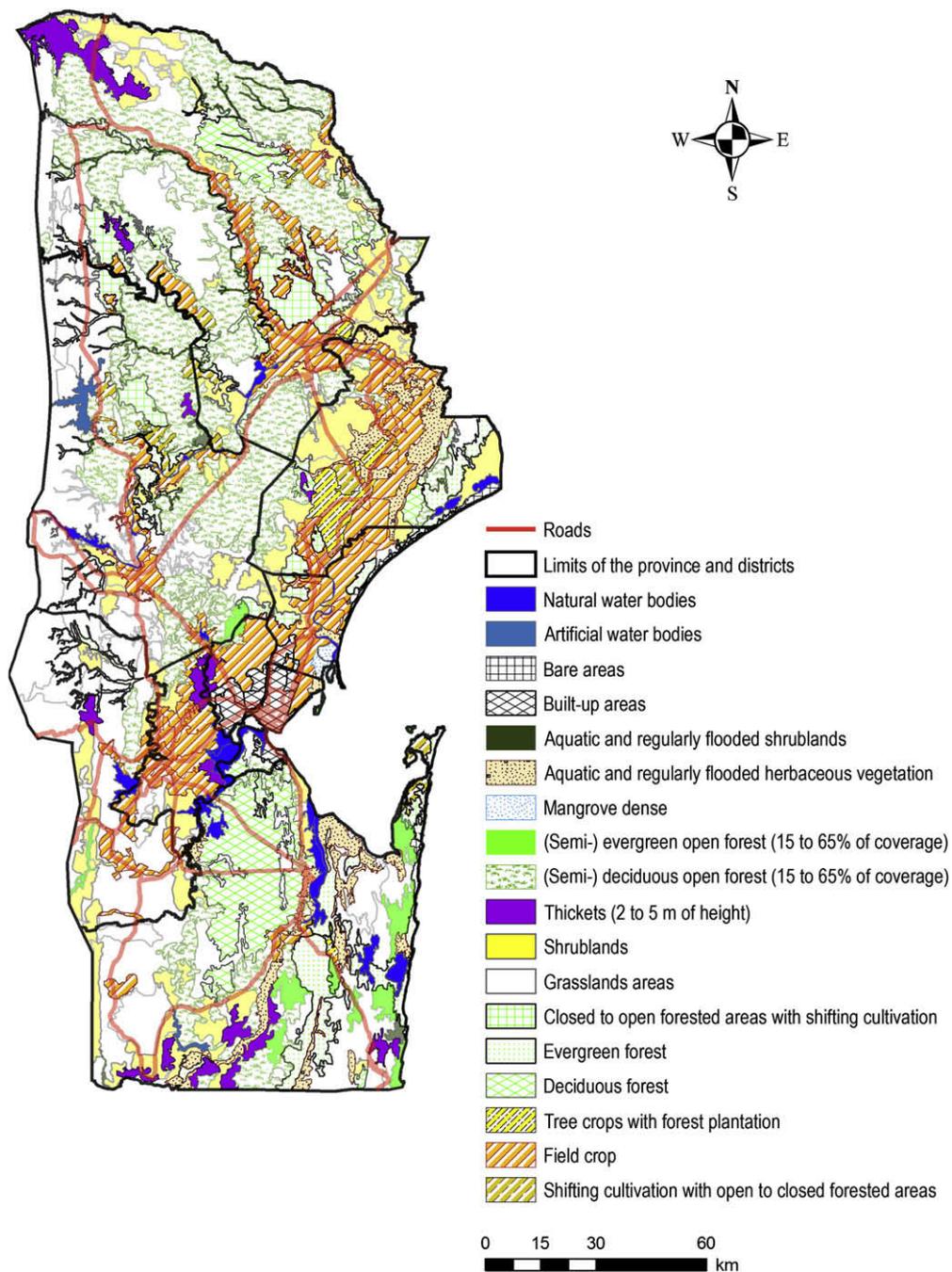


Fig. 2 – Map of the vegetable coverage of Maputo province.

- preference for areas with high risk of forest fires,
- preference for areas with a small number of consumers of forest residues,
- preference for areas with high production of forest residues,
- preference for locations with unprotected forests,
- preference for locations with good transport infrastructures,
- preference for areas with national electric network.

Mozambique, like most African countries, is a victim of uncontrolled fires. These are traditional practices widely used by the rural population, mainly in the dry season of the year, in

order to establish new areas for agricultural activities, to get hunting and to protect the crops, among others. As mentioned in section 1, these practices are one of the most severe causes of forests degradation in the country, particularly in Maputo province. The areas with high risk of forest fires encompass mainly those situated far away from the urban centers. In 2003, Mozambique had about 58,393 forest fires, of which 561 have occurred in Maputo province, particularly in the districts of Magude, Moamba and Manhiça, where, based on this criteria, the installation of biomass power plants should be considered.

