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Evaluation of potential of energetic development in isolated zones with wide biodiversity: NIZ Chocó-Colombia case study

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ABSTRACT

The implementation of a hybrid biomass gasification-photovoltaic system for electricity generation in isolated regions was evaluated. Experiments were carried out to test the gasification of agricultural residual biomass in a downdraft fixed-bed gasifier coupled to an internal combustion engine and a photovoltaic system with this set-up, electricity was successfully generated by means of rice husk (RH) gasification, which produced a synthesis gas with a calorific value below 3–5 MJ/N m^3. The gas was purified sufficiently to make it profitable in an engine through a simple cleaning system. The main contribution is given by the proposal of a hybrid system adapted to climatic conditions and renewable resources settled in the region; In order to have a portable and autonomous system. Where it can be concluded that a hybrid solar-biomass system is a versatile alternative to contribute to the generation and efficient use of electrical energy. The hybrid system provided a stable electricity supply of 24–27 kWh. Along with the analysis of residual biomass availability in the Chocó region, this indicates that the implementation of technological alternatives such as the ones tested in this research are able to sustainably fulfill the energy needs of isolated communities by making use of the resources coming from their own agricultural activities. Also, the conclusions show that the best hybrid system, from the technician-economic point of view for the energy.

1. Introduction

According to the Energy Information Administration (EIA) [1], and International Energy Agency (IEA) [2], energy demands will continue to increase as economies develop. It is projected that global energy consumption will increase by approximately 28% in the coming years, going from 575 quadrillion BTU in 2015 to 736 quadrillion BTU in 2040, with fossil fuels representing over half of the overall increase. Over 60% of the growth in fossil fuel consumption is expected to be in India, China, Africa, the Middle East and Southeast Asia, due to their demographic and economic growth [1]. This dramatic increase would lead to a large increase in pollutant atmospheric emissions, particularly of Greenhouse Gases (GG) to which the global warm is attributed. For this reason, it is suggested that the share of renewable energy must be increased, which is in agreement with the proposals adopted in the recent Paris memorandum of understanding [3]. That document states that in order to limit the global average temperature rise to less than 2 °C, the share of renewable energies must be at least of 37%, 150 million of electric vehicles should be rolled out, the annual growth of emissions from coal in the energy sector must not exceed 0.5%, and consumption of natural gas should exceed coal consumption by 50%. Thus the continuous development of renewable energy alternatives is vital.

1.1. Energy structure: background

Colombia has an area of 1142 million km^2, 52% of which is not connected to the main electrical grid, or Interconnected System (IS). These Non-Interconnected Zones (NIZ) include 17 departments, five major cities, 39 intermediate cities, and 1.448 low density populations. Chocó Department, which is located on Colombia's Pacific coast, has 307 populations belonging to the NIZ, which represents 21.2% of the total NIZ in the country, and places it as the region with the second highest NIZ area [4]. Populations living in NIZ are often unable to access stable energy supply methods, which has led to the proliferation of alternatives which differ significantly from the concept of sustainability, as defined by the governmental guidelines, in order to supply their needs [5,6]. Currently, in Chocó, 38 power plants made up mostly of diesel internal combustion engines supply electric energy to communities in the NIZ for periods of between 2 and 6 h per day. Due to

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lack of fuel and maintenance for such devices, some populations are obliged in some cases to go without electricity supply for more than a year at a time [4,7].

It is important to bear in mind that the conditions in which the nowadays society develops its daily activities, makes it fundamental to assure an energy production based on the sustainability principles which, under the transversality that the energetic production in the social development has, it is essential the evaluation of the alternative processes that generate energy according to their capacity to effectively supply the population needs, but that in their turn they are supported from the possibilities that these developments provide to the communities that are favored by their implementation, particularly regarding the access to goods and services such as health, education, internet connectivity and even the certain and permanent availability of food, among others.

1.2. Biomass availability and energy technologies

Chocó, which represents 4.1% of the country's land area and is the region in Colombia with the eighth lowest population density (10.75 hab/km^2), has the most precarious indicators of quality of life in the whole country which shows that several of the population's basic needs are not being met [8]. However, this region, due to its wide diversity of flora and agricultural practices, has a high availability of residual biomass estimated in 416.760 tons/ year, with a gross potential of 2500–3000 TJ/year. It is suggested that this presents an opportunity to provide an adequate energy supply based on biomass, as well as an opportunity for economic growth which could help mitigate poverty levels [9]. Table 1 presents the availability of the various biomass resources for the department of Chocó.

