BRUNO LEÃO SAID SCHETTINI

FURNACE-KILN SYSTEM CARBON BALANCE AND ECONOMIC VIABILITY FOR CHARCOAL PRODUCTION ON SMALL FARM

Thesis submitted to the Forest Science Graduate Program of the Universidade Federal de Viçosa in partial fulfillment on the requirements for the degree of *Doctor Scientiae*.

Adviser: Laércio Antônio Gonçalves Jacovine

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BIOGRAPHY

BRUNO LEÃO SAID SCHETTINI, son of Cláudio Márcio Said Schettini and Cândida Muniz Leão Said Schettini, was born on May 14, 1990, in the city of Formiga, Minas Gerais.

In 2007, he completed high school at Colégio Cooperativa Educacional de Iguatama, in Iguatama, Minas Gerais.

In 2009, he joined the Forest Engineering Course at the Federal University of Viçosa (UFV), in Viçosa, Minas Gerais, completing it in January 2015.

In March 2015, he joined the Postgraduate Program in Forest Science at UFV, at the Master's level, becoming a master in February 2017.

In March 2017, he joined the Postgraduate Program in Forest Science at UFV, at the Doctoral level, submitting to the defense of his dissertation in June 20

ABSTRACT

SCHETTINI, Bruno Leão Said, D.Sc, Universidade Federal de Viçosa, June 2021. **Furnace-kiln system carbon balance and economic viability for charcoal production on small farm.** Advisor: Laércio Antônio Gonçalves Jacovine. Co-advisors: Angélica de Cássia Oliveira Carneiro and Carlos Moreira Miquelino Eleto Torres.

Small rural producers are responsible for approximately 60% of the country's charcoal production, in a carbonization process that occurs mostly in rudimentary masonry ovens, of the "hot tail" type, slope and surface, with low gravimetric yield (RG) and no control over Greenhouse Gas (GHG) emissions. The furnace kiln system allows the burning of Methane (CH4), with an innovative layout that has a chimney centered with 4 furnaces, and which allows an increase in RG when compared to traditional furnaces. In this context, the work was divided into three chapters and conducted in a rural property that produces charcoal in Lamim-MG. In chapter 1, the objective was to evaluate the carbon balance with and without the use of the furnace-furnace system for burning methane. The average annual increase in carbon (IMAC) was calculated based on two forest inventories, conducted in 2018 and 2019. GHG emissions from Eucalyptus were calculated based on the IPCC Guidelines for National Greenhouse Gas Inventories. The carbon balance without methane burning was 13.9465 $MgCO_{2e}$ ha^{-1} and with burning 15.9616 $MgCO_{2e}$ ha^{-1}. The GHG emission per unit produced was 0.6105 $MgCO_{2e}$ Mg $charcoal^{-1}$ with the burning of CH4 and 1.2433 $MgCO_{2e}$ Mg $charcoal^{-1}$ without burning GHG. In chapter 2, the objective was to compare the use of destructive and non-destructive methodologies to estimate biomass and carbon in a Eucalyptus forest. Rigorous cubing was performed on 21 trees and 3 compared methodologies. In methodology 1, control, the tree was felled, sectioned, weighed in the field and the carbon stock calculated based on these data. Methodology 2 is also destructive, with the tree felled, cubed and the estimated volume based on this data. Methodology 3 is non-destructive, with the cubed tree standing upright with the aid of equipment, pentaprism, and the estimated volume based on these data. It was concluded that the evaluated non-destructive and destructive methodologies are effective, with results equal to the control, which reduces time and cost in surveys to estimate biomass and carbon. Chapter 3 evaluated the economic feasibility of producing wood and charcoal, and how the variation in costs and revenues can impact this result, through sensitivity analysis using the Monte Carlo technique. The wood production was economically viable, with a NPV of R$212.68 ha^{-1} and a VPE of R$88.74 ha^{-1} with an average production cost of R$71.37 m3 wood-1. The mean value of VPE found in the sensitivity analysis was R$ 96.82 ha^{-1}. The production of charcoal was economically viable, with NPV of R$23.41 mdc $charcoal^{-1}$ and VPE of R$18.57 mdc $charcoal^{-1}$. The average value of the VPE found in the risk analysis was R$51.78 mdc $charcoal^{-1}$. It was possible to conclude that the production of eucalyptus wood and charcoal is economically viable in the region.

Keywords: Forest Biomass. Charcoal. Sustainable Steel Industry.

RESUMO

SCHETTINI, Bruno Leão Said, D.Sc, Universidade Federal de Viçosa, junho de 2021. **Furnace-kiln system carbon balance and economic viability for charcoal production on small farm.** Orientador: Laércio Antônio Gonçalves Jacovine. Coorientadores: Angélica de Cássia Oliveira Carneiro e Carlos Moreira Miquelino Eleto Torres.

