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# EXPLORING SPENT COFFEE GROUNDS ENERGY POTENTIAL IN THE BRAZILIAN SCENARIO

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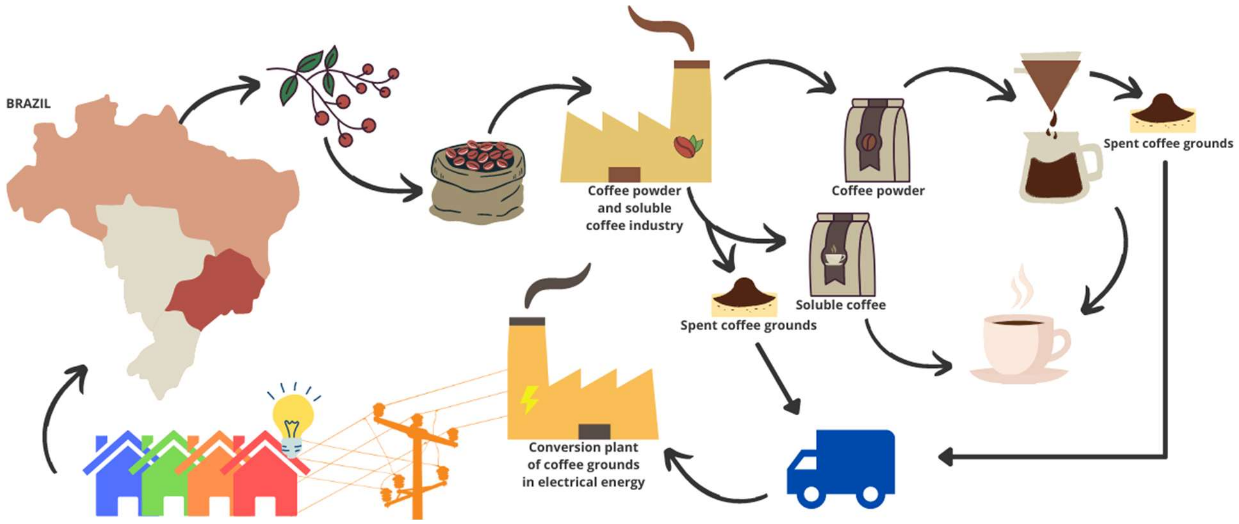
**KEYWORDS**

biomass energy, waste-to-energy, renewable energy.

**ABSTRACT**

Coffee stands out worldwide for being widely traded and consumed. However, this consumption generates a large amount of spent coffee grounds (SCGs) that are typically arbitrarily discarded. This biomass has a high heating value and molecular composition that allows for it to be a raw material for generating heat and energy. The search for renewable energy sources should consider the potential of SCGs. Thus, the objective of this study was to estimate the energy potential of SCGs in Brazil. The methodology consisted of searching for data to represent the generation of SCGs in the country and estimate its energy potential. It was found that the amount of SCGs available for power generation through direct combustion was approximately one thousand tons, and the power generation potential was 6.83 TWh/year in Brazil. This energy is sufficient to meet, for example, the total annual demand for public lighting in the country's Southeast. These results are the first steps towards evaluating the potential use of SCGs as an energy source and its environmental benefits. Additionally, this study explored limitations and barriers, providing valuable information for developing routes for using this energy residue and incentives for public policies.

**Graphical Abstract**

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## INTRODUCTION

Coffee is the second most traded commodity and the second most popular beverage after water worldwide (Atabani et al., 2019). According to the *International Coffee Organization* (ICO), Brazil is the world's largest coffee producer and exporter, accounting for 37.4% of global production and 36.9% of exports in 2020/21. Approximately 37% of the coffee produced in the country is exported. Of the coffee exporting countries, Brazil has the most significant consumption in its domestic market (ICO, 2021). According to the Brazilian Coffee Industry Association (ABIC), approximately 20.3 million 60 kg bags of coffee were consumed in the country in 2020 (ABIC, 2020). Furthermore, according to the Brazilian Soluble Coffee Industry Association (ABICS), the country is the largest producer and exporter of soluble coffee. Almost 50% of the coffee produced worldwide is processed into soluble coffee (Acevedo et al., 2013).

