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Biomass to Bioenergy in the Province of Huíla, Angola

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Abstract. The search for cleaner energy sources in Angola has grown significantly due to the need to reduce the dependence on diesel generators to supply electricity, which, combined with the fossil fuels consumption in the transport and industrial sectors, puts the country on the path of those who have increased the greenhouse gas emissions over the last years. Only 30% of the population has access to electricity despite the country's extensive resources of hydroelectric power and fossil fuels. Vegetable biomass accounts for 65% of the country's primary energy supply, and 80% of the rural population depends on it to meet most of their energy needs. This biomass is burned in poor-quality devices, making them inefficient and causing health issues for the users exposed to the combustion gases. Therefore, this work aims to evaluate options for a greener and more sustainable use of biomass to bioenergy, and different scenarios were built based on the current use of biomass. Results show that the use in the Province of Huíla of the biomass residues could replace by 50% the firewood. The replacement of the three-stone fire by using more efficient cooking stoves will reduce the amount of biomass needed and therefore, the residues from the province would suffit the demand to cook. The use of those more efficient stoves will allow also a reduction of harmful emissions. However, changing the stoves by more efficient ones also result in an economical burden that may not be reached by most rural populations.

Keywords: Biomass to Bioenergy, Cookstoves, Three-Stone Fire, Efficient Burners, Energy Scenarios.

1. Introduction

Africa is the third largest continent, with around 30,272,922 km^2, covering 20.3% of the planet's total dry land area [1], [2]. Official data estimate that of the 8 billion inhabitants the world reached in 2023, 1.2 billion are in Africa, making it the second most populous continent [3]. The population growth, with an annual doubling time of 28 years, is creating serious concerns as the predominance of young people in the population (43% of whom are under the age of 14) means that there is a need for major economic and social investment, particularly in the field of energy production, which will stimulate growth, guarantee stability and provide employment. The aim is to change the current situation by diversifying energy generation sources.

Studies carried out in 39 African countries have provided a better understanding of the continent's energy matrix, which is mostly based on mineral resources such as oil, coal and natural gas [4]. In 2008, the African continent's fossil fuel reserves consisted of 130 billion m^3 of oil barrels, 14 trillion m^3 of natural gas and 31 billion tonnes of coal, distributed unevenly [5].

In 2015, African countries contributed with around 9.1% of the world's oil production, with Nigeria and Angola among the top 10 oil export countries [6]. It should be noted that Africa has no country among the top exporters of oil-refined products. In this period, it only contributed with just 2.7% of worldwide oil-refined production and 5.8% of the 3,590 billion m^3 of natural gas produced worldwide, with Algeria and Nigeria among the top 10 world exporting countries. In terms of coal, African countries contributed with 3.5% of the total coal produced worldwide, where South Africa, is the only African country among the world's top 10 exporters of this energy source.

Despite the abundance of water resources on the continent, no African country figured on the top 10 list of hydroelectricity-producing countries in 2014 [6]. In addition, Africa has no countries exporting electricity and it generated only 3.2% of the 23,816 TW generated worldwide in 2015. Overall, there are 1,000 operational hydroelectric plants in Africa, of which 400 have an individual capacity of 10 MWh and 5 with a capacity of 1 GWh each [5]. Regarding the amount of emissions, which is in the order of 32,381 Mt of CO_2 in 2015, Africa contributed with only 3.6%, thus reflecting its low energy consumption [6]. Sub-Saharan Africa, with more than 800 million inhabitants, generates roughly the same amount of electricity as Spain, with 45 million inhabitants [7]. Only 5% of the hydroelectric potential is exploited in Angola, which represents a production of 5 TWh. All 47 hydrographic basins have a generation potential of 30 to 35 TWh of electricity [8].

Biomass is the world's fourth largest energy resource (after oil, coal and natural gas), but its use is limited by its low energy density, the complexity of the supply chain (often in competition with food and materials) and high pollutant emissions [9]. As sub-Saharan Africa is considered the epicentre of the global challenge to overcome poverty, the use of biomass as a sustainable energy source could represent a breakthrough in improving global indicators. In most African countries, biomass is used as a subsistence fuel and is still considered a "traditional" source, with solar, hydro and wind being the renewable ones [4]. This is why Malawi's energy policy planned to progressively reduce the biomass contribution from 93% of the total primary energy consumption in 2000 to 50% in 2020 [4], but by 2023 it only had reached 70% [10].