The energy potential of these biomass resources by biochemical and thermochemical pathways can be assessed. Due to the high temperatures at which they occur, thermochemical processes have greater conversion and efficiencies shorter process times with lower pre-treatment demands [10]. The thermochemical transformation can be carried out by means of three processes (pyrolysis, combustion and gasification) from which it is possible to obtain heat and electricity [11]. Gasification is of particular interest due to its versatility, technological maturity and the environmental sustainability offered by the burning of a clean fuel such as synthesis gas. Gasification is the thermal conversion of organic material by partial oxidation at high temperatures between 800 and 1000 °C, requiring oxidizing agent (air, oxygen, CO_2, H_2, steam or its combinations) [12–14], which reacts with the fixed carbon and the volatile material in order to transform them into low molecular weight gases such as CO and H_2, accompanied by CH_4, CO_2, N_2 and other light and heavy hydrocarbons (tar) and char (considered as pure carbon), depending on the gasifying agent and the degree of advance of the process [12,13,15–19]. For the particular case of gasification, studies demonstrate that depending on the type of biomass used, the syngas chemical composition can vary [20,21]. Biomass gasification is mainly carried out in fixed and fluidized beds. Fixed-bed gasifiers have proved to be appropriate for small scale plants (less than 10 MWth); whereas fluidized beds are profitable in large scale power generation applications [22,23].

The most important types of fixed-bed gasifiers for energy applications are the Updraft and Downdraft gasifiers, which differ in the direction of flow of the synthesis gas (syngas). While the syngas flow direction may seem unimportant, each type offers significant advantages and disadvantages over the other. Updraft gasifiers, due to their flow pattern, support raw materials with greater variability in size, with high ash content and moisture (up to 50%) [24]; That is why their implementation is preferred for applications oriented to syngas combustion. However they lead to the loss of 5–20% of volatile material in the form of tars [25], since the gas outlet zone has a low temperature (80–300 °C), which mix with drying and pyrolysis products. This makes them inadequate for use with internal combustion engines without a pre-cleaning system or operative and geometrical modifications with respect to the basic design.

Downdraft fixed-bed gasifiers are cited as adequate for power generation with internal combustion and turbine engines, because with proper operation, the tar production is on average less than 1%, although the output (which is at approximately 700 °C) carries a greater amount of particulate material, and so requires cleaning systems for the synthesis gas [26,27]. Furthermore, their functioning at both thermal and chemical level is unstable, and they show greater ease for operating with lower costs, when compared to other technologies [22,24,27,28]. For these reasons, downdraft gasifiers are optimal for coupling with systems of cogeneration (combined heat and power (CHP) and cooling (CCHP)), as demonstrated by the wide variety of pilot studies available in the literature [23,29–34]. To overcome the disadvantages of each type of gasifier, various improvements to the basic designs have been reported in the literature [24,27].

Biomass gasification with air (as presented in Table 2) is effective between 700 and 1000 °C, the final product is syngas, which consists mainly of H_2 and CO, along with N_2, CO_2, CH_4, and C_nH_m. In addition, it a solid residue by-product (biochar and fly ash) is obtained, which has a high potential for use as value-adding products (adsorbent, fuel, bioremedial material for lands and raw material for other products) [11,20].

The main disadvantage of biomass gasification can be the high production of liquids (tar) [24,25]. This can require: i) from simple to demanding cleaning systems to enable use of the gas, and ii) additional energy to be used by thermal cracking or other processes to generate value-adding products. Therefore, further studies are required to make biomass gasification economically competitive.

In the previous sections, the relevance of gasification as an energy generation technology and as a way to integrate forms of sustainable use of the biomass is demonstrated. That is why there is a wide variety of recent technical reports on small-scale fixed-bed gasification and pilot plants for power generation and other polygeneration configurations [29,34,35,43–45]. However, the detailed requirements of each process (types of raw material, operating conditions, etc.) and the geometrical modifications which should be made to reactors in order to enhance the performance in comparison with the basic models (downdraft or updraft), mean their success is not guaranteed, even if therefore, for the development of particular applications, the results of pilot projects must be used with parametric aims (effects over the process) and design improvements [36]. The performance of coupled systems are expected to differ significantly depending on the process which uses the syngas (such as combustion machines, micro-gas turbines, fuel cells, thermal processes, chemical processes, hybridization with other renewable alternatives or mixtures of these), so each combination should be tested experimentally.

1.3. Solar energy availability for hybrid generation

According to the measurements taken by "Unidad de Planeación Minero Energética (UPME)", in Colombia the average radiation lies in 5.3 kWh/m^2/day [5]. Regions in the interior of the country, such as

Table 1
Summary of the Agricultural Residues produced annually in Chocó [9].

Waste producing growers	Waste quantity Ton/Year
Rice Husk (RH)	54,991
Coffee Husk (CH)	1122
Sugar Cane (SC)	185,919
Waste Corn (WC)	19,766
Waste Oil Palm (WOP)	40,013
Waste Banana (WB)	628,882