JULIO PERETTI DA SILVA

TECHNICAL AND ECONOMIC FEASIBILITY OF THE BARBECUE CHARCOAL PRODUCED FROM BRIQUETTES INCORPORATING SLUDGE FROM POULTRY SLAUGHTERHOUSE WASTEWATER

A dissertation presented to the Graduate Program in Forest Engineering of the Center for Agricultural Sciences of the University of Santa Catarina, as a partial requirement to obtain the Master of Science in Forest Engineering degree.

Advisor: Dr. Philipe Ricardo Casemiro Soares.
Co-advisor: Dra. Martha Andreia Brand.

LAGES - SC
2020

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Biblioteca Setorial do CAV/UDESC,
com os dados fornecidos pelo(a) autor(a)

Silva, Julio Peretti
TECHNICAL AND ECONOMIC FEASIBILITY OF THE BARBECUE CHARCOAL PRODUCED FROM BRIQUETTES INCORPORATING SLUDGE FROM POULTRY SLAUGHTERHOUSE WASTEWATER / Julio Peretti Silva. -- 2020.
48 p.

Orientador: Philipe Ricardo Casemiro Soares
Coorientadora: Martha Andreia Brand
Dissertação (mestrado) -- Universidade do Estado de Santa Catarina, Centro de Ciências Agroveterinárias, Programa de Pós-Graduação em Engenharia Florestal, Lages, 2020.

1. biomass. 2. forest economy. 3. renewable energy. 4. briquette charcoal . I. Soares, Philipe Ricardo Casemiro . II. Brand, Martha Andreia. III. Universidade do Estado de Santa Catarina, Centro de Ciências Agroveterinárias, Programa de Pós-Graduação em Engenharia Florestal. IV. Titulo.

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I dedicate this dissertation to the scientific community and to my mother, Angela Maria Peretti, who has been the most supportive person throughout my live.

ACKNOWLEGMENTS

I would like to thank the University of the State of Santa Catarina (UDESC), the Coordination of Superior Level Staff Improvement (CAPES), and the Santa Catarina State Research and Innovation Support Foundation (FAPESC), Brazil, for funding this research project.

Also, I’d like to thank my advisor, Dr. Philipe Ricardo Casemiro Soares, and co-advisor, Dra. Martha Andreia Brand, for all the support and teaching. And my family and friends for helping me during the development of this research.

ABSTRACT

SILVA, Julio Peretti. **Technical and economic feasibility of the barbecue charcoal produced from briquettes incorporating sludge from poultry slaughterhouse wastewater.** 2020. 48 pgs. Dissertation (Master of Science in Forest Engineering – Area: Forest Engineering) – The University of the State of Santa Catarina. Postgraduate Studies in Forest Engineering, Lages, 2020.

The generation of water waste in poultry slaughterhouses has increased considerably in recent years due to the growing demand for poultry meat. This fact, combined with the current need for developing new forms of renewable energy from biomass and the lack of disposal facilities for this, has motivated this study. We aimed to determine the technical and economic feasibility of barbecue charcoal production using briquettes produced with different blends containing sludge from poultry slaughterhouse and *Pinus* spp. shavings. To determine the technical feasibility, we have mixed both residues by gradually adding 10-90% of sludge in the blends, which resulted in 9 treatments containing sludge and 1 containing only *Pinus* spp. shavings. After that, we produced four briquettes of each treatment and charred them by using a standardized heating ramp method. After charring, we submitted the charcoals to the analyzes of Moisture Content (MC), Bulk Density (BD), Compressive Strength (CS), Gross Calorific Value (GCV), and Proximate Analysis (PA). The Gravimetric Yield (GY) and the Energy Density (ED) of each treatment were calculated by using the results from the other analyzes. For data analysis, we used descriptive statistics after obtaining the averages and coefficients of variation. We then submitted all averages of the variables to the Scott Knott Test at 5% of significance. Results showed that the blend containing 90% of sludge (T9) generated the barbecue charcoal with the best characteristics. Therefore, the economic analysis was performed based on T9. We evaluated the economic feasibility using the following indicators: Net Present Value (NPV), Internal Rate of Return (IRR), and Cost-Benefit Ratio (C / B). Besides, we performed the Sensitivity Analysis to assess how sensible the NPV and the IRR are to changes in the sales prices and the price of the sludge. The results from the economic analysis indicate that the project is feasible as long as the sales price isn’t lower then R$ 1,58 per kilo and the price to be paid for the sludge isn’t higher than R$ 100,00 per ton, including transportation, considering all other variables unchanged.

Keywords: biomass; forest economy, renewable energy; briquette charcoal.

RESUMO

SILVA, Julio Peretti. **Viabilidade técnica e econômica da produção de carvão de briquetes produzidos com misturas de efluente flotado de abatedouro de aves e maravalha de *Pinus* spp**. 2020. 48 pgs. Dissertação (Mestrado em Engenharia Florestal) – Universidade do Estado de Santa Catarina. Pós-graduação em Engenharia Florestal, Lages, 2020.

A geração de efluentes nos abatedouros de aves aumentou consideravelmente nos últimos anos devido à crescente demanda por carne de frango. Esse fato, combinado com a atual necessidade de desenvolvimento de novas formas de energia renovável a partir da biomassa e a falta de instalações de descarte para isso, motivou este estudo. O objetivo foi determinar a viabilidade técnica e econômica da produção de carvão para churrasco usando briquetes produzidos com diferentes misturas contendo lodo de abatedouro de aves e maravalha de *Pinus* spp. Para determinar a viabilidade técnica, misturou-se os dois resíduos adicionando gradualmente 10-90% de lodo nas misturas, o que resultou em 9 tratamentos contendo lodo e 1 contendo apenas maravalha. Depois disso, quatro briquetes de cada tratamento foram produzidos e carbonizamos pelo método de rampa de aquecimento. Após a carbonização, os carvões foram submetidos às análises de teor de umidade (MC), densidade a granel (BD), resistência à compressão (CS), poder calorífico superior (GCV) e análise imediata (PA). O Rendimento Gravimétrico (GY) e a Densidade Energética (DE) de cada tratamento foram calculados usando os resultados das outras análises. Para análise dos dados, utilizou-se a estatística descritiva após a obtenção das médias e coeficientes de variação. Em seguida, todas as médias das variáveis foram submetidas ao teste de Scott Knott com 5% de significância. Os resultados mostraram que a mistura contendo 90% de lodo (T9) gerou o carvão com as melhores características. Portanto, a análise econômica foi realizada com base no T9. Avaliou-se a viabilidade econômica usando os seguintes indicadores: Valor Presente Líquido (VPL), Taxa Interna de Retorno (TIR) e Taxa de Custo-Benefício (C / B). Além disso, realizamos a Análise de Sensibilidade para avaliar a sensibilidade do VPL e da TIR às mudanças nos preços de venda do carvão e no preço do lodo. Os resultados da análise econômica indicam que o projeto é viável desde que o preço de venda não seja inferior a R$ 1,58 por quilo e o preço a ser pago pelo lodo não seja superior a R$ 100,00 por tonelada, incluindo transporte e considerando todas as outras variáveis inalteradas.

Palavras-chave: biomassa; economia florestal, energia renovável; carvão de briquete.

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SUMMARY

GENERAL INTRODUCTION

In the last decade, the production of chicken meat in Brazil has increased significantly. According to the ABPA’s 2019 annual report (Brazilian Association of Animal Protein), Brazil produced 12.86 million tons of chicken meat in 2018, which placed the country as the second-largest producer. USA's production reached 19.361 million tons in the same year (ABPA, 2019).

This production in poultry slaughterhouses generates a large number of liquid effluents with a high concentration of pollutants, which makes it necessary to use high-efficiency treatments to lessen the impacts on the environment. According to Sena (2009), the industry commonly uses flotation processes as primary treatments in effluents containing a high load of suspended oils and greases. They intend to increase the efficiency of removing the organic matter from the water. The substantial portion resulting from the flotation process is called floated sludge, which has inherent characteristics to be used as fuel. In this study, the floated sludge is mention as sludge.

In this regard, the increase in the amount of industrial organic wastes has raised awareness and generated new demands on society. There are current social pressures for clean sources of energy. Tolmasquim (2005) claims that this new demand was due to the increase in the number of agriculture wastes and the need to dispose of them correctly, and with economical use.

The United Nations Development Programme (UNDP) launched in December 2015 the Agenda 2030 for Sustainable Development, with 17 Sustainable Development Goals (SDG). UNDP's goal number 7 is directly related to energy: "Ensuring reliable, sustainable, modern, and affordable access to energy for all." (UNDP, 2015, p.15).

Amid this social pressure, we have the biomass. The use of biomass as an energy source is one of the options to mitigate the harmful effects of global warming. Biomass can come from two main routes: energy crops or lignocellulosic residues from agroforestry activities. The second route offers the advantage of appropriately targeting potential pollutants of the environment (PROTASIO, 2012).

One way of turning biomass into energy is through its compaction or densification. Among the different densification processes, we have the production of briquettes. Granada et al. (2002) state that biomass briquetting is a densification process that improves the characteristics of the residual biomass. The process turns the biomass into fuel with higher gross calorific value, lower volatile content, higher fixed carbon content, uniformity in shape and size, lower O / C ratio, and low moisture (PRINS et al., 2006).