Bioenergy is obtained from biomass sources, such as dedicated crops, agricultural wastes, forestry and urban wastes. These sources are renewable and can be used sustainably, unlike fossil fuels, which are finite and contribute to increasing carbon dioxide emissions. By using bioenergy as a substitute for fossil fuels, it is possible to significantly reduce greenhouse gas emissions, as burning biomass only releases the carbon that was previously absorbed by plants during their growth, closing the cycle. Biofuel production can help diversify energy sources and reduce the dependence on fossil fuels. However, it is important to ensure that bioenergy is produced and used sustainably, taking into account some issues, such as responsible land use, biodiversity protection, deforestation reduction, and efficient conversion of biomass to bioenergy.

The three-stone fires traditionally used in rural households are very inefficient in doing the thermochemical conversion of biomass, and are a major source of household air pollution, resulting in acute respiratory infections, which cause premature deaths, especially in women and children [11], [12] due to the lack of efficient ventilation. In addition, women and children are responsible for collecting firewood, spending several hours per day in that activity, which is a time-consuming task that prevents them from going to school or earning money, and the demand for local biomass may exceed the natural re-growth of local resources, causing deforestation problems [11], [13]. Cleaner and improved efficient cookstoves burn less biomass which reduces the pressure on forests, saves cooking time, and reduces health impacts by reducing environmental emissions and increasing ventilation [11], [14], [15].

Among the factors that most affect stove efficiency are the type of food cooked and the batch size, which affects the cooking times; the characteristics of the equipment (design and performance), which are related to energy dissipation and incomplete combustion processes; the type and very of low-quality aluminium pans used by households; the quantity and quality of the wood/coal, which when very wet or extremely dry, inhibit efficiency [16].

This study aims to create different scenarios on the sustainable thermochemical conversion of biomass to bioenergy in the province of Huíla, Angola, by identifying domestic cookstoves with improved efficiency, that can be used for cooking, like the Rocket Mud Stove (RMS) [13], the Patsari [12] or the Ugastove [11], being more efficient than the three-stone fire, and can be used with different fuel sources, from firewood to crop residues. The available agroforest residues in the 52 communes of the 14 municipalities of Huíla province were considered, and the potential bioenergy production and greenhouse gas emissions saved were calculated for the different scenarios.

Changing the equipment will generate an economic burden, but socially, it will improve the life quality of the populations exposed to the combustion gases, especially women and young children [12]. Different scenarios are being evaluated under the three pillars of sustainability (economic, social and environmental) to provide recommendations and policies.

2. Methodology

Angola is located on the west coast of Africa. It has an area of 1,246,700 km^2 and a population of 25,789,024 inhabitants distributed into 18 provinces [17]. The country is located in the tropical region, with an arid coastal strip, humid inland plateau, dry savannah in the southeast and tropical rainforest in the north. influenced by factors such as the cold Benguela current, the inland relief and the Namib desert, it has two seasons, a rainy season and a dry season.

The study was carried out in the Huíla province, which is located in the Southwest part of Angola (Figure 1). It has 52 Communes, an area of 79,023 km^2 and a population of 2,497,422 inhabitants, of which 66% live in rural areas [17]. In this work, only households located in rural areas were considered, totalling 351,678 households. With a semi-arid tropical climate, its main activities are agriculture, cattle breeding and industry.