In 2019, approximately 4 million 60 kg bags of soluble coffee were exported by Brazil, representing the most significant volume in history (ABICS, 2020). Soluble coffee consumption in the Brazilian domestic market is also significant: in 2019, approximately 0.9 million 60 kg bags of soluble coffee were consumed in the country (ABICS, 2020).

However, coffee consumption worldwide is responsible for a high rate of waste generation, with spent coffee grounds (SCGs) being the main waste product (Franca & Oliveira, 2019; Getachew & Chun, 2017). It is estimated that globally, more than 6 million tons of SCGs are generated annually in soluble coffee industries and coffee consumption points, residential or commercial (Getachew & Chun, 2017). With the increasing world population and the increase in coffee consumption, the number of SCGs generated increases every year. The disposal of coffee waste results in economic and environmental impacts in coffee-producing and coffee-consuming countries (Mata et al., 2018). When treated as waste, SCGs are usually disposed of in landfills or incinerated (Franca & Oliveira, 2019).

Approximately 97% of SCGs are disposed of in landfills immediately after their generation, which can lead to methane and other greenhouse gas emissions (Cameron & O'Malley, 2016). However, SCGs have the potential to be used as a raw material in a variety of ways. Although SCGs are currently used in low value-added ways, such as direct application to soil or as compost, higher value-added products made with SCGs are being researched (Franca & Oliveira, 2019). This is because SCGs have more than 50% carbon and approximately 7% hydrogen by weight, a low ash content (approximately 2% on average), and an average higher calorific value of 23 MJ/kg (Tsai, 2017). These characteristics suggest that SCGs are a promising feedstock for energy production (Franca & Oliveira, 2019).

There is a considerable generation of SCGs because of the production and consumption of coffee in the country, which could be valorized into energy. In this way, there is a path to diversify the country's energy matrix and reduce the consumption of fossil fuels, in addition to providing sustainable management of this waste. This is an opportunity not only for Brazil, the largest producer of soluble coffee and a significant consumer of coffee, but also for countries worldwide. Therefore, this research aimed to estimate the energy potential of SCGs generated in the production of soluble coffee and coffee consumption in Brazil. Furthermore, we sought to evaluate how much of the country's energy demand could be supplied by this alternative source.

The results presented in this research refer to the quantification of the physical generation of SCGs and their energy content and are the first steps towards evaluating their potential use. Thus, the energy feasibility presented in this work represents an important advance for the valorization of SCGs for several applications, providing valuable information for the development of routes for the use of this energy residue and public incentive policies.

## MATERIAL AND METHODS

### Study area

Brazil has a territorial extension of approximately 8.5 million km² and a population estimated to exceed 210 million people in 2021 (IBGE, 2021). According to the Ministry of Agriculture, Livestock, and Supply (MAPA), coffee is Brazil's 5$^{th}$ most exported product, reaching approximately US $5.2 billion in 2017. Coffee cultivation occupies an area of approximately 2 million hectares, with approximately 300,000 producers distributed throughout all geographic regions of the country. Most of these regions are in the southeast (3,955-41,223 thousand bags), followed by the north (876–3,955 thousand bags), northeast (876–3,955 thousand bags), midwest (411-876 thousand bags), and south (411-876 thousand bags) regions, as shown in Figure 1. The coffee production chain is responsible for generating more than 8 million jobs in Brazil, providing income for workers and their families and developing the country (MAPA, 2018).