Os pequenos produtores rurais são responsáveis por aproximadamente 60% da produção de carvão vegetal no país, em um processo de carbonização que ocorre, em sua maioria, em fornos rudimentares de alvenaria, do tipo “rabo-quente”, encosta e de superfície, com baixo rendimento gravimétrico (RG) e sem controle nas emissões de Gases de Efeito Estufa (GEE). O sistema forno fornalha que permite a queima de Metano (CH_4), com um layout inovador que possui uma chaminé centralizada a 4 fornos, e que permite o aumento do RG quando comparado com os fornos tradicionais. Nesse contexto, o trabalho foi dividido em três capítulos e conduzidos em uma propriedade rural produtora de carvão vegetal em Lamim-MG. No capítulo 1, o objetivo foi avaliar o balanço de carbono com e sem o uso do sistema forno-fornalha para queima do metano. O incremento médio anual em carbono (IMAC) foi calculado baseado em dois inventários florestais, conduzidos em 2018 e 2019. As emissões de GEE referentes ao Eucalipto foram calculadas baseadas no IPCC *Guidelines for National Greenhouse Gas Inventories*. O balanço de carbono sem a queima de metano foi de 13,9465 $MgCO_{2e}$ ha^{-1} e com a queima de 15,9616 $MgCO_{2e}$ ha^{-1}. A emissão de GEE por unidade produzida foi de 0,6105 $MgCO_{2e}$ Mg carvão $vegetal^{-1}$ com a queima de CH_4 e 1,2433 $MgCO_{2e}$ Mg carvão $vegetal^{-1}$ sem a queima de GEE. No capítulo 2, o objetivo foi comparar o uso de metodologias destrutivas e não destrutivas para estimativa de biomassa e carbono em uma floresta de Eucalipto. A cubagem rigorosa foi realizada em 21 árvores e 3 metodologias comparadas. A metodologia 1, testemunha, a árvore foi abatida, seccionada, pesada no campo e o estoque de carbono calculado baseado nesses dados. A metodologia 2 também é destrutiva, com a árvore abatida, cubada e o volume estimado baseado nesses dados. A metodologia 3 é não destrutiva, com a árvore cubada em pé com o auxílio de um equipamento, pentaprisma, e o volume estimado baseado nesses dados. Concluiu-se que as metodologias não destrutivas e destrutivas avaliadas são eficazes, com resultados iguais à testemunha, o que traz redução no tempo e custo em levantamentos para estimativa de biomassa e carbono. O capítulo 3 foi avaliada a viabilidade econômica da produção de madeira e carvão vegetal, e como a variação nos custos e receitas podem impactar esse resultado, por meio da análise de sensibilidade utilizando a técnica de Monte Carlo. A produção de madeira foi viável economicamente, com VPL de R$212,68 ha^{-1} e VPE de R$88,74 ha^{-1} com custo médio de produção de R$71,37 m^{3} madeira^{-1}. O valor médio do VPE encontrado na análise de sensibilidade foi de R$ 96,82 ha^{-1}. A produção de carvão vegetal foi viável economicamente, com VPL de R$23,41 mdc carvão vegetal^{-1} e VPE de R$18,57 mdc carvão vegetal^{-1}. O valor médio do VPE encontrado na análise de risco foi de R$51,78 mdc carvão vegetal^{-1}. Foi possível concluir que a produção de madeira de eucalipto e de carvão vegetal é viável economicamente na região.

Palavras-Chave: Biomassa Florestal. Carvão Vegetal. Siderurgia Sustentável.

SUMMARY

GENERAL INTRODUCTION

Brazil stands out worldwide as the largest producer and consumer of charcoal for industrial purposes, as it is used as a thermo-reducer in approximately 84% of its production destined for the pig iron and ferroalloy sectors and the rest consumed by others industries and domestically (EPE, 2015). Brazilian production is mostly carried out in rudimentary masonry kilns, with low gravimetric yield and without temperature control, which results in negative social, environmental and economic impacts.The Brazilian production takes place in 70% with the use of hot tail and surface kilns, which are used by small and medium producers, 20% in rectangular kilns, technology used in large companies, and the rest by new technologies (Carneiro et al., 2013).

Replacing these rudimentary systems with more technological ones is a challenge in the sector, as they require greater investments, which increases carbonization costs, and may inhibit their adoption by small and medium producers (Vilela et al., 2014; Ribeiro et al., 2020). Among these new technologies there is the use of a furnace coupled to the furnace that allows the burning of methane in the carbonization process.

The adoption of this layout by small rural producers is important, as it allows for the improvement of environmental and working conditions, as it avoids exposing the carbonizer to smoke, since temperature control is done by pyrometry, and not empirically (smoke color), in addition to respecting the tripod of sustainability, with economic, environmental and social benefits.To address the aforementioned issues, the government of State of Minas Gerais, through the Normative Deliberation COPAM nº227 (COPAM, 2018) established procedures for reducing GHG emissions over charcoal production from eucalpytus and for assessing the quality of the air in its surroundings. The normative decision applies to all producers with a capacity greater than 50 thousand mdc charcoal year^{-1}.