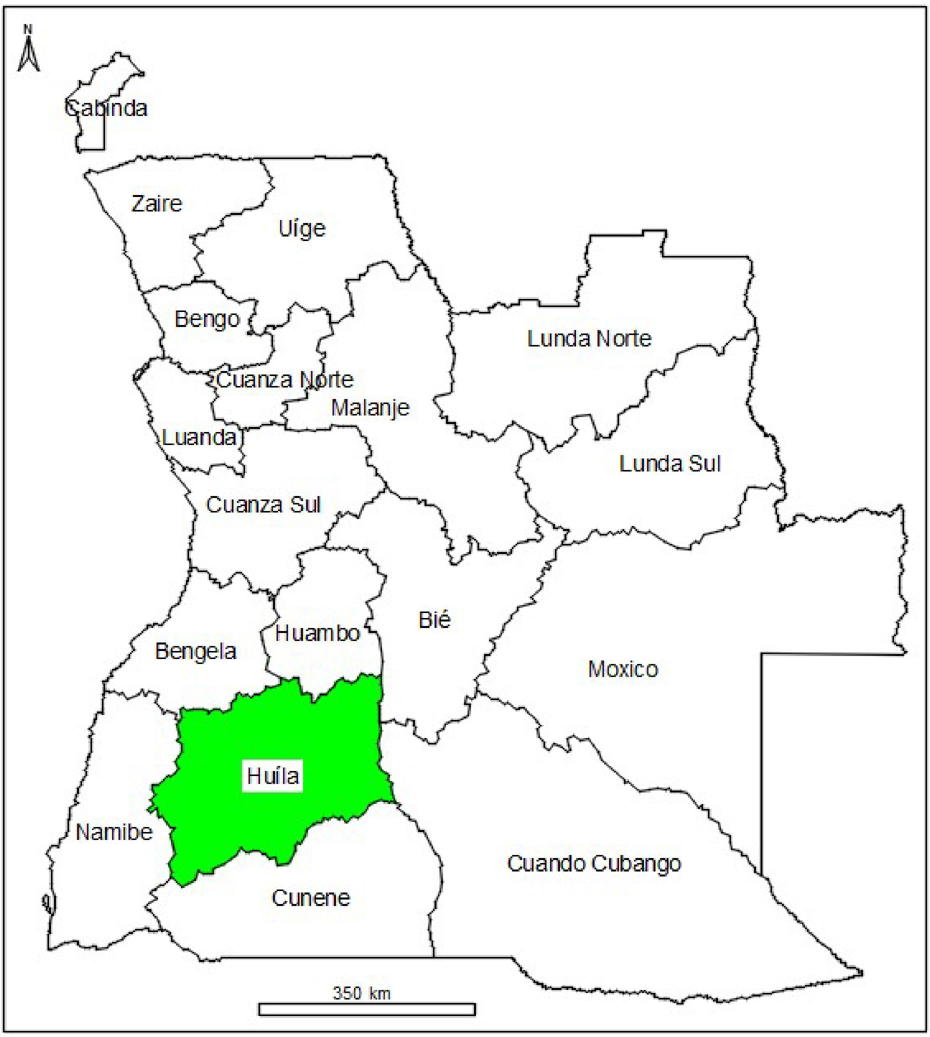

Figure 1. *Angola and its Provinces [adapted from 17].*

Given the lack of data on biomass availability, energy needs and consumption, the potential of agricultural residues was identified. For this purpose, the selected crop residues for energy production were sorghum, maize and millet. Also, a survey was developed to provide representative sample data. The survey covered 2,354 households and was carried out in 2015, corresponding to 0.1% of households, chosen randomly and equitably in each of the communes of the Huíla province. The survey collected information such as the main sources of energy used, including price and quantities, and the type of stove used in each household so it would be possible to relate the information obtained on energy consumption patterns.

The potential of agricultural residues for energy was determined for each Comuna, based on the methodology used by [18]–[23]. Equation 1 gives the amount of crop residues obtained in each harvest.

$$CR_i = RPR_i \times PrC_i \quad (1)$$

Where:
CR_i is the amount of biomass residues from each harvest (t);
RPR_i is the Ratio of Residue per Product for the harvest, based on dry matter;
PrC_i is the total annual production for each crop (t).

Not all crop residues derived from the harvest can be used for energy production. After each harvest, the soil must be covered with crop residues to prevent erosion and to maintain soil organic matter. The minimum amount of residues that must be kept in the soil to guarantee its function is set between 30-60%, corresponding to 2-3 t/ha [24], [25], [26]. It was considered that 2.5 t/ha must be kept in the soil, except for Comunas with productivities below 2.5 t/ha. In those Comunas, all the crop residues resulting from the harvest are left in the soil.