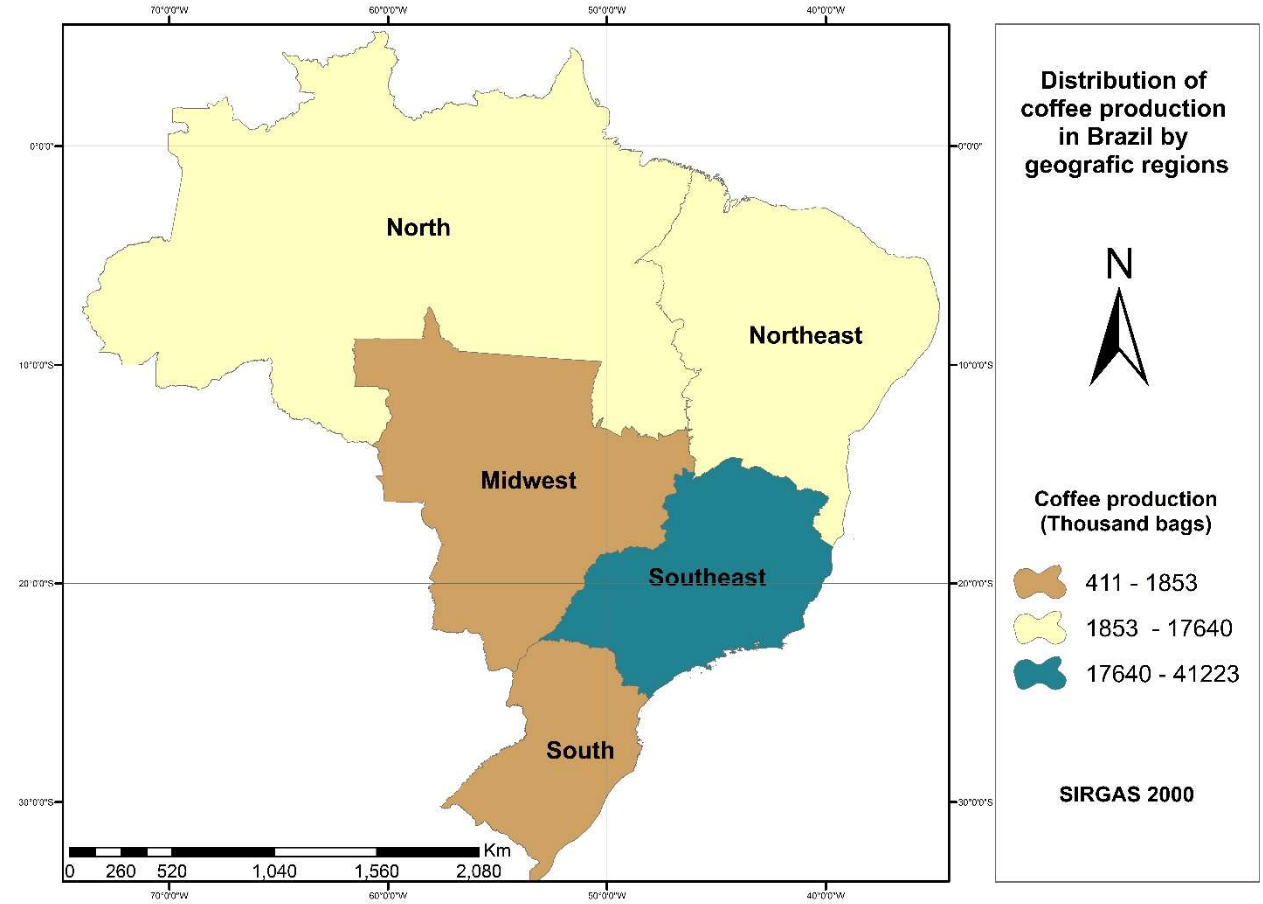


FIGURE 1. Distribution of coffee production in Brazil by geographic region. This map was generated using data from CONAB (2021).

**Estimate of SCGs generation**

The generation of SCGs in Brazil was estimated due to the consumption of roasted and ground coffee in the country and the production of soluble coffee. The SCG generation of coffee consumed roasted and ground in Brazil was calculated using [eq. (1)].

$$SCGs = Pop * CPC * R \quad (1)$$

Where:

*SCGs* are the generation of SCGs from the consumption of roasted and ground coffee in kg;

*Pop* is the number of inhabitants in Brazil in each geographical region (data from IBGE (2021));

*CPC* is the average per capita consumption of roasted coffee in Brazil and equal to 4.81 kg of roasted coffee per person per year (ABIC, 2020), and

*R* is the SCGs yield and is equal to 0.91 g of dry SCGs for each g of roasted coffee (Blinová et al., 2017).