The briquette market, mainly for domestic use, is still not widespread in Brazil. Therefore, one alternative use for the briquettes produced with the sludge from poultry slaughterhouses and *Pinus* spp. shavings can be to transform it into charcoal through the carbonization process. This way, it becomes a viable source of energy.

In 2015, Brazil consumed nearly 6 million tons of charcoal, 84% of which destined for the industrial sector (BRAZIL, 2016). In homes and small commercial applications, the country consumed about 870 thousand tons, which represents 0.14% of the country's total production (BRAZIL, 2016).

Knowing this, if the results indicate the technical feasibility of this charcoal’s production, it will present itself as an alternative to a highly hazardous waste, which is a current environmental problem. That is, the transformation of animal biomass into a source of clean and sustainable energy for cooking would be possible.

In this dissertation, Chapter 1 covers all the details of the technical feasibility analysis. The results obtained from Chapter 1 allowed the study of the economic feasibility of the production of this charcoal that might enter the market as an alternative source of energy in the future.

As the production of the charcoal is feasible technically, the application of the economic analysis criteria comes in handy when considering that this product might be marketed.

According to Guimarães et al. (2007), financial and economic analyses are essential tools as they aid in the decision making of the investment and are indispensable studies for production systems that present technological innovations.

Economic and financial feasibility analysis integrates the list of activities developed by economic engineering, which seeks to identify what are the benefits expected in a given investment to put them in comparison to the investments and costs associated with it in order to verify its feasibility of implementation (ZAGO et al. 2009).

Veras (2001) states that economic engineering is the study methods and techniques used for the economic and financial analysis of investments. The author also points out that the analysis of investments comprises not only alternatives between two or more investments to choose from, but also the analysis of a single investment in order to evaluate the interest in the implementation of the same.

Some tools are essential when it comes to economic analysis. Among them, we have the income stream, the minimum acceptable rate of return (MARR), the net present value (NPV), the internal rate of return (IRR), the cost/benefit ratio (B / C), and the sensitivity analysis. They compare the costs and revenues inherent to the project in order to verify whether or not the investor should implement it.

Chapter 2 of this dissertation covers the economic feasibility analysis of the charcoal in question, which we carried out after concluding Chapter 1 based on the results of the technical feasibility analysis.

OBJECTIVES

The general aim of this study was to determine the technical and economic feasibility of the production of barbecue charcoal made with briquettes incorporating different blends of sludge from poultry slaughterhouse wastewater and *Pinus* spp. shavings.

The specific objectives were:

- Defining the best percentage of sludge to be incorporated in the briquettes in order to get the best technical performance.
- Verifying the suitability of using this charcoal for cooking as barbecue charcoal.
- Determining the economic feasibility of the production of this charcoal.
- Analyzing how the main economic variables affect the project’s economic feasibility.

1 TECHNICAL FEASIBILITY OF THE BARBECUE CHARCOAL PRODUCED FROM BRIQUETTES INCORPORATING SLUDGE FROM POULTRY SLAUGHTERHOUSE WASTEWATER

ABSTRACT

The generation of water waste in poultry slaughterhouses has increased considerably in recent years due to the growing demand for poultry meat. This fact, combined with the current need for developing new forms of renewable energy from biomass and the lack of disposal facilities for this residue, has motivated this study. We aimed to determine the technical feasibility of barbecue charcoal production using briquettes produced with different blends (treatments) containing sludge from poultry slaughterhouse wastewater and *Pinus* spp. shavings. To that end, we have mixed both residues by gradually adding 10 to 90% of sludge in the blends, which resulted in 9 treatments containing sludge and 1 containing only *Pinus* spp. shavings. After that, we produced four briquettes of each treatment and charred them by using a standardized heating ramp method. After charring, we submitted the coals to the analyzes of Moisture Content (MC), Bulk Density (BD), Compressive Strength (CS), Gross Calorific Value (GCV), and Proximate Analysis (PA). The Gravimetric Yield (GY) and the Energy Density (ED) of each treatment were calculated by using the results from the other analyzes. For data analysis, we used descriptive statistics after obtaining the averages and coefficients of variation. We submitted all averages of the variables to the Scott Knott Test at 5% of significance. Results showed that the production is technically feasible and the briquettes containing 90% of sludge generated the charcoal with the best characteristics for household use.

Keywords: Biomass; Renewable Energy; Barbecue Charcoal.

1.1 INTRODUCTION

Brazil is a huge generator of organic wastes considering its population. It has abundant food and fuel production, animal growing, and several production processes that eliminate by-products that companies could exploit in different ways (DE LUCAS & SANTOS, 2016).

The production of chicken meat in Brazil has increased lately. According to the ABPA's 2019 annual report (Brazilian Association of Animal Protein), Brazil produced 12.86 million tons of chicken meat in 2018, which makes the country the second-largest producer in the world. United States production reached 19.361 million tons in the same year (ABPA, 2019).

In this sense, it is common knowledge that the growth in the number of poultry slaughterhouses has caused an increase in the generation of effluents from them, which are highly pollutants and can, if inadequately disposed of, cause serious environmental problems.

The wastewater from poultry slaughterhouses contains blood, viscera, excrement, fats, substances contained in the digestive tract of animals, among others, characterizing an effluent with high organic matter concentration (BEUX, 2005).

The meat processing industries use approximately sixty-two million cubic meters of water per year around the world. They transform most of this water into effluents with high concentrations of pollutants containing high values of biochemical oxygen demand (BOD5), chemical oxygen demand (COD), oils, and greases (OG), total solids (TS), and other wastes. If companies do not treat these residues, they will represent insect proliferation sources, producing unpleasant odors and, when released into rivers and lakes, characterize intense water pollution (SENA, 2005).

According to Garcia (2016), these effluents require active treatment, and one of the processes used as a treatment is the coagulation followed by flotation, which aims to increase the efficiency of removing organic matter, oils, and greases from the water. This process generates a large amount of residual sludge that needs to undergo treatment and eliminated appropriately. The author also claims that companies generally intend this sludge for disposal or landfill, which culminates in the generation of undesirable residues such as slurry and methane (CH4), polluting the water, the air, and the soil.

The physical-chemical treatment of poultry slaughterhouse wastewaters occurs with the equalization of the raw effluent, followed by adding the flocculating agent and polymers to potentiate the fat separation process. Along with the dosages of products, there is the microinjection of air bubbles that aid the flotation process, which is responsible for grouping particles of fat and suspended organic material into "flakes" by raising them to the surface of the water. Once the material is separated, the system removes the sludge generated from the emergent flakes from the flotation tank and send the water to secondary treatment in treatment ponds (PINTO et al., 2018).

According to Unfried and Yoshi (2012), after separating the wet sludge, as it is called the material removed from the floatation tank, from the water, it is heated to 90°C and sent to a centrifuge called Tridecanter. This equipment has the active principle of separating the heated sludge in three phases: mud oil, water or clarified effluent, and floated sludge.

The floated sludge is the substantial portion of the effluent, containing nearly 60% of moisture content, and it has inherent characteristics to be used as fuel. Unfried and Yoshi (2012) recommend the drying of the sludge “cake” as it favors its energy use by direct combustion. In this way, this material must undergo a drying process to reduce its moisture content to a range between 12 and 15%.

Moreover, this dried sludge characterizes itself as an environmental problem because it does not decompose in nature. Tomasquim (2005) states that there has been a growing interest in new energy production alternatives from biomass due to the increase in the number of agriculture residues along with the need for disposing of them correctly and with economical use. Also, the world has raised social pressures for clean sources of energy which do not emit greenhouse gases in the last few years.

The United Nations Development Program (UNDP) launched the Sustainable Development Agenda 2030 with the 17 Sustainable Development Goals (SDG) in December 2015. According to this document, "A world where the human environment is safe, resilient and sustainable, and where there is universal access to the energy of reasonable, reliable and sustainable cost" should be sought, and "... knowledge about scientific and technological innovation in areas as diverse as medicine and energy " must be developed (UNDP, 2015).

UNDP's goal number 7 is directly related to energy: "Ensuring reliable, sustainable, modern, and affordable access to energy for all." This goal focuses on renewable energy, energy efficiency, international cooperation in research and clean energy technologies, clean energy infrastructure, and modern and sustainable energy services for all developing countries.

Regarding waste management, the Agenda 2030 proposes "to reduce negative environmental impact per capita of cities by 2030, including paying special attention to air quality, municipal waste management, and others" (UNDP, 2015).

In Brazil, it is understood that an environmentally appropriate final destination to wastes means "[...] waste disposal which includes re-use, recycling, composting, recovery, and energy utilization..." since all legal standards and restrictions are observed.

This understanding comes from the launch of the National Solid Waste Policy (PNRS) - Law 12.305 of 2010 and Decree No. 7.404 of December 23, 2010, which regulates Law No. 12.305 (BRAZIL, 2010). In Article 7, the PNRS also mentions the use of energy as a practice to be encouraged in companies.

Companies can recover the organic wastes of several processes in the form of renewable energy. Many of them can be used in the same production place, which decentralizes energy production, minimizes the logistics, and creates the possibility of energy self-sufficiency for several producers. Renewable energy production contributes to the increase of the world energy matrix, the reduction of inadequate disposals in the environment, the generation of business opportunities, and more significant social and economic development (DE LUCAS AND SANTOS, 2016).

