Non-recyclable cellulosic waste briquettes consumption in Andean areas: assessment of social acceptance and potential applications

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Introduction

Improving food cooking conditions in rural developing settlements has been an area research with great impact (Gitau et al., 2019). The high consumption of firewood from forested areas causes the degradation of natural resources and the threat of natural ecosystems. In rural Bolivia, the most used fuel for cooking is liquefied gas (jars), around 50% in 2018, followed by firewood that reaches 42%. The use of alternative fuels to fossils and forest biomass is also important for those areas of the Andean where resources are very scarce and where climatic conditions are particularly extreme (Demirbas, 2008).

The objective of the research is to study the use and the possible adoption of alternative fuels in Andean rural areas using biomass residues (sawdust from wood processors) and cellulose-based residues from the non-recyclable fractions (Ferronato et al., 2022b). The hypothesis is that cellulosic waste briquettes can be employed as alternative fuels in Andean areas for (i) cooking in domiciliary areas or (ii) for oven pre-heating in small production activities. The reason behind the research is to reduce the consumption of natural fuels (fuel, shrubs, cow dung…) and to provide a more efficient fuel with a safer and more efficient provision system (Ferronato et al., 2022a). Therefore, the objective of the research is to assess the population willingness to employ alternative fuels for cooking and heating (social surveys) and to analyse alternative fuels in terms of energy consumption efficiency and quality of the final product with both a quantitative (laboratory tests) and qualitative approach (field studies).

The research took place in the urban areas of Colquencha and the community of Vichaya, Bolivia, at an average height of 4,018 meters a.s.l. The towns are located in the Andean plateau, the first counting about 10,000 inhabitants scattered in around 311 km^2. The main productive activities are agriculture, the exploitation of limestone for plaster production and the use clay resource for ceramics. The municipality of Colquencha does not have a gas pipeline connection system. However, natural gas is the most widely used fuel for preparing food, while dung and firewood are the second source of energy for cooking. At the same time, animal dung, brushes and wood are employed for small production activities that require high energy production for heating.

Methods

Social survey. The social survey was carried out through face-to-face interviews conducted with structured questionnaires. The forms submitted to the population counts 24 questions related to the social characteristics of the respondents and the behaviour in energy consumption. The research took place in March 2022 in four days of field campaigns. Four people were involved to move around the area and interview the citizens. The questionnaire survey was dedicated to ten women's associations in the Colquencha municipality, in the four most important counties of the town. Globally, 150 citizens were interviewed. The results have 5% of confidence interval (in case of binary response) and 95% confidence level considering the community of Colquencha as reference.

Combustion tests at household level. From these surveys carried out, meetings were held to identify those women who were willing to be part of the field study. Two families were selected, giving their availability to test the briquettes. The tests were carried out in the traditional stoves (*khiri*) made of mud (land with water), bricks, and a long iron bar to divide the stove burners. In general, the method used for the field study is based on a simplification of the Water Boiling Test (WBT) protocol combined with the Clean Cooking Test protocol, carrying out a food cooking process and simultaneously measuring fuel consumption and food processing times. Two tests with cellulosic waste briquettes were carried out in March 2022 and two tests with manure in the same period. The test were used to: i) compare the amount of fuel used when cooking a meal that is prepared in the identified households ii) compare the time needed to cook the meal and iii) to know if the briquettes cooks well following the citizens' perception.

Qualitative analysis of combustion in production activities. The pilot test for the use of briquettes as fuel in the artisan industrial sector were carried out in Vichaya, where plaster is produced mostly using wood and dung. Field tests were carried out in traditional kilns for burning limestone to obtain plaster. The kiln is made by a hole with a depth that varies depending on the ability of the owner to obtain the final product. Once the dimensions of the chamber and its capacity have been defined, steel joists are installed to support the load of limestone that will be deposited in the oven, leaving a space for the combustion chamber. Two pilot tests were carried out. For the first pilot test, a small kiln with a capacity to obtain 400 bags of plaster was chosen, while the second kiln had a capacity

of about 300 bags. The tests were carried out in August and September 2022, for about 6h to 10h out of 12h of burning time, typical for plaster production system. In the first test, a pre assessment was conducted to evaluate the amount of fuel employed for the production activity. During the second test, briquettes were employed together with conventional fuels to qualitatively assess if the final product satisfied the owner and to visually verify the quality of the emissions. At the same time, the amount of biomass saved during the production phase was assessed.

Results and Discussion

Almost half of the families interviewed have a gas stove and wood stove, which is mostly located outside their homes. In some cases, they have built covers to protect the stoves from the rain. Of the 150 surveyed, 92 citizens state that they use both types of stoves (stove and gas stove) and among their fuels, there is the use of gas, dung, and firewood. Natural gas costs between 3-4 USD per jar. The use of dung or firewood for the use of the stove is related to a customary theme: "in the stove, the food has more flavour. It is not the same as in a gas stove". In addition, there is the need to minimize costs, which represent an important factor to be assessed. According to the data collected, dung is the second most used fuel for cooking since it is free of charge.

During the field work, the results obtained at laboratory test were confirmed: For briquettes, it was observed that the boiling time was 31 and 52 min respectively, with a thermal efficiency of 5.2% and 4.8% in rural stoves, and a power of 0.29 and 0.48 kW. On the other hand, for dung combustion, it was observed that the boiling time was 28 and 26 min, with a thermal efficiency of 4.7% and 5.4%, and a power of 0.62 and 0.67 kW. Therefore, making a comparison of the three parameters analysed (thermal efficiency, boiling time, and cooking power), it is found that the thermal efficiency of both fuels have a minimal difference and oscillates in the range of 4.6 to 5.4%, while the cooking power of the dung is greater than that of the briquettes. This also means that the consumption of dung is greater than that of the briquette, about 1.63 kg of briquettes and about 2.16 kg of cow dung during the cooking phase. Hence, briquettes can be better fuels if employed to pre-heat or maintain the heating temperature inside the stove, reducing the fuel consumption and guaranteeing constant temperatures.

The tests carried out during the plaster production activity allows calculating the fuel consumption and the production time. On balance, the fuel consumption tax was calculated of about 1.88 kg and 1.25 kg per minute, respectively during the first and second test. Therefore, using briquettes allowed reducing the fuel consumption tax. About 282 kg of briquettes were employed during the pilot tests, using briquettes for a period of about 150 minutes, and staying in the chamber for 3 additional hours, reducing the use of conventional fuels. In this way, the emissions are reduced, as well as the fuel supply frequency that can support the operators to rest during the combustion phase. In particular, it has been estimated that the operator might have a rest time of about 4h per day if 30% briquettes are employed instead of cow dung or brushes, thanks to the briquettes' higher combustion efficiency.

Conclusions

In Bolivia, the local population is willing to employ alternative fuels in order to reduce the consumption of cow dung, or to reduce costs. On the other hand, the population is more willing to cook with natural fuels both for social acceptance (they are used to cook in this way) as well as for the quality of the final product (tasty food or high-quality plaster). Briquettes cannot be used to substitute the 100% of conventional fuels (natural or fossil). However, it can be used to pre-heat or maintain the heating of the cookstoves or kilns, both for production activities and for cooking. Therefore, briquettes can be employed for reducing about 30% of the conventional fuels currently employed in the Andean areas. The research demonstrates that the cellulosic waste briquettes can be employed as alternative fuels in Andean areas and that a potential market can be introduced. This can reduce the amount of natural or fossil fuels currently employed for heating and cooking. Research should be done to test the indoor air quality and to obtain data statistically significant to estimate the quality of cooking in rural areas or plaster production in small manufacture activities.

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