To estimate the number of SCGs generated in the soluble coffee industry, [eq. (2)].

$$Soluble\ SCGs = Prod * R_S \quad (2)$$

Where:

*Soluble SCGs* is the generation of SCGs in the soluble coffee industry in kg;

*Prod* is the production of soluble coffee in Brazil, obtained by adding the amount of soluble coffee exported (4 million 60 kg bags) and the amount consumed in the domestic market (0.9 million 60 kg bags) (ABIC, 2020), and

$R_S$ is the yield of dry SCGs, equal to 0.50 kg of dry SCGs for each kg of soluble coffee produced (Acevedo et al., 2013).

A literature search was conducted to find the high heating value (HHV) measured in experiments on a dry basis performed with SCGs to estimate the energy potential of SCGs. The experimental HHV values ranged from 17.07 to 29.50 MJ per kg of SCGs, with an average value of 23.35± 2.63 MJ/kg (Table 1). Some researchers have used different treatments to obtain HHV.

TABLE 1. HHV values were found in the literature as the arithmetic mean.

| *HHV*, in MJ/kg | Reference | *HHV*, in MJ/kg | Reference |
|---|---|---|---|
| 17.07 | | 25.30 | |
| 22.38 | | 26.60 | Barbanera & Muguerza, 2020 |
| 24.62 | | 27.30 | |
| 25.86 | Chen & Chen, 2021 | 29.50 | |
| 23.40 | | 21.77 | Zhang et al., 2018 |
| 25.59 | | 21.80 | Kim et al., 2017 |
| 26.21 | | 18.80 | Kang et al., 2017 |
| 22.80 | Van Nguyen et al., 2021 | 23.20 | Li et al., 2014 |
| 24.15 | | 20.10 | Vardon et al., 2013 |
| 22.00 | | 23.40 | |
| 23.80 | Martinez et al., 2021 | 22.74 | Bok et al., 2012 |
| 21.80 | | 23.50 | Tsai et al., 2012 |
| 24.30 | | 23.72 | Zuorro & LaVecchia, 2012 |
| 22.14 | Kibret et al., 2021 | 19.82 | Skreiberg et al., 2011 |
| The arithmetic mean of the values found was 23.35± 2.63 MJ/kg. | | | |

To obtain the potential for energy generation from SCGs, [eq. (3)].

$$Energy\ potential = (SCGs + soluble\ SCGs) * HHV\ SCG \quad (3)$$

Where:

*Energy potential* is the energy generation potential through SCGs, assuming that the SCGs were dried, in MJ;

*SCGs* is the generation of SCGs from the consumption of roasted and ground SCGs generation;

*soluble SCGs* is the generation of SCGs in the instant coffee industry, and

*HHV SCG* is the high heating value of spent coffee grounds, estimated at 23.35± 2.63 MJ/kg.

A conversion factor of 0.2778 kWh per MJ was applied to the energy potential of the SCGs to find the potential for generating electricity from this residue. The calculated potential energy assumed was the primary energy.

## RESULTS AND DISCUSSION

### The electric potential of SCGs in Brazil

With the consumption of raw coffee beans data, Brazil's coffee consumption and the production of SCGs in 2020 were estimated. The energy potential of SCGs was estimated at 6.83 TWh/year (779.68 MW), considering the primary energy. Additionally, the energy potential was calculated for each Brazilian federal region. The results showed that the potential energy generation was more expressive in the southeast region (3.00 TWh/year or 342.19 MW), followed by the northeast (1.93 TWh/year or 220.24 MW), south (1.02 TWh/year or 115.92 MW), north (0.62 TWh/year or 70.38 MW) and Midwest (1.55 TWh/year or 62.85 MW), as shown in Figure 1. In addition, the potential power generation of SCGs in the soluble coffee industry in 2020 was 0.94 TWh/year (107.21 MW).

In the present work, the primary energy of the waste was considered for calculating the energy potential. Thus, the efficiency of no specific thermodynamic cycle for electricity generation was considered. The efficiency of the process varies according to the technology of transforming biomass into energy used, which can be combustion, pyrolysis, and gasification, for example (Malico et al., 2019). The efficiency of those processes varies from 30 to 40% for combustion, 60 to 70% for pyrolysis and 80 to 90% for gasification (Faaij, 2006; Mana et al., 2021). However, regardless of the transformation route, SCGs have great energy potential due to the amount of waste available.