Marafon et al. (2016) claim that the biomass is a low-cost, fast-access raw material that stores large amounts of energy, carbon, oxygen, and hydrogen. It is one of the few sources that can facilitate large-scale and sustainable energy production to support the development of society.

One of the ways to turn biomass into energy is through its compaction or densification. Granada et al. (2002) mention that biomass briquetting is a densification process that improves the characteristics of the residual biomass, i.e., it increases energy density, reduces transportation costs, and produces a uniform fuel. The briquetting process consists of applicating pressure to a mass of particles by adding or not a binder, and with or without subsequent heat treatment (QUIRINO et al., 1991).

Briquetting is a very efficient way to concentrate the available energy in the biomass as 1.00 m^3 of briquettes contain at least five times more energy than 1.00 m^3 of waste, taking into account the bulk density and the mean calorific value of these materials (QUIRINO et al. 1991).

Having that in mind, the commercialization of briquettes is still not widespread in Brazil. Therefore, an alternative for the briquette produced with the sludge from poultry slaughterhouses and *Pinus* spp. shavings is to char the briquettes in order to produce charcoal.

Prins et al. (2006) state that roasting and charring briquettes may be alternatives to improve their quality and commercialization since biomass thermal treatments result in increased energy density and decreased moisture content.

During the carbonization process, the thermal degradation of the biomass occurs in the absence of a controlled presence of oxygen, between 350 and 600ºC, but it can occur in higher temperatures. Besides, the process converts briquettes into fuel with higher gross calorific value, lower volatile content, higher fixed carbon content, uniformity in shape and size, lower O / C ratio, and low humidity (PRINS et al., 2006).

The final destination of the charcoal produced in Brazil is varied. According to the National Energy Balance (BEN) of 2016, Brazil consumed about 6 million tons in 2015 and destined 84% to the industrial sector. In homes and small commercial applications, the country consumed about 870 thousand tons, which represents 0.14% of the country's total production (BRAZIL, 2016).

Barbecue charcoal features a large and robust charcoal market niche. According to Brand et al. (2015), the use of charcoal in industries for energy purposes is not significant in South Brazil. However, when it comes to domestic use, its application stands out for the preparation of barbecue, considering that this food has great cultural importance for the population of the Southern States.

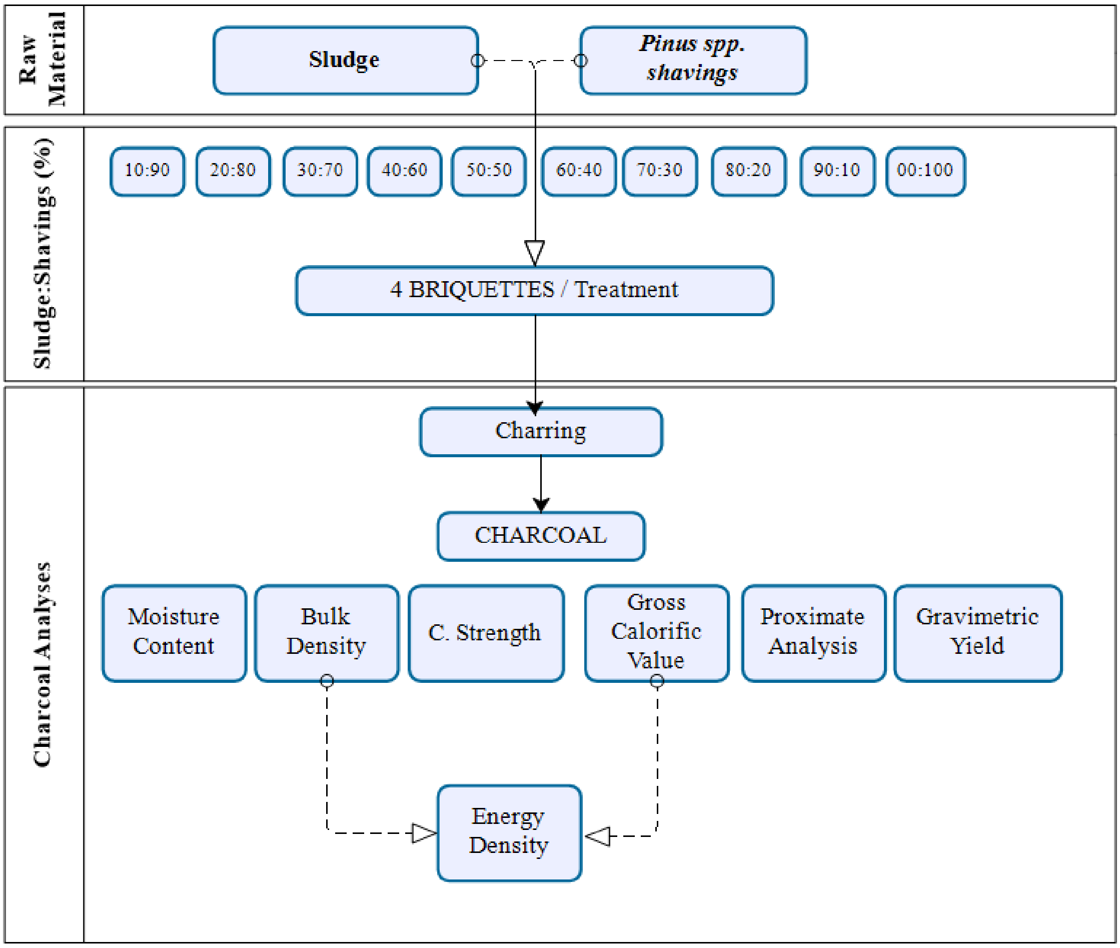
In this sense, this study aimed to determine the technical feasibility of the production of barbecue charcoal by using briquettes incorporating different blends of sludge from poultry slaughterhouse wastewater and *Pinus* spp. shavings.

1.2 MATERIALS AND METHODS

The poultry waste used in this research is the floated sludge after the drying process. Therefore, it is going to be mentioned here as only sludge. We seek to evaluate the technical feasibility of using this sludge for energy production in the form of charcoal. To that end, the sludge needs to be mixed with lignocellulosic biomass and densified into briquettes. The lignin and cellulose from wood materials improve the densification as they are well-known for their binding characteristics in this process. Because of the well-known quality of *Pinus* spp. shavings, we have chosen this lignocellulosic material for this research, and we are going to mention it as only shavings.

Figure 1 shows a general flowchart of the technical feasibility analysis. It covers the structural and energy quality analyzes that have been carried out in this research.

Figure 1 - General flowchart



Source: The authors (2019).

The residues are from different sources. We collected the *Pinus* spp. shavings at a company that manufactures doors, and the sludge from poultry slaughterhouse at a solid-waste treatment company, which works with composting and production of organic fertilizers. Both companies are in Lages, Santa Catarina, Brazil.

We produced the briquettes using blends made with different proportions of sludge and *Pinus* spp. shavings, which featured the treatments, according to Table 1. The blends had been conditioned in an air-conditioned room until the stabilization of the moisture content. The briquetting has been carried out by a pilot hydraulic piston briquette machine. We produced a total of 4 briquettes of each treatment presented in Table 1.

Table 1 - Percentage composition used to produce the briquettes.

Treatment	Blend	Composition (%)
T1	Sludge – *Pinus* shavings	10:90
T2	Sludge – *Pinus* shavings	20:80
T3	Sludge – *Pinus* shavings	30:70
T4	Sludge – *Pinus* shavings	40:60
T5	Sludge – *Pinus* shavings	50:50
T6	Sludge – *Pinus* shavings	60:40
T7	Sludge – *Pinus* shavings	70:30
T8	Sludge – *Pinus* shavings	80:20
T9	Sludge – *Pinus* shavings	90:10
T10	*Pinus* shavings	100

First, we heated the briquette machine to the test temperature of approximately 90°C. Then, we weighed 40g of samples containing the residues in different proportions for briquette production. The process duration was 12 minutes, the pressure applied during the first 10 minutes was 5 MPa, and during the remaining 2 minutes was 12 MPa. Furtado et al. (2010) described this methodology. However, we made some adjustments in this study to achieve better densification. The machine operator applied the pressure according to his own will to make sure the briquettes did not break or present cracks. Therefore, this procedure might not be replicated precisely in future studies.

Next, after the densification process, there was a gradual pressure release, and the briquettes were kept under gentle compression until they cooled down. The final size of the produced briquettes was 35mm in diameter, and they presented varied lengths. We present some of the physical and chemical characteristics of the briquettes in Table 2.

Table 2 - Physical and chemical characteristics of the briquettes of each treatment to be used for charring.

	MC (%)	CR (MPa)	BD (g/cm^3)	FC (%)	VC (%)	AC (%)
T1	9.56	1.49	1.05	18.89	79.37	1.74
T2	10.2	1.38	1.03	19.12	77.56	3.32
T3	10.45	1.59	1.06	19.74	77.75	2.51
T4	9.72	1.16	1.02	18.66	77.81	3.53
T5	9.70	0.92	1.10	18.49	77.64	3.87
T6	9.15	0.77	0.99	15.85	79.43	4.72
T7	10.16	0.42	0.92	16.53	77.57	5.89
T8	9.14	0.32	0.96	14.52	79.23	6.25
T9	8.20	0.11	0.92	13.75	79.03	7.22
T10	13.17	1.86	1.08	17.45	82.17	0.38

Note: MC = Moisture Content; CR = Compressive Resistance; BD = Bulk Density; FC = Fixed Carbon Content; VC = Volatile Content; AC = Ash Content.