Likewise, the areas with few consumers of forest residues are also those located far from the urban centers, namely

Table 4 – Total area occupied, biomass growth rates, forest residues and energy potential by forest type in Maputo province.

Forest type	Area (ha)	Growth rate (ton/ha/year)	Forest residues (ton/year)	Energy potential (GJ/year)
Shifting cultivation with open to closed forested areas	28,173	0.7	19,721	276,094
Tree crops and forest plantation	24,220	0.7	16,954	237,356
(Semi-) deciduous forest	115,368	1.045	120,560	1,687,840
(Semi-) deciduous open forest (15–65% coverage)	451,300	1.045	471,609	6,602,526
(Semi-) evergreen forest	110,058	1.16	127,667	1,787,338
Closed to open forested areas with shifting cultivation	87,493	1	87,493	1,224,902
Evergreen open forest (15–65% coverage)	32,317	1	32,317	452,438
Aquatic and regularly flooded open forest	33,053	1	33,053	462,742
Shrublands	219,558	0.93	204,189	2,858,646
Thickets (2–5 m of height)	50,607	0.93	47,065	658,910
Mangrove dense	5007	0.98	4907	68,698
Aquatic and regularly flooded herbaceous vegetation	68,854	0.93	64,034	896,476
Aquatic and regularly flooded shrublands	4129	0.93	3840	53,760
Total	1,230,137		1,233,413	17,267,771

Magude (64,434 inhabitants in 2005), Moamba (62,392 inhabitants in 2005) and Matituíne (52,703 inhabitants in 2005). Thus, based on this criteria, the installation of biomass power plants in the districts of Maputo city, Matola, Boane, Manhiça, Marracuene and Namaacha should not be considered.

In regard to the areas with high production of forest residues, it was found that the districts of Magude, Moamba and Matituíne are those that best suit this criterion (see Table 5).

Maputo province has two forest reserves and a wildlife reserve. These reserves are located in the districts of Matituíne (the Liquati forest reserve and the wildlife reserve of Maputo river) and Marracuene (the Bobole forest reserve). Thus, based on the unprotected forests criterion, these two districts must be excluded from the list of those that can receive a biomass power plant.

Locations with good transport infrastructures are decisive for the exploitation of power plants because they are critical for forest harvesting and transport operations. Maputo province has about 2538 km of asphalted roads distributed by the nine districts (see Figs. 1 and 2). This network includes about 1759 roads, of which 323 are main roads, 169 are secondary

Table 5 – Energy potential by district in Maputo province.

District	Forest residues (ton/year)	Energy potential (GJ/year)
Boane	18,444	258,209
Maputo city	8971	125,599
Magude	450,416	6,305,825
Manhiça	135,048	1,890,667
Marracuene	20,139	281,942
Matituíne	325,126	4,551,767
Matola	4110	57,546
Moamba	225,936	3,163,099
Namaacha	45,223	633,116
Total	1,233,412	17,267,771

roads and 557 tertiary roads. All districts of Maputo province have in general reasonable transport infrastructures and, therefore, none of the districts should be excluded from the possibility to receive a biomass power plant based on this criteria.

In Mozambique, Maputo province is the only one that is fully covered by the national electric network. In all districts of Maputo province there is coverage of very high-, medium- and low-voltage. This means that none of the districts should be disregarded as a good candidate to receive a biomass power plant based on this criteria.

In light of the discussion above, it can be concluded that there are two districts that fulfill well the six criteria established: the districts of Magude and Moamba.

6.2. Suitable combustion technology for the biomass power plants

The combustion technology for biomass power plants is determined, to a large extent, by factors such as the cost of the technology and the degree of pre-treatment of the forest residues. In this context, the grate burning technology emerges as the most advantageous from costs/benefits viewpoint, being our preference here. This technology is commonly used to burn forest biomass residues, being one of its main advantages the possibility of using residues of relatively large dimensions, typically between 12 and 20 mm, which avoids the need of severe pre-treatment of the residues.

The project of a biomass power plant requires the knowledge of the quantities and characteristics (proximate and ultimate analysis, heating value, moisture, etc...) of the forest residues, among others. Let us estimate the forest biomass residues available to burn in the power plants. Existing studies regarding the consumption of forest biomass residues in Maputo province indicate the biomass consumed by the population but do not identify the origin of the residues. Estimates for the districts of Maputo city and Matola indicate a consumption of forest biomass residues by the population of about 650,000 ton/year. Assuming that all this amount of residues comes from Maputo province (in fact, there are studies [1] indicating that only around 10% of the residues comes from other provinces – mainly from the Gaza province), it may be concluded that around 1,098,978 ton/year (1,098,978 = 1,748,978 – 650,000) of residues have no utilization at the present time. In light of this scenario, it is proposed