Regarding biomass thermochemical conversion technologies for electricity generation, it should be noted that Brazil has the national capacity, both technological and industrial, to build thermoelectric cycles at the highest efficiency conditions that technologies offer. The growth of the domestic market for these technologies, resulting from the expansion of electricity generation using biomass as a fuel source, offers conditions for increasing the efficiency characteristics and thus results in a scale-favourable effect on investment and operating costs (EPE, 2007). Thus, this enormous potential shown in Figure 2 explains the need to verify the economic viability of this use.

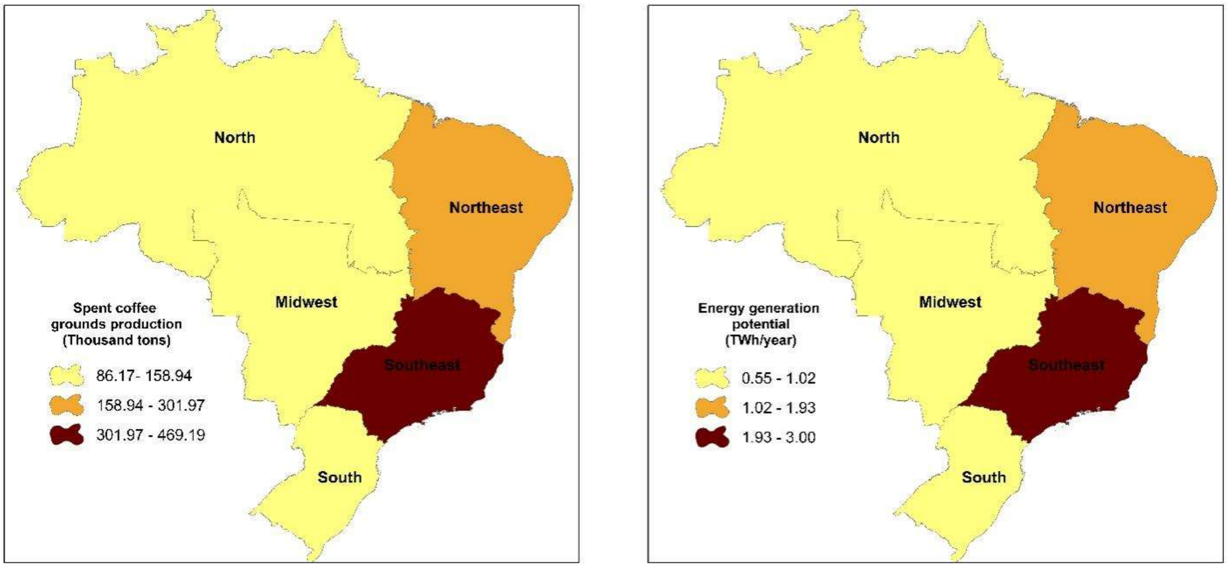


FIGURE 2. Potential for energy generation from spent coffee grounds production.

Several works calculating the potential of energy generation through biomass have been developed in other countries. The total potential of power generation from rice straw calculated in Vietnam was 2,565 MW, which was higher than the total found in the present study for SCGs. This was probably due to the amount of rice straw available for transformation into energy (54 Mt), which was greater than the number of SCGs available for the same purpose (1.07 Mt) (Cuong et al., 2021). The potential for energy generation found for olive waste in Morocco was 2.83 TWh/year, lower than that found in the present study, which was 6.83 TWh/year (Mana et al., 2021). Regarding coffee, de Oliveira and colleagues calculated the energy potential in Brazil using biomass coffee husks, coffee wood, and eucalyptus wood (Oliveira et al., 2013). They found 55.9 TWh as the total energy potential for all these biomasses, in which coffee waste corresponded to 30% of the complete waste available.