Finally, the carbonization procedure has been carried out in a laboratory. Four briquettes of each treatment have been weighed and measured before charring in order to determine the charcoal's bulk density (BD). The briquettes were wrapped with aluminum foil, identified, and placed in a muffle for charring for 4 hours and 30 minutes by following the heating ramp method below (Table 3).

Table 3 - Heating ramp used for charring.

Heating ramp		
	Temperature (°C)	**Current Time**
1	50	00:30
2	100	01:00
3	150	01:30
4	200	02:00
5	250	02:30
6	300	03:00
7	350	03:30
8	400	04:00
9	450	04:30

Analyzes of the physical and energetic properties of the charcoal have been carried out according to specific standards. Table 4 presents the analyzes and their respective standards.

Table 4 - Analyzes and standards used for characterizing the blends and the charcoal.

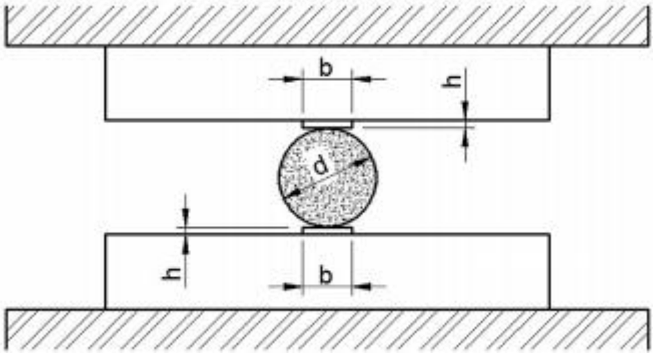
Properties	**Charcoal**
Moisture Content (%)	EN 14774:2009
Bulk Density (Kg.m^3)	EN 15103:2009
Compressive Strength (MPa)	*
Gross Calorific Value (Mj.kg^{-1})	DIN 51900
Proximate Analysis (%)	ASTM 1762
Gravimetric Yield	*

Note: *= described below.

After charring and cooling, the briquette charcoals were weighed and measured again to determine the Gravimetric Yield (GY). According to Nones et al. (2014), the gravimetric yield is the relation between the final weight of the charcoal and the dry weight of the raw material (pre-carbonization), expressed as a percentage.

The Compressive Strength (CS) is the maximum amount of weight that a briquette or charcoal can withstand before cracking or breaking. We performed the CS test according to what was stated by Brand et al. (2017), calculated by the diametric compression test according to Figure 2, where *h* is the height (mm), *d* is the sample diameter (mm), and *b* is equal to *d* multiplied by 0.15 ± 0.01.

Figure 2 - Positioning of the sample in the diametrical compression test



Source: Brand et al. (2017).

We loaded the charcoal between two flat and parallel presses with facial areas more extensive than the projected area of the charcoal. An increasing load was applied at a constant rate (2 mm min^{-1}) until the test body cracked or broke. The fracture load was read by a pressure overload curve, which is the compressive strength reported as force or stress. Then, we determined the compressive strength of the samples by the diametric compression test.

The maximum load was calculated using Equation 1.

$$C=\frac{2 \times F}{\pi \times d \times l}$$

Equation 1

In which: C = cracking or breaking maximum load (MPa);

F = strength in Newtons;

d = diameter (mm);

l = length (mm).

Regarding the descriptive statistics of the data, we obtained the averages and coefficients of variation and submitted all variables to statistical analysis using the software SISVAR and the Scott-Knott Test at 5% of significance. In order to assess the relationship between de Energy Density (ED) and the Gross Calorific Value (GCV) and the Energy Density (ED) and the Bulk Density (BD), we have calculated the Pearson correlation coefficient.

1.3 RESULTS AND DISCUSSION

Table 5 shows the results regarding the mechanical characteristics of the charcoal.

Table 5 - Physical and mechanical properties of the briquette charcoal and statistical analysis.

	MC (%)	**CR (MPa)**	**BD (g/cm^3)**	**GY (%)**
T1	6.34 a	0.60 a	0.663 c	34.54 b
T2	5.63 b	0.57 a	0.675 c	34.76 b
T3	6.01 b	0.60 a	0.693 c	34.56 b
T4	5.10 c	0.39 b	0.673 c	34.62 b
T5	6.37 a	0.44 b	0.695 c	34.11 c
T6	6.94 a	0.22 c	0.695 c	34.18 c
T7	5.65 b	0.17 c	0.690 c	35.58 a
T8	4.74 c	0.22 c	0.765 b	34.88 b
T9	4.62 c	0.22 c	0.815 a	33.36 c
T10	5.90 b	0.48 b	0.683 c	33.66 c
CV (%)	7.44	26,86	2.79	1.45
Average	5.73	0.391	0.705	34.43

Note: MC = Moisture Content; CR = Compressive Resistance; BD = Bulk Density; GY= Gravimetric Yield; CV= Coefficient of Variation

Results show that the different blends influenced the charcoal's moisture content (MC) but without showing a pattern among treatments. However, there was a variation between treatments. According to the São Paulo Premium Seal (SÃO PAULO, 2015), the moisture content of household charcoal must be up to 5%. Thus, only the T8 and T9 treatments would meet this barbecue charcoal quality criterion.

The effect of mixing the residues for briquette production was significant for the compressive resistance (CR). The increase in the amount of sludge contributed considerably to the reduction of the charcoal’s CR. Briquettes produced with 10, 20, and 30% of sludge had similar CRs, and higher than the other treatments. The ones produced with 40 to 50% formed an intermediate CR group, and briquettes with 60 to 90% of sludge generated the charcoals with the lowest CRs.

Santos (2008) claims that CR is an essential feature of the charcoal used in the steel industry. However, for household use, it relates only to the number of fines generated during transport and the allowed weight above in storage. As the average CR was 0.391 MPa, which is around 6,110 kg/m^2, we can say that each charcoal's square meter can support 6,110 kg above without breaking. Although the CR values found in the literature are higher than the ones found in this study (e.g., VEIGA et al., 2016), this is enough considering the household application.

The amount of sludge in the blends influenced the charcoal's bulk density (BD) in an opposite way. The increase in the amount of sludge caused the charcoal’s BD to increase. The charcoals produced with 10 to 70% of sludge had BDs of 663 to 695 kg.m^{-3}. The 10% increase of sludge in the composition of the briquettes led to an increase of at least 70 kg for each cubic meter of charcoal with 80% of sludge. Moreover, adding 10% of sludge into the blend increased an additional 50 kg per cubic meter of the charcoals produced with 90% of sludge.

Wood charcoal's BD is often lower than the one found in this study. Brand et al. (2015) presented BDs around 0.403 g/cm^3 when studying the leading brands of household wood charcoal marketed in South Brazil. Similarly, Protásio et al. (2013) found BDs varying from 0.220 to 0.440 g/cm^3 when studying *Eucalyptus* spp. clones used for charcoal production.

The gravimetric yield (GY) was different between treatments. T7 was the best, presenting the highest GY, followed by treatments T8, T1, T2, T3, and T4. Although the results did not explain the influence of the different mixing proportions on the charcoal’s GY, they are similar to the ones found in the literature for wood charcoal (e.g., PROTÁSSIO et al., 2013, GY = 32.02%; BOTREL et al., 2007, GY = 35.03%)

Regarding the chemical and energetic analysis, the results show that the different blends influence the charcoal's proximate analysis, as presented in Table 6.

Table 6 - Chemical and energetic properties of the briquette charcoal with the statistical analysis.

	VM (%)	FC (%)	AC (%)	GCV (MJ/kg)	ED (GJ/m^3)
T1	30.34 a	66.21 b	3.45 i	29.138 b	19.38 b
T2	29.62 a	64.09 c	6.28 h	28.301 c	19.05 b
T3	28.33 b	62.93 c	8.75 g	28.020 c	19.31 b
T4	28.27 b	61.77 d	9.97 f	27.466 d	18.54 c
T5	26.83 c	61.37 d	11.80 e	26.482 e	18.41 c
T6	26.52 c	59.12 e	14.35 d	25.702 f	17.86 d
T7	27.00 c	56.58 f	16.42 c	24.795 g	17.12 d
T8	26.80 c	54.07 g	19.01 b	24.398 h	18.65 c
T9	26.24 c	51.83 h	22.07 a	23.714 i	19.30 b
T10	28.65 b	70.07 a	1.20 j	30.086 a	20.52 a
CV (%)	2.20	1.14	2.63	0.9	2.94
Average	27.86	60.80	11.33	26.81	18.81

Note: VM = Volatiles matter; FC = Fixed Carbon; AC = Ash Content; GCV = Gross Calorific Value; ED = Energy Density; CV = Coefficient of Variation.

The increase in the amount of sludge in the blends decreased the volatile matter (VM), which is good, and the fixed carbon content (FC) of the charcoal. The lowest and, therefore, the best VMs were the ones from treatments T9, T8, T7, T6, and T5, which were all statistically similar to each other. These values were lower than the one obtained from T10, which is produced only with *Pinus* spp. shavings. As the sludge is composed of mainly animal organic matter, the T9 may have presented the lowest VM because the combustion process released most of the volatiles.

