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A Geospatial Analysis of Clean Cooking Alternatives in Brazil's North and Northeast regions

Ruan Luzia[1], Carlos E. Velasquez[1], Camilo Ramirez[2], Francesco Fuso-Nerini[2]

[1]Departamento de Engenharia Nuclear – Escola de Engenharia
Universidade Federal de Minas Gerais (UFMG)
Av. Antônio Carlos, 6627 campus Pampulha 31.270-901, Belo Horizonte, MG, Brasil

[2]Division of Energy Systems, KTH Royal Institute of Technology, Brinellvägen 68, SE-100 44Stockholm, Sweden

carlosvelcab@nuclear.ufmg.br

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ABSTRACT

Access to electricity and clean fuels for cooking is one of the important goals to prioritize towards Agenda 2030, which is the first target of SDG-7. Besides, Brazil has high access to electricity, with about 99.6% according to the World Bank. The residential sector uses firewood and charcoal heavily (25.93%), according to the Research Energy Company in Brazil (EPE). Hence, electricity covers 46.2% of the energy sources used in the residential sector, with illumination and appliances being the priority. 22.1% use LPG. It is possible to infer that a substantial percentage of the population still uses solid fuels as their primary source of energy. In the least developed parts of the countries, the North and Northeast regions continue to consume high amounts of firewood. These areas are known for their low market access to new technologies, low income, difficult access, and their use of firewood and charcoal as cooking fuels. To facilitate the transition to clean cooking, it is crucial to develop effective energy planning methods from this perspective are important to analyze the solutions. The analysis used the open-source OnStove tool, which was modified to take into account the structure of natural gas pipelines. Comparing the unmodified and modified versions using data from public geospatial databases meant for academic purposes will help determine if natural gas is a viable option.

1. INTRODUCTION

Amongst the Sustainable Development Goals, SDG 7.1 targets the access to electricity and clean fuels and technology by the year of 2030. [1] According to the Research Energy Company in Brazil(EPE), Brazil is currently a country with a high level of electrification. Despite this, the consumption of charcoal and firewood for domestic cooking is still high, especially in rural areas[2]. The percentage of households in Brazil still using firewood for cooking can exceed 40% in rural settlements, which presents an environmental, health and gender equality problem. According to EPE, the north and northeast regions of Brazil still rely heavily on charcoal and firewood, with 10.3% and 17.9% of their main stove fuel being charcoal and firewood.

The high consumption of firewood can be harmful to both the environment and the users. Increasing the dangers of developing multiple diseases, including lung cancer and chronic obstructive pulmonary diseases, and causing at least 4.3 million deaths worldwide. [3,4] While also being related to a substantial amount of greenhouse gas emissions and deforestation for the production of charcoal and firewood.

The residential sector has been seeing a rise in the usage of natural gas, which is a clean cooking solution. Besides, it is slowly replacing firewood and liquid petroleum gas (LPG) while the national pipeline structure expands. [5] In comparison to LPG, it has lower emissions, cost, and density, which make it easier to disperse in the air when leaks occur, making it more secure. These advantages turn it into an interesting choice for study as an alternative to cooking in the regions where it is available.

Therefore, it is fundamental that policy makers have reliable and precise tools available to plan solutions for this problem. OnStove is an open-source tool that can assist decision makers in making a clear decision. Geographic Information Systems (GIS) are the basis of the spatial tool, which is scalable and reproducible and can compare different clean cooking alternatives to determine the highest net-benefit option for a given region.

This project's objective is to examine whether natural gas was a good alternative using the modified OnStove version in eight states in the north and northeast where natural gas pipelines were present.

2. METHODOLOGY

The OnStove is a free open-source tool that was utilized in a modified version to identify the optimal stove for each section considering now natural gas as an option. The modified version was applied to eight states in both north and northeast, where there would be natural gas pipeline structures, to compare with the primary results obtained with the regular version of OnStove.

The tool utilizes a variety of GIS datasets, as well as socio-economic and techno-economic data, for the analysis region. The usage of various cooking technologies in both urban and rural settlements can be determined after calibrating the model by using the share of each stove in the region adjusted by the population information supplied by the user in the socio-economic data. The tool calculates the net-benefit for each technology by taking into account the changes to mortality, morbidity, time spent, fuel costs, carbon emissions, operational and maintenance costs. The net-benefit for the stove is calculated by subtracting the benefits from the costs, and the stove with the highest positive net-benefit is selected as the best for that portion of the area.[6] Each region analyzed was divided in smaller parts of 1km² each, where the best net-benefit stove was determined for that square, in the scenario with and without natural gas.