Equation 2 gives the energy potential of each available crop residue, considering the remains applied in the soil.

$$Q_i = \sum_{i=1}^{n}(NAP_i \times LHV_i) \times n_c \quad (2)$$

Where:
Q_i is the energy potential (GJ/year);
NAP_i is the available quantity of crop residues (t/year);
LHV_i is the lower calorific value (GJ/t);
n_c is the conversion Efficiency.

The baseline of potential energy is log wood because most of the population cooks with this kind of firewood, with an LHV of 14.7 MJ/kg [27]. The calorific value used in each crop residue was considered to be dried at the sun before use, giving an *LHV* of 16.34 MJ/kg for corn stover [28], [29], 16.40 MJ/kg for sorghum stover [30], and 13.15 MJ/kg for millet stover [31].

Four types of cookstoves were considered: the traditional three-stone fire, acting as a baseline, the Envirofit, the improved ONIL/HELPS and the Uganda rocket Ugastove. The efficiency was set based on the permiss that all cookstoves were already running and in a low-power phase simmer. The n_c for traditional three-stone fire is set at 19% [12], Envirofit at 50% [32], improved ONIL/HELPS at 60% [33], and Ugastove at 45% [11].

To determine the amount of firewood used per meal, each household selected an amount of firewood it usually uses to cook a meal. The firewood was weighed on a scale and handed back to the household to prepare the meal. The procedure was carried out in three different households and the mean value of firewood used was 5 kg/meal. As for carbon monoxide (CO) and particulate matter (PM), and other harmful emissions from cooking, efficient stoves like the Envirofit or the ONIL/HELPS achieve reductions ranging from 80% to 99% [11].

3. Results and discussion

Data in Figure 2 summarises the total amount of corn, sorghum and millet residues, available after soil deposition, and Figure 3, the distribution per comuna. It is possible to see that the Province of Huíla produce large quantities of crop residues, which allows them to partially replace firewood for cooking. A total of 890 kt residues are available in The Province and the Comunas that produce the highest amount are Caluquembe, Quipungo, Caconda and Chipundo. The highest amount of residues (86% of the total) are from corn production. Sorghum residues represent only 11% of the total and millet residues only 3% of the total. The total energy potential, based on the LHV of each crop residues provides 14,4 PJ.

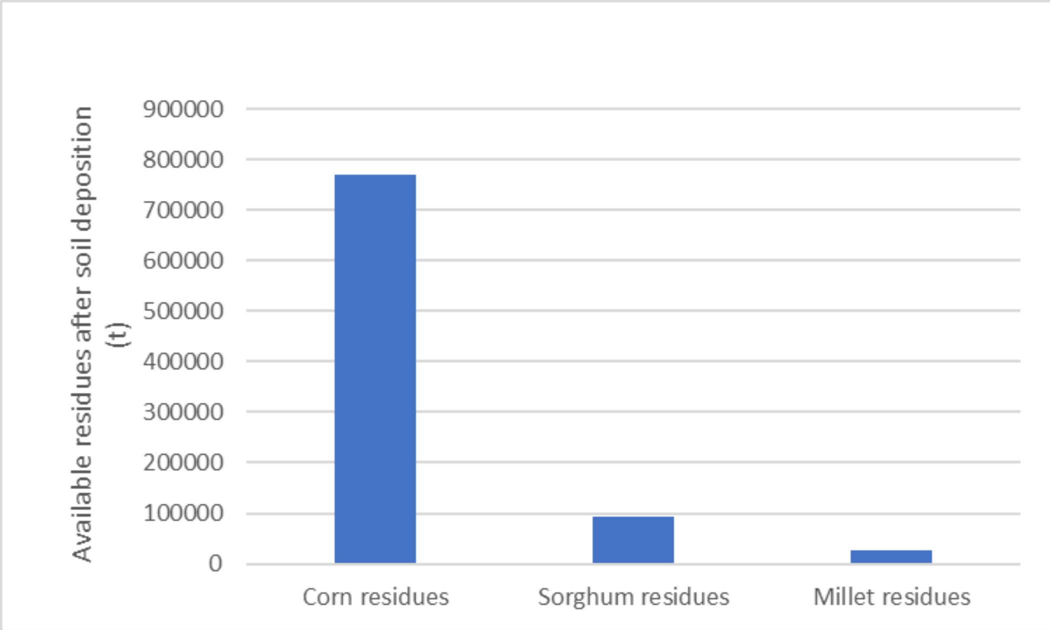

Figure 2. *Availability of corn, sorghum and millet residues in the Province of Huíla.*