The charcoal's VM was excellent and close to the VM of wood charcoal. Brand et al. 2015 found a mean VM of 32.85% in wood charcoal for household use of brands marketed in South Brazil. Similarly, Oliveira et al. (2015) presented VMs varying from 14.53 to 40.70% when studying wood charcoal for household use in Paraná, South Brazil.

Treatments T1, T2, and T3, showed the best fixed-carbon contents (FC), being only lower than T10. The São Paulo Premium Seal (SÃO PAULO, 2015) demands an FC above 73%, which would exclude all treatments from household use. However, not even the charcoal produced only with wood shavings presented an FC higher than 73%. Moreover, Brand et al. (2015) claim that the leading brands marketed in South Brazil sell household charcoal with FCs of 65.17%, which is similar to the ones found in this study.

Nevertheless, the charcoal’s ash content (AC) presented an inverse behavior. Adding 10% more sludge to the blends caused each treatment to be statistically different from each other. The AC was the property that was most influenced by the amount of sludge in the blends, and all the treatments would not be fit for household use according to the São Paulo Premium Seal (SÃO PAULO, 2015). Although the high AC can be a problem in the furnaces of steel industries, it would only represent more residue after burning in barbecue grills. The energy densities (ED) were higher than the ones found in the literature for wood charcoal. Costa et al. 2017 showed energy densities of around 11.15 GJ/m^3 when studying the household charcoal marketed in Cuiabá (MT), Brazil. Similarly, when studying the household charcoal marketed in Paraná, Brazil, Oliveira et al. 2019 claimed that the highest ED among all the studied brands was 14.94 GJ/m^3.

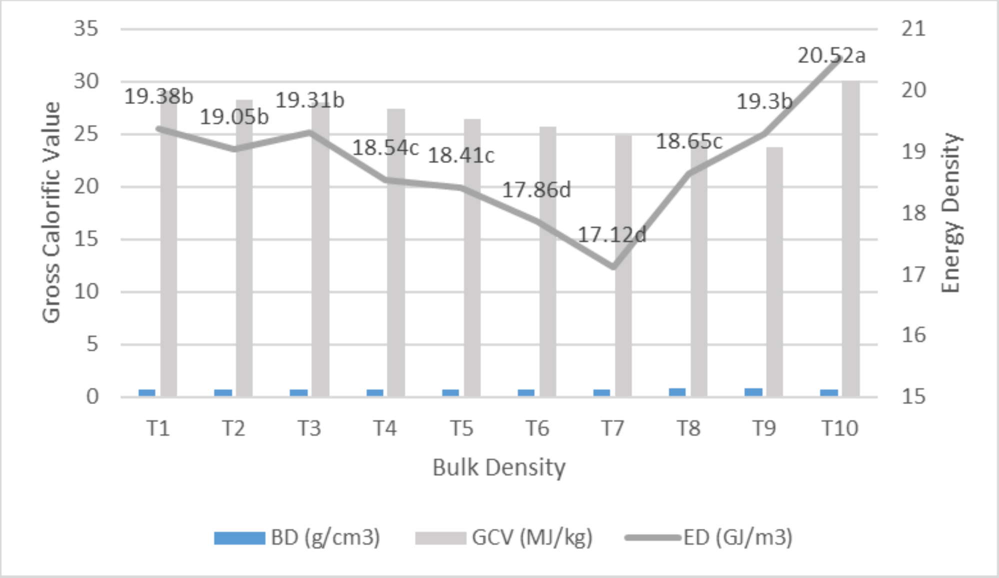
The charcoal produced with briquettes made exclusively from *Pinus* spp. shavings presented the highest gross calorific value (GCV). The increase in the proportion of sludge in the blends caused a sequent reduction in the charcoal's GCV. Values lower than 28.47 MJ represents charcoals with lower quality than those produced from wood, thus presenting low energy potential.

Brand et al. (2015) found an average GCV of 27.00 MJ in wood charcoals marketed in South Brazil, which is lower than the GCVs of treatments T1, T2, T3, and T4. On the other hand, Rosa et al. (2012) presented GCVs between 30.98 MJ and 32.65 MJ when studying wood charcoal samples for household use, and Neves et al. (2011) found a mean GCV of 32.02 MJ in *Eucalyptus* spp. charcoals.

Regarding the energy density (ED), up to 70% of sludge in the blend had an evident influence on the reduction of the charcoal's ED with the increase of sludge proportion in the blend. However, blends containing 90 % of sludge (T9) showed increased EDs, and they were statistically similar to treatments T1, T2, and T3. As shown in Table 6 and Figure 3, the high ED of the treatment T9 was due to the high charcoal's BD. On the other hand, treatments T1, T2, and T3 presented high EDs because of the GCV and not the BD.

Pearson's correlation coefficient (r) may explain why T9 containing 90% of sludge presented an ED similar to treatments containing only up to 30%. The r between the ED and the GCV was 0.56, and between the ED and the BD was 0.19. Both values are low, which represents that the relationship between the variables is not strong.

Figure 3 - Relationship between Gross Calorific Value (GCV), Bulk Density (BD), and Energy Density (ED) of the briquette charcoal



Source: The author (2019).

In the production process, the GY is the leading property. Our results were similar to the ones found in the literature for wood charcoal. The CR is essential in the handling, and, as mentioned before, the charcoal produced with briquettes containing sludge presented adequate numbers. According to Rosa et al. (2012), the quality of the charcoal in its final use is linked to a high ED, low AC, and low VM.

Overall, results did not show a tendency to place only one treatment as the one which presented the best numbers in all the analyzed properties. The treatment T7 presented the best GV on its own. Treatments T1, T2, and T3 had the highest CRs. Treatment T9 showed the lowest VM, followed by T5, T6, T7, and T8, which were all statistically similar. Treatment T1 presented the best percentage of AC. Treatments T9, T1, T2, and T3 showed the highest EDs, all statistically similar.

However, we highlight the treatment T9 as the one that resulted in the charcoal with the best characteristics for energy generation in household barbecue grills. It is among the treatments with the highest EDs, the lowest VM, and, even though it presented a lower GY than the other treatments, the numbers are similar to the ones found in the literature for wood charcoal. Moreover, the charcoals produced with T9 have the highest amount of sludge, and this study aimed to better optimize the use of this residue in charcoal production without harming the quality of the charcoal.

Besides, we would like to highlight that the composition of the sludge from poultry slaughterhouse wastewaters varies and, therefore, each sludge from different slaughterhouses must be tested individually before using it in charcoal production.

1.4 CONCLUSIONS

The different proportions of sludge in the blends used to produce the briquettes influence the charcoal's compressive resistance (CR), bulk density (BD), gross calorific value (GCV), proximate analysis (VM, AC, and FC), and energy density (ED). It does not influence the charcoal's moisture content (MC) and the gravimetric yield (GV), however.

The compressive resistance (CR), the gross calorific value (GCV), the volatile matter (VM), and the fixed carbon content (FC) of the charcoals decreased by increasing the proportion of sludge in the blends. On the other hand, the charcoal's bulk density (BD) increased with the addition of sludge in the blends, also increasing their energy density (ED) and ash content (AC).

Based on the results, considering the energy potential of the charcoal per volume unit, the low volatile matter (VM), and the amount of sludge in the blends, we highlight that the best blend to produce charcoal for household use was the one containing 90% of the sludge and 10% of *Pinus* spp. shavings (T9).

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2 ECONOMIC FEASIBILITY OF THE BARBECUE CHARCOAL PRODUCED FROM BRIQUETTES INCORPORATING SLUDGE FROM POULTRY SLAUGHTERHOUSE WASTEWATER

ABSTRACT

Firewood processing into charcoal and its final use in homes represent 31.1% and 24,7% of the total intake of firewood in Brazil, respectively. Barbecue charcoal represents a significant and robust charcoal market niche in South Brazil. In its production, companies convert timber into charcoal through pyrolysis. However, there are other biomass sources. The water waste from poultry slaughterhouses has increased considerably in recent years due to the growing demand for poultry meat. Slaughterhouses often treat this water, and one of its final forms is the dried sludge, which is a material with potential for energy generation. This study aimed to determine the economic feasibility of barbecue charcoal. We performed the economic analysis based on the results from Chapter 1, which indicated that the charcoal produced with 90% of sludge and 10% of *Pinus* spp. shavings has the best characteristics to market for household use. We evaluated the economic feasibility using the following indicators: Net Present Value (NPV), Internal Rate of Return (IRR), and Cos-Benefit Ratio (C / B). Moreover, we performed the Sensitivity Analysis to verify how sensible the NPV and the IRR are to changes in the sales price and the price of the sludge. Results showed that the project's NPV is positive, the IRR is higher than the MARR, and the B/C ratio is higher than 1. Therefore, it is economically feasible to produce the charcoal. Also, to maintain the project's economic feasibility, the company should not pay more than R$100,00 per ton for the sludge or should not sell the charcoal for less than R$1.58 per kilo, keeping all other variables unchanged.

Keywords: biomass; forest economy, renewable energy; barbecue charcoal.