2.1 THE REGION OF ANALYSIS

The north region is the largest region in Brazil by territorial extension, but it has the lowest demographic density with only 4.5 inhabitants per square kilometer, with only 4.5 inhabitants per square kilometer, mostly concentrated near rivers and capitals. [7] It is divided into seven different states: Acre, Amapá, Amazonas, Pará, Rondônia, Roraima, and Tocantins. The region's innermost locations are difficult to access due to the large forest cover, and most of the transportation of goods and people is done by boats. The Amazon rainforest is the primary habitat for vegetation, as it is the largest tract of tropical rainforest in the world, with dense forests, high humidity, and high average temperatures. The extraction of natural resources and agriculture are its primary economic activities, which raises serious concerns about the environmental risks of these activities in the area, particularly due to deforestation. [8]

In regard to energy, this region has the greatest potential for hydroelectric energy production. The exploration is still problematic because it has a significant impact on protected land and nearby cities to the rivers, because a substantial amount of land is required to be flooded in the process. [7]. The region often encounters issues with access to basic healthcare, sanitation, and high levels of inequality due to its low GDP per capita and large population settlements. [8,9].

The northeast region is the most populous and densely populated area in the country. In the 16th century, this region became the first in Brazil to be explored. It is divided into nine different states: Alagoas, Bahia, Ceará, Maranhão, Paraíba, Pernambuco, Piauí, Rio Grande do Norte, and Sergipe. The beginning settlements were focused on wood extraction and sugarcane cultivation. The coastline regions have a strong presence of this activity due to their flat terrain and adequate rainfall levels. Making sugarcane cultivation and processing into subproducts a key activity in the region. In contrast, the innermost section is a hot and dry area that lies predominantly within the Caatinga biome and is renowned for its arid soil and smaller plants. In this segment, the population becomes less dense, and the majority of its income is derived from livestock and fruit farms. The deep and ancient agricultural roots of the northeast of Brazil have caused a serious problem with deforestation. The removal of most of its forest cover was done to enable livestock and sugarcane, as well as use for firewood in residences and sugar farms. [8]

2.2 THE DATA

The first part of the data is composed of GIS datasets. The datasets used in the analysis, as well as its sources are present in Tab. 1.

Tab. 1. GIS datasets used and its sources.

Dataset	Source
Population	Worldpop [10]
Administrative boundaries	GADM [11]
Urban-rural status	GHS-SMOD [12]
High-voltage lines	ONS [13]
Nighttime lights	VIIRS-VNL V2 [14]
Travel time	MalariaAtlas [15]
Walking friction	MalariaAtlas [15]
Motorized friction	MalariaAtlas [15]
Livestock	FAO [16]
Forest cover	GLAD [17]
Relative wealth index	Humdata [18]
Temperature	Global Solar Atlas [19]
Natural gas pipelines	Mapbiomas Brasil [20]

The second part of the data inputs consisted of socioeconomic information of the country. These are the data on the state's population, urbanization, and electrification rates. Mortality, morbidity, and estimated cost of illness are reported for five different diseases related to indoor house pollution, which include Chronic Obstructive Pulmonary Disease, Ischemic Heart Disease, Lung Cancer, Acute Lower Respiratory Infection, and Stroke. Data also included average household size, average meals per day, minimum wage, discount rate, cost of carbon emissions, value of statistical life, health spillover factor, and the fraction of non-renewable biomass.

The technoeconomic data comprised the final portion of the data. This inputs now provides the information for each different fuel type, regarding its greenhouse gas emissions, investment cost, fuel cost, efficiency, energy content, time spent cooking, estimated useful life of the stove, and, when it’s applicable, time of collection of fuel and salvage cost of the stove. The Brazilian electrical matrix generation distribution was used to determine the energy source's cleanliness, specifically for electricity.

2.3 THE MODEL

The model computes the net benefit by comparing the benefits and costs. Equations 1 and 2 can be used to calculate them.

$$\textbf{Benefits} = \text{Morb} + \text{Mort} + \text{Time saved} + \text{Carb} \qquad (1)$$

$$\textbf{Costs} = \text{Capital} + \text{O\&M} + \text{Fuel} \qquad (2)$$

In the Benefits equation, Morb and Mort are the costs avoided associated with morbidity and mortality respectively, Time saved is the costs avoided associated with the reduction of time spent cooking by changing stoves and Carb is the value associated with the reduction of carbon emissions. In terms of expenses, Capital covers the initial cost of the stove, O&M covers the operating and maintenance expenses, and Fuel covers the cost of fuel.