Brazil has great potential for creating energy from forestry and agricultural biomass as a substitute for petroleum. Approximately 41 million tons of wood waste are generated annually from the wood processing and forest harvesting industry, which can generate energy equivalent to 1.7 GW/year (Ferreira et al., 2018). This demonstrates that the residual biomass has great potential for energy generation, which depends on the amount available and the High heating value of each residue. Table 2 shows the amounts of agricultural waste production in Brazil in millions of tons and the amount of primary energy available in TWh/year.

TABLE 2. Energy availability of the waste in Brazil.

| | Waste Available [Mt/year] | LHV [GJ/t] | Energy availability of the waste [TWh/year] |
|---|---|---|---|
| Rice Straw | 14 | 16.0 | 61.42 |
| Bean Straw | 4 | 14.0 | 5.55 |
| Cotton Waste | 1 | 14.6 | 4.79 |
| Cassava Branches | 16 | 16.0 | 27.22 |
| Corn Straw | 101 | 17.7 | 198.26 |
| Soybean Straw | 94 | 14.6 | 114.5 |
| Wheat Straw | 17 | 12.4 | 23.33 |

Source: EPE (2014)

**Brazil's Electricity Context**

According to the "National Energy Balance 2021 - base year: 2020", prepared by Brazil's Energy Research Company (EPE, in Portuguese), 645.9 GWh were offered in 2020. Although renewable sources represent 84.8% of the country's electricity matrix, most of the country's electricity is generated by hydraulic sources (65.2%), leaving the country dependent on the annual availability of hydroelectric dams. However, biomass is an alternative source and is constantly generated in the country, regardless of seasonality, representing only 9.1% of Brazil's electricity matrix. Among the biomasses used in the country are sugar cane, firewood, and charcoal. Approximately 58.7 TWh from these biomasses are annually offered (EPE, 2021b). As estimated in this study, adding the potential of SCGs consumed in roasted and ground and soluble coffee production, approximately 5.89 TWh could be added to Brazil's electricity supply per year. Approximately 6.83 TWh could be added to Brazil's electricity supply annually in coffee and soluble coffee production.

Considering Brazil's electricity consumption by region and by sector (Table 3), presented in the "Electric Energy Statistical Yearbook 2021 - base year: 2020", also prepared by the EPE, SCGs have the potential to supply, for example, the total annual demand for public lighting in the southeast region of the country (6.223 GWh/year) or to supply the total annual demand for Amazonas state (6.142 GWh/year) (EPE, 2021a). Furthermore, the potential for power generation through SCGs could supply the electricity demanded by 3,509,042 households, supplying almost 5% of Brazil's households (IBGE, 2019), considering the average monthly residential consumption of 162.2 kWh/month in 2020 (EPE, 2021a).

TABLE 3. Brazil's electricity consumption in 2020 by region and sector in TWh/year.

| Sector | North | Northeast | Southeast | South | Midwest |
|---|---|---|---|---|---|
| Residential | 10.34 | 30.61 | 69.99 | 23.80 | 13.43 |
| Industrial | 14.52 | 21.11 | 87.80 | 32.80 | 10.10 |
| Commercial | 4.95 | 13.21 | 42.88 | 14.45 | 7.03 |
| Rural | 1.15 | 5.41 | 9.82 | 10.55 | 3.98 |
| Public power | 1.54 | 3.10 | 5.20 | 1.49 | 1.44 |
| Street lighting | 1.08 | 3.93 | 6.22 | 2.54 | 1.68 |
| Public Service | 0.74 | 3.53 | 9.01 | 1.88 | 1.18 |
| Own consumption | 0.34 | 0.24 | 2.11 | 0.39 | 0.05 |
| Total | 34.66 | 81.14 | 233.03 | 97.90 | 38.89 |

Source: EPE (2021a).

Thinking about the concept of the circular economy, Mayson & Williams (2021) proposed that the energy generated with SCGs could be used in the coffee industry itself in the coffee roasting stage as a way to reduce energy consumption from traditional sources. Li et al. (2014) considered biochar for heating a building near the SCG generating source. They found that approximately 6% of the building's annual thermal energy consumption could be met with SCGs.