2.1 INTRODUCTION

Brazil produced 12.86 million tons of chicken meat in 2018, which placed it as the second-largest producer of the world (ABPA, 2019). The production of chicken meat in poultry slaughterhouses increases the number of wastewaters containing a high concentration of pollutants that must be eliminated through high-efficiency treatments to minimize the impacts on the environment.

According to Sena (2009), companies commonly use flotation processes as primary treatments in effluents containing a high load of suspended oils and greases. The solid portion resulting from this process is called floated sludge, which has inherent characteristics to be used as fuel. The floated sludge goes through a drying process, and after that, it is called dried sludge or floated sludge. In this study, we mentioned it as only sludge.

Garcia (2016) states that slaughterhouses generally intend the sludge for disposal or landfill, which culminates in the generation of undesirable residues such as slurry and methane (CH4), polluting the water, the air, and the soil.

In this regard, the increase in the amount of industrial organic wastes has raised awareness and generated new demands on society. There are current social pressures for clean sources of energy. Tolmasquim (2005) claims that this new demand was due to the increase in the number of agriculture wastes and the need to dispose of them correctly, and with economical use. As there is demand, it is highly essential to carry out analyses that show the economic feasibility of these new energy sources.

The United Nations Development Programme (UNDP) launched in December 2015 the Agenda 2030 for Sustainable Development, with 17 Sustainable Development Goals (SDG). UNDP's goal number 7 is directly related to energy: "Ensuring reliable, sustainable, modern, and affordable access to energy for all." (UNDP, 2015, p.15).

Amid this social pressure, we have the biomass. The use of biomass as an energy source is one of the options to mitigate the harmful effects of global warming. Biomass comes from two main routes: energy crops or lignocellulosic residues from agroforestry activities. The second route offers the advantage of appropriately targeting potential pollutants of the environment (PROTASIO, 2012).

One way of turning biomass into energy is through its compaction or densification. Among the different densification processes, we have briquetting. Granada et al. (2002) state that biomass briquetting is a densification process that improves the characteristics of the residual biomass. The process turns the biomass into fuel with higher gross calorific value, lower volatile content, higher fixed carbon content, uniformity in shape and size, lower O / C ratio, and low moisture (PRINS et al., 2006).

According to what we showed in Chapter 1, the briquette market is still not widespread in Brazil. Therefore, a sustainable alternative for the sludge from poultry slaughterhouses is to mix it with *Pinus* spp. shavings to produce briquettes and, afterward, transform them into charcoal through charring. This way, the charcoal becomes a viable source of energy that can be used for cooking and also a sustainable alternative for the sludge.

In 2015, Brazil consumed nearly 6 million tons of charcoal, and it destined 84% of the charcoal for the industrial sector (BRAZIL, 2016). In homes and small commercial applications, the country consumed about 870 thousand tons, which represents 0.14% of the country's total production (BRAZIL, 2016). Moreover, Brazil is responsible for 11% of all the charcoal produced in the world (IBA, 2019).

According to Brand et al. (2017), the use of charcoal in industries for energy purposes is not significant in South Brazil. However, when it comes to domestic use, its application stands out for the preparation of barbecue, considering that this food has great cultural importance for the population of the Southern States. Therefore, this area holds a significant market niche for barbecue charcoal.

Charcoal production depends on the conversion technology, the kind of furnace, the characteristics of the timber used for charring, and the workforce (OLIVEIRA et al., 2017). In this sense, the production of charcoal using a different process, and other biomass sources demands economic studies to support the decision making regarding the structuring of a factory plant.

Guimarães et al. (2007) state that financial and economic analyzes are essential tools as they aid in the decision making of whether an investment is worth it or not. They are indispensable studies for production systems that present technological innovations.

The application of the economic analysis criteria in forestry is substantial in deciding the best project. Some tools are essential when it comes to economic analysis. We highlight the income stream, the minimum acceptable rate of return (MARR), the net present value (NPV), the internal rate of return (IRR), the cost/benefit ratio (B / C), and the sensitivity analysis. They compare the costs and revenues inherent to a project in order to verify its economic feasibility.

The project that presents NPV higher than zero (positive) is economically viable. However, the one that presents the highest NPV is the best, considering the same Planning Horizon. The Internal Rate of Return (IRR) equals NPV to zero. It provides the rate of the real return on investment, and, for that reason, it is considered the internal rate of the enterprise. A project is feasible when the IRR is higher than the Minimum Acceptable Rate of Return (MARR) (SILVA & FONTES, 2005).

Moreover, the Cost-benefit Ratio (B / C) consists of a criterion that establishes the relationship between the current value of revenues and the current value of costs. When the ratio B / C > 1, the NPV is higher than zero, and the IRR is higher than the project rate (RESENDE & OLIVEIRA, 2008).

Lima Junior et al. (2007) claims that the Brazilian forest literature uses real interest rates between 6 and 12% per year. The choice seems to be random and based only on the fact that it is a tradition in the forest sector to use interest rates in this range. It is always challenging to determine the interest rate since it varies according to the characteristics of the project, the company, the economic situation, among others.

When analyzing the economic variability of a project, the investor in the forestry sector cannot be guided by the current market's interest rates, which may be reflecting, among other reasons, only a short-term government policy (LIMA JUNIOR et al., 1997).

Given the above, this study aimed to verify the economic feasibility of the production of barbecue charcoal produced with briquettes incorporating sludge from poultry slaughterhouse wastewater and *Pinus* spp. shavings. We carried out the study according to the results obtained from Chapter 1, which indicated the best percentage of each residue in the blend used for briquetting.

2.2 MATERIALS AND METHODS

We planned a factory supposedly located in Lages, Santa Catarina, Brazil, in a facility rented in the city’s industrial area, and it has started operating in January 2020. The production process involves turning the raw materials into charcoal to market in packages for household use. Therefore, the plant includes a briquette machine, furnaces, and a packaging machine. Also, we considered that the sources of both materials are located in Lages.

According to Chapter 1, we produced the briquettes using 90% of sludge and 10% of *Pinus* spp. shavings. Then, the process consists of mixing the raw materials, densifying them into briquettes, turning briquettes into charcoal by pyrolysis, and packing the charcoal to market.

The briquette machine can produce 1 ton per hour, and we assumed that it is going to operate 8 hours a day / 6 days a week. The furnaces' volume is 14.4 m^3, around 12 m^3st of firewood, and it takes each furnace seven days to complete the carbonization process.

To project the investment costs, we estimated the price of the needed items in specialized stores in the region in 2019. They were a briquette machine, three furnaces, one packaging machine, one forklift, forty big bags, one hundred wooden pallets, personal protective equipment (PPE) for seven employees, one car, and office furniture. The office furniture included one desk, three chairs, one desktop computer with a printer, and a cabinet. Also, we estimated the costs to build the furnaces, to open the business, and to improve the facilities to set the machines.

Also, we added a tractor. The tractor's price of purchase and annual maintenance are the same presented by the Santa Catarina Rural Extension and Agricultural Research Enterprise (EPAGRI, 2019).

Similarly, we projected the variable and fixed annual costs considering a planning horizon (PH) of five years. They include wooden pallets, PPE, rent, both raw materials including ground transportation (sludge and *Pinus* spp. shavings), labor, tractor maintenance, other machines maintenance, depreciation, insurance, fuel, internet, telephone, electricity, water, packages for delivery, and administrative costs.

We considered the annual cost with PPE as 30% of the investment cost (considering their lifespan), the administrative annual cost as 10% of the total annual cost, and depreciation as 10% of the total annual cost - as established by the Department of Federal Revenue of Brazil. As suggested by Filippetto et al. (2008), we estimated the annual insurance as 1% of the total annual cost, and the maintenance of the briquette machine, the furnaces, and the packaging machine, as 5% of the investment cost of each machine.

After computing all costs, we projected the revenues by using the production schedule presented in Table 7 for January 2020 and forecasted it along the planning horizon, considering a sales price of R$2.13 per kilo.

Table 7 - Production schedule considering the month of January 2020.

		Loading			Burning	Cooling	Unloading	
Week	**Furnace**	**Day**	**Volume (m^3)**	**Briquette Stock (ton)**	**Days**	**Days**	**Day**	**Charcoal (ton)**
1	1	Wed	14.4	X	Thu-Sat	Sun-Tue	Wed	4.32
	2	Fri	14.4	1.6	Sat-Mon	Tue-Thu	Fri	4.32
	3	Sat	14.4	3.2	Sun-Tue	Wed-Fri	Sat	4.32
2	1	Wed	14.4	4.8	Thu-Sat	Sun-Tue	Wed	4.32
	2	Fri	14.4	6.4	Sat-Mon	Tue-Thu	Fri	4.32
	3	Sat	14.4	8	Sun-Tue	Wed-Fri	Sat	4.32
3	1	Wed	14.4	9.6	Thu-Sat	Sun-Tue	Wed	4.32
	2	Fri	14.4	11.2	Sat-Mon	Tue-Thu	Fri	4.32
	3	Sat	14.4	12.8	Sun-Tue	Wed-Fri	Sat	4.32
4	1	Wed	14.4	14.4	Thu-Sat	Sun-Tue	Wed	4.32
	2	Fri	14.4	16	Sat-Mon	Tue-Thu	Fri	4.32
	3	Sat	14.4	17.6	Sun-Tue	Wed-Fri	Sat	4.32
Total								**51.84**

Next, we build the cash flow to calculate the following economic indicators: Net Present Value (NPV), Internal Rate of Return (IRR), Cost-Benefit Ratio (B / C), and Sensitivity Analysis.