2.4 SCENARIOS

Two different scenarios were used, one with the latest version available of OnStove and the other with a modified version of it, to account for natural gas. The analysis was made for eight different states that presented natural gas pipeline structure in those two regions, being: Alagoas, Amazonas, Bahia, Ceará, Paraíba, Pernambuco, Rio Grande do Norte e Sergipe.

The tool was altered to recognize the pipelines through one of the GIS datasets and based on the distance from the point of analysis to the pipeline, determine if natural gas should be taken into consideration and its benefit. The natural gas was taken into account at a distance of 5km from the main pipeline. The reason for the distance is that any extension or ramification beyond this point would necessitate additional legal procedures. This would make this process and solution less appealing when compared to other alternatives that could yield quicker results.

3. RESULTS

For every square kilometer where a human settlement is detected in the area of interest, the tool presents a map that shows the best net-benefit cooking technology. The map includes information about the average number of deaths avoided per year by switching stoves and the amount of money saved in health-related expenses. Additionally, it displays the amount of carbon emissions avoided and the hours per day per household that are saved with the new stoves. The model presents graphs that exhibit the percentage of people who use each of the best stoves, as well as a graph that identifies the factors that contribute to the net benefit of each stove. These include health costs avoided, emission costs avoided, opportunity costs gained, investment costs, fuel costs, and O&M costs.

3.1 NORTHEAST

The results for Alagoas were identical in both versions. Alagoas' high cost of natural gas makes it hard to compete with LPG's cheaper option, as shown in Fig.1 and Fig.2. Considering this, the most significant benefits were the time savings and the avoidance of emissions. In Alagoas, there was a 10% share of firewood or charcoal stoves, which resulted in the greatest impact of the change to LPG on the aspects mentioned earlier.

Ceará's initial results indicated that LPG was the best option, as shown in Fig.1. The price of natural gas in this state was the lowest among all the analyzed states. This made it the most suitable option for everywhere in the pipeline range, resulting in a savings of around $100 million in fuel expenses. The pipeline is situated on the coast, where a significant portion of the state's population lives, as shown in Fig. 2. Although the area is smaller, it still covers 49% of the stoves in the state.

Both versions yielded the same results for Bahia due to the natural gas price issue. Although the difference wasn't as significant as Alagoas, it still caused no change, as displayed in Fig.1 and Fig. 2. LPG is still the most advantageous option, with the most significant benefit being time saved, followed by emissions. The same arguments for Alagoas apply to Bahia, with 20% of its stoves using firewood or charcoal.

In Paraiba, LPG was the only option in the first analysis, as presented in Fig. 1. Although the price difference between natural gas and LPG was minimal in this state, natural gas was more advantageous due to its greater energy content per kilogram. Natural gas was the most popular cooking option in the coastline where the pipeline is located, as depicted in Fig.2.

Initial findings indicated that LPG was the top choice, with fuel costs playing a major role, as shown in Fig.1. In places where it was available, natural gas was preferable to LPG due to the price difference and higher energy content per kilogram. Natural gas was chosen by 62% of the state as the best alternative due to its proximity to the pipeline and its deeper penetration into the state, as shown in Fig.2.

Pernambuco and Rio Grande do Norte faced similar challenges, with LPG being the most cost-effective option due to fuel prices, as shown in Fig. 1. In areas where it was available, natural gas was the best option once again because of its price and energy efficiency. Natural gas is now fueling 49% of stoves mostly in coastal areas, as depicted in Fig.2.

Sergipe chose LPG as the most effective option because it saves time and reduces emissions, but it also raises fuel costs, as shown in Fig. 1. Once again, when fuel costs are considered, natural gas is the best option due to its competitive price compared to LPG, as presented in Fig. 2.

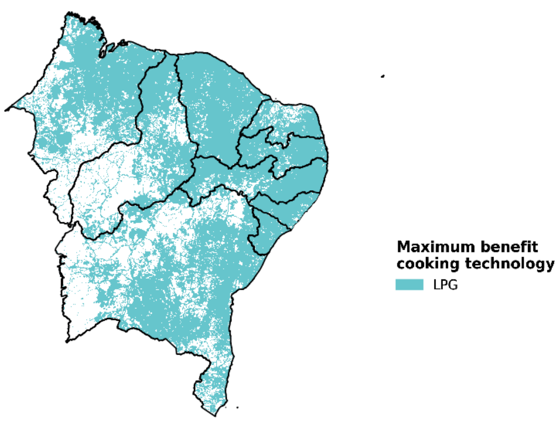

Fig. 1. Maximum net-benefit cooking technology for the northeast region without considering natural gas. From bottom to up, right to left: Bahia, Sergipe, Alagoas, Pernambuco, Paraíba, Rio Grande do Norte, Ceará, Piauí and Maranhão.