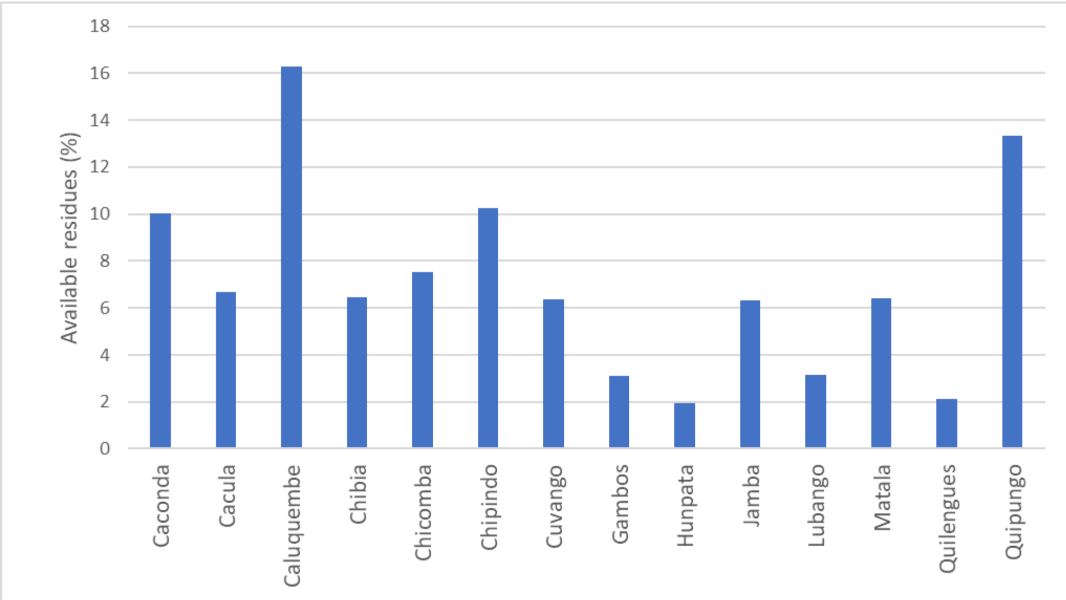

Figure 3. *Availability of residues in the different Comunas of the Province of Huíla (% to the total residues available in the Province).*

Considering Scenario 1, business-as-usual, when using a three-stone fire to cook, only around 2.75 PJ of net energy is obtained, with various associated environmental impacts. Currently, the potential energy needed to satisfy the 351,678 households in rural areas that use firewood has been estimated at around 28.3 PJ per year, and its use in the three-stone fire to cook, will produce around 5.34 PJ of net energy. This means that the use of the residues could replace *circa* 50% of the energy needed to cook. To estimate the amount firewood and energy needed to cook it was determined the firewood demand by each household, which was around 15 kg/day, using a three-stone fire. This result is in line with those obtained by [34], [13], [35] and [16], whose studies showed values ranging between 10 kg/day and 15.5 kg/day. The variability of firewood consumption depends on several factors, including the type of firewood used, its moisture content and the type of meal being prepared. It is interesting to note that authors such as [16] presented much lower daily firewood consumption (around 5.5 kg/day) because the study focused on a population whose main diet is based on plantains (demanding low cooking times), but the same author also presents results for cooking beans, which needs more than 5 kg of firewood per meal.

Improving the efficiency of the stoves and cookers improves the amount of energy produced per unit of crop residues and also the amount of greenhouse gas emissions saved. Using more efficient cooking stoves like the Envirofit, ONIL/HELPS or Ugatove, the need in biomass and firewood to obtain the same amount of net energy would be significantly lower. The use of those more efficient ccoking stoves would result in a net production of 7.24 PJ, 8.68 PJ and 6.51 PJ, respectively. And therefore, the residues from the province would suffit the demand to cook.