To that end, we have defined a minimum acceptable rate of return (MARR) of 6%, which is higher than the SELIC rate established by the Central Bank of Brazil for December 2019 (4,5%). Choosing the MARR is hard because many factors can directly affect it, as inflation, risk, the planning horizon, etc. According to Lima et al. (1997), the MARR traditionally used in forestry projects vary from 6% to 12% a year.

2.2.1 Net Present Value (NPV)

We obtained the NPV using the algebraic sum of the values, discounted from the cash flow and according to the minimum acceptable rate of return (MARR) adopted, according to equation 2 (RESENDE &OLIVEIRA, 2008):

$$\mathrm{NPV} = \sum_{j=1}^{n} \frac{R_j}{(1+i)^j} - \sum_{j=1}^{n} \frac{C_j}{(1+i)^j}$$

Equation 2

In which: NPV = net present value;

Rj = present value of revenues;

Cj = present value of costs;

i = interest rate;

j = period in which the revenues and costs occur; and

n = number of periods or project duration.

2.2.2 Internal Rate of Return (IRR)

The IRR is the result of the equation 3 (RESENDE & OLIVEIRA, 2008):

$$\sum_{j=1}^{n} R_j (1+IRR)^{-j} - \sum_{j=1}^{n} C_j (1+IRR)^{-j} = 0$$

Equation 3

In which: IRR = internal rate of return;

Rj = present value of revenues;

Cj = present value of costs;

i = interest rate;

j = period in which the revenues or costs occur; and

n = number of periods or project duration.

2.2.3 Cost-Benefit Analysis (B/C)

We performed the Cost-Benefit analysis using equation 4 (RESENDE &OLIVEIRA, 2008):

$$B/C = \frac{\sum_{j-0}^{n} Rj\,(1+i)^{-j}}{\sum_{j-0}^{n} Cj\,(1+i)^{-j}}$$

Equation 4

In which: B/C = cost-benefit ratio;

Rj = present value of revenues;

Cj = present value of costs;

i = interest rate;

j = period in which the revenues or costs occur; and

n = number of periods or project duration.

2.2.4 Sensibility Analysis

Finally, we performed the sensitivity analysis in order to verify the feasibility of the project considering changes in the price of the sludge and the charcoal's sales price. To that end, we used prices of the sludge varying from R$ 0.00 to R$ 130.00 per ton and sales prices from R$ 1.38 to R$ 2.13 per kilogram and projected them to forecast Net Present Value (NPV) and Internal Rate of Return (IRR) values.

2.3 RESULTS AND DISCUSSION

Table 8 presents the estimated investment costs, along with the estimated variable and fixed annual costs during the planning horizon.

Table 8 – Estimated investment costs and estimated variable and fixes annual costs.[1]

Description	**Year**	**Price (R$)**	**Number**	**Annual Price (R$)**
Briquette machine	0	310,000.00	1	310,000.00
Furnaces	0	29,612.00	3	88,836.00
Build furnaces	0	7,000.00	1	7,000.00
Packaging machine	0	45,000.00	1	45,000.00
Tractor	0	120,117.96	1	120,117.96
Forklift	0	50,000.00	1	50,000.00
Big Bags	0	400.00	40	16,000.00
Wooden pallets	0	29.50	100	2,950.00
PPE	0	334.20	7	2,339.40
Hand tools	0	2,000.00	1	2,000.00
Improvement of the facilities	0	20,000.00	1	20,000.00
Opening of the company	0	1,600.00	1	1,600.00
Office furniture	0	5,046.00	1	5,046.00
Car	0	30,000.00	100%	30,000.00
Total Investment				**700,889.36**

Note: PPE = Personal Protective Equipment.

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[1] To be continued.

Table 9 – Estimated investment costs and estimated variable and fixes annual costs.

Description	**Year**	**Price (R$)**	**Number**	**Annual Price (R$)**
Wooden pallets	1 a 5	29.50	200	5,900.00
PPE	2 a 5	2,339.40	30%	701.82
Rent	1 a 5	60,000.00	1	60,000.00
Sludge	1 a 5	0.00	1	0.00
Pinus spp. shavings	1 a 5	25,454.00	1	25,454.00
Labor	1 a 5	20,338.16	7	142,367.12
Tractor maintenance	1 a 5	24,966.83	1	24,966.83
Other machines maintenance	1 a 5	434,612.00	5%	21,730.60
Depreciation	1 a 5	554,729.96	10%	27,736.50
Insurance	1 a 5	700,889.36	1%	7,008.89
Fuel	1 a 5	46,024.89	1	46,024.89
Internet + Phone	1 a 5	3,850.00	1	3,850.00
Electricity + Water	1 a 5	49,896.07	1	49,896.07
Packages for delivery	1 a 5	22,000.00	1	22,000.00
Administrative costs	1 a 5	437,636.72	10%	43,763.67
Annual costs				**481,400.39**

Note: PPE = Personal Protective Equipment.

The results showed a total investment cost of R$ 700,889.36. It is a high investment when we compare it with the investment needed to open a charcoal or briquette production plant. Belchior et al. (2017) stated that the investment to open a charcoal factory using three different procedures in Nioaque, Mato Grosso do Sul, Brazil, was R$451,600.00. Also, Silveira & Lopes (2011) estimated an investment cost of around R$400,000.00 to open a briquette factory that uses industry residues as raw materials in Pelotas, Rio Grande do Sul, Brazil. Although our investment is higher than the ones above, these authors did not consider the product's packaging and delivery, and their production process is more straightforward than ours.

Annual costs of R$481,400.39 were among the expected. We highlight the fixed costs with labor and rent as the most expensive costs over the years. Although the sludge has no cost, we considered it as an annual variable cost because the supplier may charge it if the charcoal presents good profits. The cost of the sludge can influence the project's feasibility and, therefore, we used it in the sensitivity analysis. Nevertheless, we did not include the tax costs in Table 8.

The Brazilian government has created a program named "Simples Nacional", which gathers most of the taxes on sales (e.g., IRPJ, CSLL, COFINS, PIS/PASEP, CPP, IPI, and ICMS) in one principal value and categorizes companies based on their income and size. According to the Complementary Law 155 from 2016 (BRASIL, 2016), a small size company is a company that its gross income is over R$360,000.00 or lower than R$4,800,000.00, which features the charcoal factory under study. Small size companies must pay 11.20% of the sales in taxes.

As shown in Table 7, the plant can produce 51.84 tons of charcoal a month (5,184.00 kilograms). Considering that the product is going to be marketed throughout the year (12 months), and the average sales price of the charcoal in the studied region is R$2.32 per kilogram, we estimated the possible annual income to be R$ 1,325,030.40.

We have considered that the income is going to increase over the planning horizon, starting at 40% of the total capacity in the first year, 60% in the second year, 80% in the third year, and 100% in the last two years, as presented in Tables 9 and 10 along with the respective estimated yearly tax costs and economic indicators.

Table 10 - Tax costs along the planning horizon.

Year	**Possible Income**	**Sales (%)**	**Taxes (%)**	**Tax Costs**
1	1,325,030.40	40	11.2	59,361.36
2	1,325,030.40	60	11.2	89,042.04
3	1,325,030.40	80	11.2	118,722.72
4	1,325,030.40	100	11.2	148,403.40
5	1,325,030.40	100	11.2	148,403.40

Table 11 - Cash flow with the NPV, TIR, and B/C of the project.

Year	**Cost (R$)**	**Income (R$)**	**Flow (R$)**
0	700,889.36	0.00	-700,889.36
1	540,761.76	530,012.16	-10,749.60
2	570,442.44	795,018.24	224,575.80
3	600,123.12	1,060,024.32	459,901.20
4	629,803.80	1,325,030.40	695,226.60
5	629,803.80	1,325,030.40	695,226.60
NPV			945,181.44
IRR			33%
B/C			1.30

Results show that the project is feasible under the assessed conditions as the NPV was positive (R$945,181.44), the IRR (33%) was higher than the MARR (6%), and the