Moreover, using SCGs as a renewable energy source is relevant for mitigating environmental and climate issues (Gebreeyessus, 2022). The inadequate disposal of SCGs can cause eutrophication of water bodies due to the high organic matter content (Thenepalli et al., 2017). In addition, the coffee production chain results in a carbon footprint of 0.27-0.70 kg $CO_2$ eq/l coffee (Usva et al., 2020). However, Kim and collaborators demonstrated that a 1% increase in total biomass energy consumption causes a 0.65% reduction in long-term $CO_2$ emissions (Kim et al., 2020). Therefore, using biomass obtained through SCGs avoids soil and water pollution and contributes to reducing $CO_2$ emissions.

**Limitations and barriers. Limitations for energy generation from surplus SCGs in Brazil.**

*Other uses of biomass resources.* SCGs have great potential to be used as energy in food production, health care, fertilizer, and biomaterials production (Mcnutt & He, 2019). In most of these areas, studies are still being developed to determine the best route to obtain by-products. Regarding use as a fertilizer, several types of research show that deliberately using SCGs directly into the soil can harm some crops. However, moderate use of this biomass promotes increased soil health by decreasing pesticide leaching, mineral content, and antioxidant activity (Hardgrove & Livesley, 2016; Cervera-Mata et al., 2019).

*Need for drying.* SCGs must be dried so their storage time is extended and transportation costs are reduced. This is because drying reduces the weight of the material to be transported from the generating unit, thinking of a soluble coffee factory, to the place of conversion into energy (Tun et al., 2020). Interestingly, drying is carried out by more natural methods that demand less energy so that the energy demand in this process does not exceed its energy yield.

*Environmental obstacles.* Mayson & Williams (2021) conducted a life cycle assessment of a circular economy approach using SCGs biochar obtained through roasting to supply the energy demand in the coffee roasting stage. The authors' results have shown that using SCGs biochar reduces carbon emissions compared to conventional approaches. However, one concern with the use of SCGs for energy generation is the nitrogen oxide (NOx) emissions resulting from the nitrogen content in the SCGs (Kang et al., 2017; Mayson & Williams, 2021). Therefore, attention should be given to the efficiency of the equipment for converting SCGs or spent coffee ground biochar into energy and with the performance of NOx emissions (Kang et al., 2017).

*Transportation.* According to Massaya et al. (2019), one of the key limitations of spent coffee ground bioprocessing is ensuring the continuous supply of feedstock, which requires the collection and transportation of SCGs from independent cafes, major coffee chains, commercial offices, and public-sector facilities. Therefore, aspects such as the collection points, quantities available for collection, seasonality, type, and costs of transportation are parameters/variables that need to be further investigated. Rough estimations of transportation costs can be made based on other biomasses of similar densities (Battista et al. 2020). Attaching small-scale production plants to major coffee companies should be a good alternative to reduce transportation costs and improve the local economy.

**Future Perspectives and Recommendations**

Most of the energy potential of coffee grounds is due to the production of coffee grounds in a decentralized way. Using this waste is more advantageous if the production is centralized (Kookos, 2018). Thus, for the use of SCGs for energy generation to be feasible, it is essential to encourage public policies for this purpose. In the European Union, the use of waste based on the circular economy has been encouraged, as well as for food industries to pay for the management of their waste, based on the "polluter pays" principle, avoiding the potential impact on health and the environment (Kourmentza et al., 2018). Brazil could encourage energy generation through SCGs through policies that hold coffee-producing companies responsible for the waste generated. Another option would be reducing the value of the electricity bill of people who take the SCGs to preestablished fixed points in their city, as happens concerning recyclable waste in cities such as Niterói - RJ (CLIN, 2021). Thus, public policies and initiatives may be developed to collect this waste and transform it into energy.

## CONCLUSIONS

The worldwide popularity of coffee as a beverage is responsible for the great generation of SCGs as waste. The potential energy use of SCGs in Brazil was studied based on the current SCG availability, limitations, barriers, and policy recommendations. Brazil's SCG power generation potential is 6.83 TWh/year from one thousand tons of SCG. This power generation potential represents almost 5% of Brazil's households, or the supplying Brazilian Southeast annual street lighting or annual demand for Amazonas state. Future research should include the environmental and economic effectiveness of SCGs as a waste-to-energy source in Brazil.

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