Considering also the firewood consumption, the amount needed could be also substantially reduced if efficient stoves were used instead of a three-stone fire. If the same meals were prepared with an efficient cooking stove like Envirofit, the wood consumption in each household could drop to 5.7 kg/day (62% less wood). If the improved ONIL/HELPS were used, the firewood consumption would be only 4.8 kg/day (68% less wood), and even when using the Ugastove, the firewood consumption would be around 6.3 kg/day (58% less wood).

The significant reduction in firewood consumption is of extreme importance for households, as it will represent a substantial reduction in the daily time spent gathering firewood, a task that is mostly assigned to women and children and can take up to 2 hours per day [11]. Reductions in firewood consumption have direct consequences in increasing the available time for children to study and play, as the time spent gathering firewood can be reduced to around 30 minutes a day.

Equally important is the pressure reduction on the forest. If less firewood is needed, less firewood is going to be collected from the forest, reducing deforestation. This deforestation reduction could also be boosted by using crop residues instead of firewood in daily cooking. This would further reduce or even eliminate the time spent on gathering the firewood, as those residues can all be collected after the crop harvests. One downside of using crop wastes is its intermittency as there is the need to dry and store those residues, which would require the existence of a warehouse.

Figure 4 depicts a family member from the Chibia Commune starting a three-stone fire to prepare a meal. Figure 5 depicts the relaxed atmosphere of a family around the fire, while massango fuba is being cooked. In both cases, it is possible to observe the continued exposure to biomass combustion gases and particles. These emissions could be drastically reduced if an efficient cook stove were used.

Considering the average PM and CO emissions per kilogram of firewood burned in a three-stone fire determined by [34], [36], which are 2.45 g and 67 g respectively, the replacement with an efficient stove, such as Envirofit or ONIL/HELPS, can substantially diminish emissions (by 80 per cent for the former, regarding smoke and harmful gas emissions and by 99 per cent CO_2 emissions and 90% of carbon particles for the latter [11]. The use of a chimney can also make a difference in the indoor atmosphere when accounting for the household‘s exposure to combustion gases and particles.

Figure 4. *Starting the fire in a traditional three-stone fire cookstove by the patriarch of a family living in Chibia Comune.*

Figure 5. *Family gathering around the three-stone fire before the meal. The three-stone fire plays a central role in family meetings.*

In terns of costs, the acquisition of new stoves can be a burden to the Comunas. Ugastove has a price of US$ 5-11, Envirofit, around US$ 30, and the ONIL/HELPS, around US$ 87. Yet, for the last one, users can receive the stove free from an NGO, or by contributing a token of the market price [11].

Conclusions

Preliminary data shows that sustainable bioenergy production in the province of Huila is possible and represents an opportunity, but also poses several challenges, such as investment and social acceptance. In line with the Sustainable Development Goals, the replacement of basic stoves by their efficient counterparts could contribute to SDGs 3, 7, 10 and 12, and this replacement could be fostered by policies that support and sponsor the replacement of the basic ones. Investing in this initiative could enhance long-term social benefits such as the reduction in health issues derived from exposure to combustion emissions and an increase in the population's life expectancy. The Investment must be made not only in replacing basic household cookers with their advanced counterparts but also in the infrastructure to dry and store the crop residues.

Although there is legislation that encourages the use of biomass, such as Law no. 6/10, of April 23rd, which establishes the general bases for boosting the cultivation of agricultural species for the production of biofuels, and Resolution no. 122/09, of March 23rd, which approves the strategy for the development of biofuels in Angola, the Angolan government has yet to define policies to support households to replace the three-stone fire with more efficient cookstoves. Some time ago, there was a programme to install community kitchens in all the 14 Communes, managed by the local government executives, to serve vulnerable segments of the population, but some were installed in difficult access areas, which is why they were not used by the population. Most of these community kitchens were converted into commercial activities, with private management.

Data availability statement

The data presented in this study are available on request from the corresponding author.

Author contributions

Fernando Cativa: Data curation; Formal analysis; Investigation; Methodology; Software; Roles/Writing - original draft; Writing - review & editing.

Jorge Costa: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Supervision; Validation; Roles/Writing - original draft; Writing - review & editing

Ana Luisa Fernando: Conceptualization; Data curation; Formal analysis; Funding acquisition; Software; Project administration; Resources; Supervision; Validation; Writing - review & editing.

Competing interests

The authors declare that they have no competing interests.

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