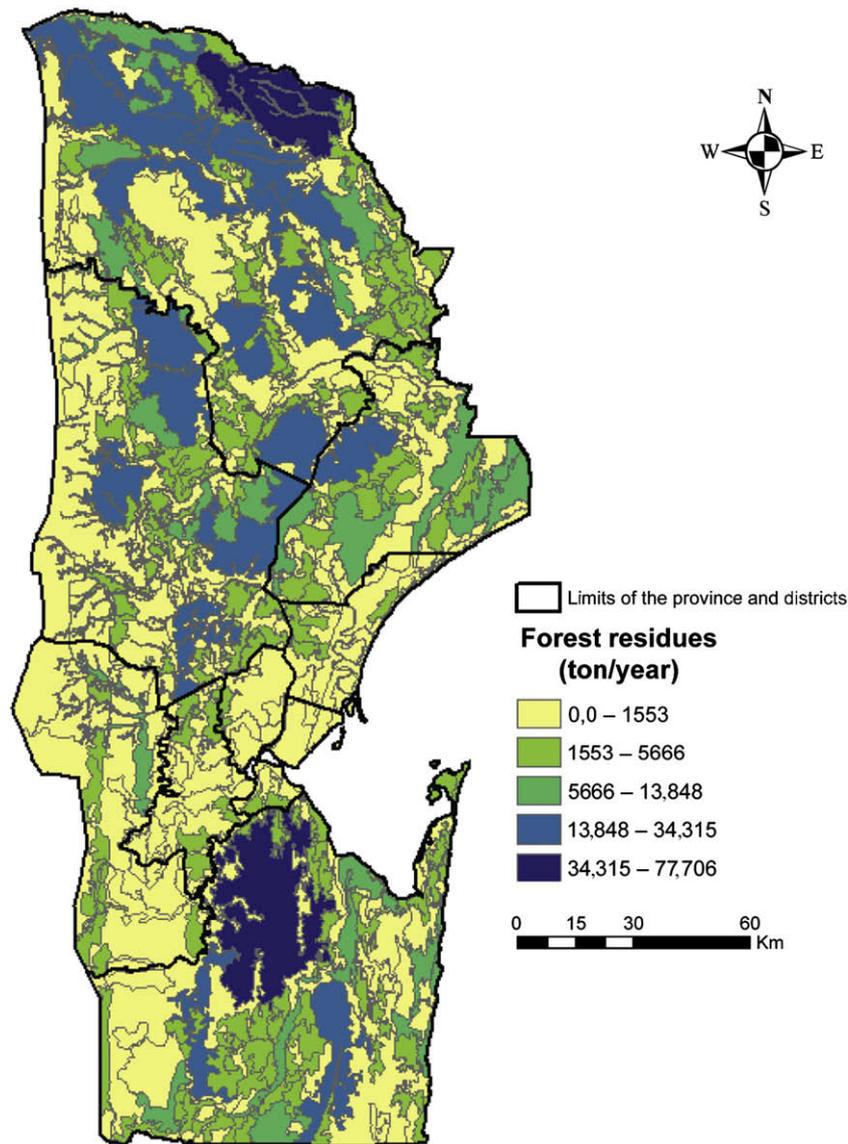


Fig. 3 – Distribution of the forest residues in Maputo province.

that the power plants consumption do not exceed 25% of the total forest biomass residues available in the districts of Magude and Moamba.

For these particular circumstances, Table 6 summarises the main characteristics of the two proposed biomass

power plants for Maputo province. As can be seen in the table we have considered an availability of 7884 h/year and electrical efficiency of 25% [15]. The two proposed power plants can produce about 236,520 MWh, which is equivalent to 32% of the energy consumed in Maputo province in 2004.

Table 6 – Main characteristics of the proposed power plants for Maputo province.

Technology	Grate burning	
Electrical efficiency (%)	25	
Availability (h)	7884	
District location	Magude	Moamba
Existing forest residues (ton/year)	450,416	225,936
Estimated consumption of forest residues (ton/year)	112,604	56,484
Nominal power (MW)	19.8	10

7. Conclusions

The main objective of this study was to quantify the forest residues in Maputo province (Mozambique) and to examine the feasibility of installing biomass-based electrical energy systems in this province. The quantification of the forest biomass residues was performed with the aid of a GIS. Information from the thematic cartography of soils of Maputo province and data for the forest growth rates from the literature has been used. It was estimated that the total production

of forest biomass residues in Maputo province is 1,233,412 ton/year, with a corresponding energy potential of 17,267,771 GJ/year. In regard to installation of biomass power plants it was concluded that the districts of Magude and Moamba are those that fulfill well the various criteria established, in particular residues availability, protected forests and transport infrastructures. The choice of the combustion technology for the biomass power plants took into consideration factors such as the cost and the degree of pre-treatment of the forest residues: the grate burning technology has been chosen. The proposed power plants are able to produce about 236,520 MWh, which is equivalent to 32% of the energy consumed in Maputo province in 2004.

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