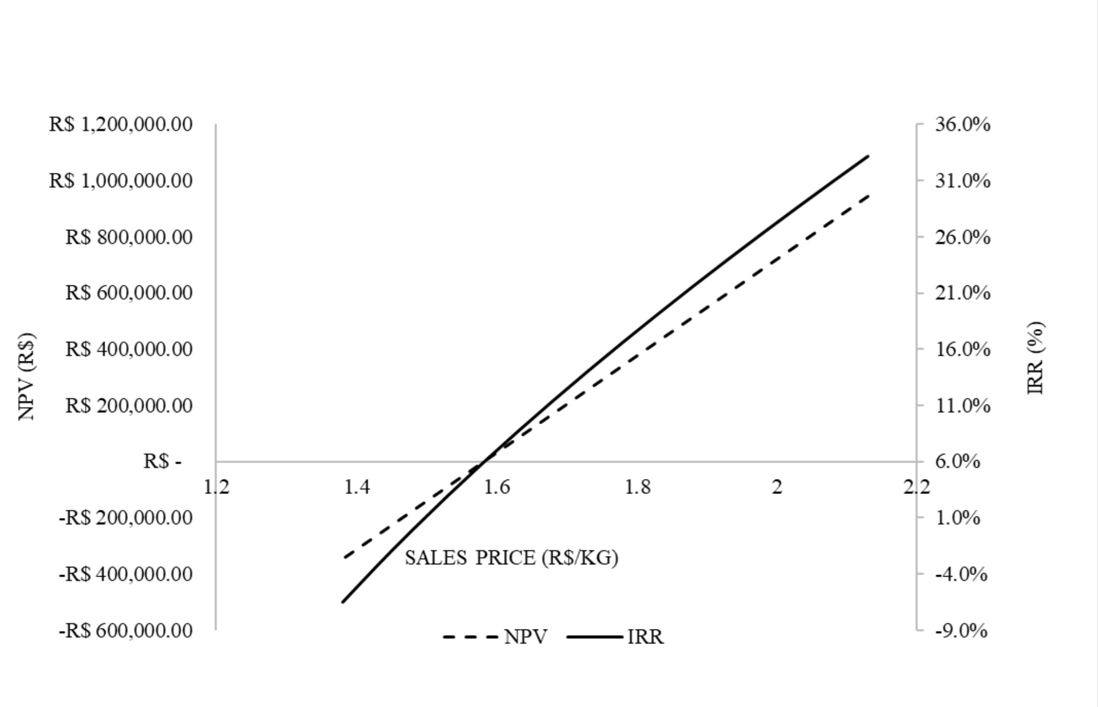
B/C (1.30) was higher than one. The IRR was higher than the MARR, which indicates the profitability of the investment, and the B/C ratio indicates that the revenues were 30% higher than the costs in the planning horizon.

Even though there are several studies in the literature regarding the economic feasibility of forestry projects, it is doubtful to directly compare their results to ours. Our plant is unique, and it involves a process that no one has studied before, different from the regular charcoal and briquette production processes.

However, Silva et al. (2014) presented an NPV of R$1,266,432.83, an IRR of 31.79%, and a B/C ratio of 1.15 when studying thee different charcoal production systems using the same furnaces in this study but considering a MARR of 15%. When analyzing the economic feasibility of charcoal production in Mato Grosso do Sul, Brazil, Belchior et al. (2017) found indicators lower than the ones in this study. They presented an NPV of 175.687,64, an IRR of 22%, and a B/C ratio of 1.06 using the same MARR (6%). Also, De Castro et al. (2007) presented an NPV of R$1.814,10, an IRR of 11.95%, and a B/C ratio of 1.13 when studying the risk and economic profitability of using planted forests for charcoal production in Minas Gerais, Brazil.

Figure 4 shows the sensitivity analysis regarding the influence of the changes in the sales price on the project’s NPV and IRR.

Figure 4 - Influence of the sales price on the project’s NPV and IRR



Source: The author (2019).

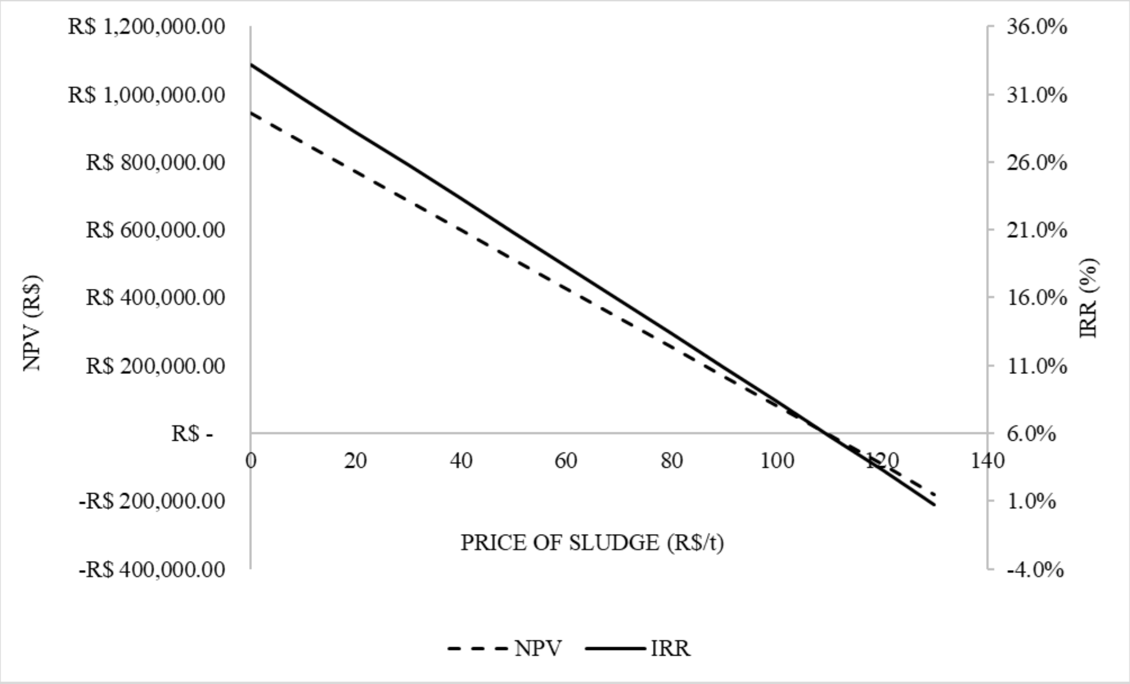
The project's output variable NPV is positive only if the sales price remains above R$1,58 per kilogram, considering that the other variables remain the same. When the sales price reaches R$1.58, the NPV becomes -R$3,479.32.

The sales price is one of the most critical variables in the economic feasibility analysis of a project. As the price of a product depends on different elements, and it changes continuously, the pricing should be dynamic so that it can bear the changes over time (SINGH, 2012). Besides, if there is a change in other cost variables, the price of a product may vary. Singh (2012) claims that an important factor in pricing is deciding the cost of the product, strategy for marketing, and its expenses related to distribution, advertisement, or any kind of price variation in the market.

Similarly, the IRR is only equal or higher than the MARR (6%) if the sales price remains above R$1.58 per kilogram. At R$1.58, the IRR reaches 5,88%, which would not represent the expected economic return.

Figures 5 present the sensitivity analysis regarding the influence of the changes in the price of the sludge on the project's NPV and IRR, considering that all other variables remain the same.

Figure 5 - Influence of the price of the sludge on the project's NPV and IRR



Source: The author (2019).

The NPV is very sensible to the price of sludge. In case the sludge needs to be purchased, its price per ton, including transportation, must not be more than R$100. At R$109,30 the NPV is zero and the IRR lower than 6%.

Also, the price of sludge strongly affects the project's IRR. It should not cost more than R$100,00 per ton, including transportation, to obtain an IRR of 6% or higher. If the price reaches R$110,00, the IRR becomes lower than the MARR (5,82%), indicating that the project is not economically feasible.

Although the indicators showed that the project is feasible, the decision-making process regarding investment is dynamic, and it needs to rely on as many tools as possible to reduce risk. We strongly advise that further studies should be carried out to verify potential risks and to study the targeted market.

2.4 CONCLUSIONS

The project’s NPV is positive, the IRR is higher than the MARR, and the B/C ratio is higher than 1. Therefore, it is economically feasible to produce charcoal for household use by using briquettes incorporating 90% of sludge from poultry slaughterhouse wastewater and 10% of *Pinus* spp. shavings.

The NPV and the IRR are highly sensitive to changes in the charcoal's sales price. They become negative if it goes lower than R$1.58 per kilogram. Moreover, the cost to purchase the sludge also affects the project's NPV and IRR. If the supplier charges the sludge, the company should not pay more than R$ 100,00 per ton, including transportation. Therefore, to maintain the project’s economic feasibility, the company should not pay more than R$100,00 for the sludge or should not sell the charcoal for less than R$1.58 per kilo, keeping all other variables unchanged.

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FINAL CONCLUSIONS

Overall, Chapter 1 shows that it is technically feasible to produce the briquette charcoal. Although we highlight that the best blend is the one containing 90% of sludge and 10% of *Pinus* spp. shavings (T9), it is possible to produce charcoal from the other blends. However, we highly recommend that elemental analyses must be carried out in the sludge from each slaughterhouse or source of sludge, as different chemicals may appear in the sludge.

Chapter 2 shows that it is also economically feasible to produce this charcoal for household use by using briquettes incorporating 90% of sludge from poultry slaughterhouse wastewater and 10% of *Pinus* spp. shavings. The project's NPV is positive, the IRR is higher than the MARR, and the B/C ratio is higher than 1.

The NPV and the IRR are highly sensitive to changes in the charcoal's sales price. They become negative if it goes lower than R$1.58 per kilogram. Moreover, the cost to purchase the sludge also affects the project's NPV and IRR. If the supplier charges the sludge, the company should not pay more than R$ 100,00 per ton, including transportation. Therefore, to maintain the project's economic feasibility, the company should not pay more than R$100,00 for the sludge or should not sell the charcoal for less than R$1.58 per kilo, keeping all other variables unchanged.

We suggest that further studies should be carried out to verify potential risks and to study the targeted market as the decision-making process regarding an investment is dynamic, and it needs to rely on as many tools as possible to reduce risk.

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