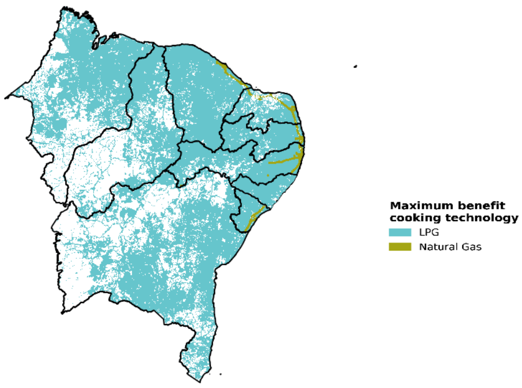

Fig. 2. Maximum net-benefit cooking technology for the northeast region considering natural gas. From bottom to up, right to left: Bahia, Sergipe, Alagoas, Pernambuco, Paraíba, Rio Grande do Norte, Ceará, Piauí and Maranhão.

3.2 NORTH

In Amazonas, the initial results indicated a mix of LPG and electricity in regions with restricted road access, as depicted in Fig.3. In this instance, the price of natural gas was slightly lower than that of LPG. Due to the concentration of the population near the Amazon River (and the pipeline), natural gas was considered the most suitable option for most people. The biggest advantage of the transition to cleaner fuels was the significant price difference, making fuel costs the highest benefit and saving up to $30 million in fuel expenses, as presented in Fig.4. LPG experienced the greatest impact when natural gas was introduced, while electricity remained unchanged from its previous state.

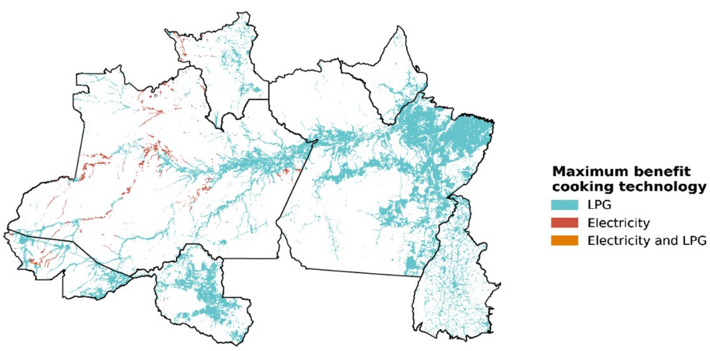

Fig. 3. Maximum net-benefit cooking technology for the north region without

considering natural gas. From bottom to top, right to left: Tocantins, Pará, Amapá, Rondônia, Amazonas, Roraima and Acre.

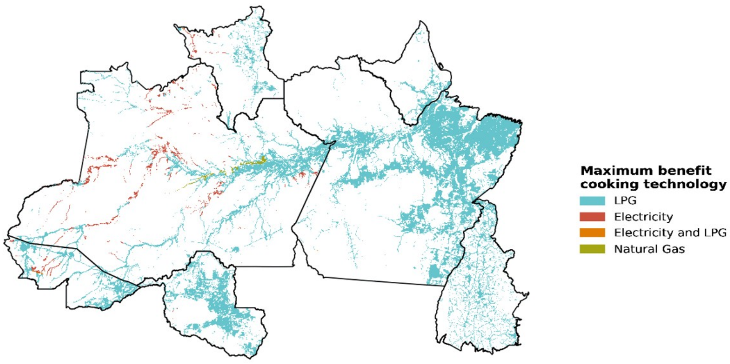

Fig. 4. Maximum net-benefit cooking technology for the north region considering natural gas. From bottom to top, right to left: Tocantins, Pará, Amapá, Rondônia, Amazonas, Roraima and Acre.

4. CONCLUSION

Agenda 2030's goal of access to clean energy requires clean cooking solutions to be implemented. The north and northeast regions of Brazil benefit the most from a clean cooking transition, as they consume a lot of charcoal and firewood. Clean cooking can be achieved with natural gas, which is a promising alternative that deserves attention because of its cleaner nature and similar prices to LPG. The OnStove tool provides a thorough GIS analysis to assist in determining the most effective solution for each square kilometer within a specific area of interest. Pipelines were not included in the tool's analysis of natural gas. To include natural gas in the account, a modified version has been developed by the authors. In earlier times, LPG was the primary technology in all states, with electricity emerging as a substitute for some minor regions. Considering natural gas, it was superior to LPG in all except two states where it was available. Whether natural gas was the best option or not depended heavily on its price.

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