To reduce atmospheric emissions in the charcoal production process, the United Nations Development Program (UNDP) implemented the Sustainable Steelmaking Project, which encourages innovative and more efficient technologies, productive arrangements for the production of this input from planted forests, and its consumption by the steel industry (UN, 2018). Thus, in the thesis first chapter, we evaluated the carbon balance in a charcoal-producing rural property, with and without the use of a gas burner.Producing accurate forecasts of forest biomass is a challenge for several reasons, a forest inventory project with accurate measurements of tree attributes is required and requires that biomass models be representative of the forest inventory data to which the model is applied (Dutcâ et al., 2020). The methodologies usually used are defined as destructive, where trees of a plot or diameter classes are felled and measured (Singh et al., 2011) and non-destructive, in which it is not necessary to slaughter the plants (López-López et al., 2017). Non-destructive methodologies for biomass estimation are faster, cheaper and avoid environmental problems arising from the felling of trees (Mòntes, 2009).

Forest biomass studies are carried out for different purposes, including: knowing the energy potential of the forest, quantification of nutrient cycling, (Silveira et al., 2008), tree growth monitoring (Zhao et al., 2018) and carbon storage potential (Chieppa et al., 2020). Destructive sampling, due to its higher cost, is limited by capital, labor and logistics. Samples may be under-represented in areas of irregular topography and unfavorable weather conditions (Picard et al., 2012). In the second chapter, in this context, we assess the possible differences between destructive and non-destructive methodologies for estimating biomass accumulation and carbon stock.

Economic analyzes are important as they assist in investment decision making, and studies in this line of knowledge are essential, especially for production systems that present technological innovations. In addition to technical, social and environmental issues, the economic issue must be considered when investing in a particular technology is desired, and it must be established which option is available with greater profitability for the producer. Thus, in chapter 3, we assess the economic feasibility of producing wood and charcoal using the furnace-kiln system.

The United Nations (UN), together with its partners, established the 17 goals for sustainable development, which address the main development challenges faced by people in Brazil and around the world. The Sustainable Development Goals are a global call to action to end poverty, protect the environment and the climate, and ensure that people everywhere can enjoy peace and prosperity. Studies related to climate change contemplate goal 13 (action against climate change), which further emphasizes its importance (UN, 2021).

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CHAPTER 1

Furnace-Kiln System: How does the use of new technologies in charcoal production affect the carbon balance?

Abstract: Most of the Brazilian charcoal is produced in rudimentary kilns without greenhouse gas emissions (GHG) control. The furnace-kiln system, which allows the burning of methane (CH_4), stands out in this context. Thus, the goal of this study was to evaluate the carbon balance in the charcoal production with and without the use of the furnace-kiln system. The study was conducted in a farm in Lamim, State of Minas Gerais - Brazil. The average annual carbon increment (AACI) was calculated based on two forest inventories, one conducted in 2018 and another in 2019. The GHG emissions related to the eucalyptus forest were calculated based on the Intergovernmental Panel on Climate Change *Guidelines for National Greenhouse Gas Inventories*. The collection and quantification of gases emitted during the wood carbonization were carried out using a gas analyzer. The annual carbon balance was calculated using the AACI of the eucalyptus forest, the farm annual emissions, and the charcoal production emissions with and without methane burning. The farm carbon balance without methane burning was 13.9465 $MgCO_{2eq}$ ha^{-1} and with methane burning was 15.9616 $MgCO_{2eq}$ ha^{-1}. The GHG emission per unit produced was 0.6105 $MgCO_{2eq}$ Mg $charcoal^{-1}$ with methane burning and 1.2433 $MgCO_{2e}$ Mg $charcoal^{-1}$ without methane burning. Thus, the replacement of traditional kilns by the furnace-kiln system was shown to be effective to reduce the emissions established in the Paris Agreement in the Brazilian steel sector as the emission reduction capacity was of 40.26%.

Keywords: Low carbon economy, Paris Agreement, sustainable steel industry.

INTRODUCTION

The Brazilian steel industry, differently of rest of the planet, uses charcoal instead of coke in the process of reducing iron for pig iron production, in blast furnaces (Rodrigues and Junior, 2019). The growing demand for Brazilian steel will bring economic benefits to the country, however, despite having a more sustainable production, the increase in greenhouse gas emissions (GHG) emissions in the sector is predicted (Souza and Pacca, 2021), which makes the scenario challenging from an environmental point of view.

Brazil has 9.0 million hectares of reforestation, which are responsible for 91% of all wood consumed for industrial purposes, contributing 1.2% of the country's gross domestic product, in addition to being one of the segments with the greatest potential for contribution to the development of a green economy (IBÁ, 2020). Of these 9.0 million hectares, 12% are destined for the charcoal-based steel industry, obtained from areas that are fully reforested with seminal species and hybrids of *Eucalyptus* sp. Due to the good adaptation of Eucalyptus in the country and technological innovations for the development of the crop, in 2019, Brazil led the global ranking of forest productivity, with an average of 35.3 m^3 ha $year^{-1}$. Eucalyptus plantations occupy 6.97 million hectares of planted forest area and are located mainly in Minas Gerais (27.5%), due to the state's steelmaking vocation (IBÁ, 2020).

The brazilian charcoal consumption in 2019 was 5.1 million tons and the sector continues to develop to promote the continuous growth of forestry activity (IBÁ, 2020). Currently, most of the 180 steel and metallurgical industries use charcoal to produce pig iron, ferroalloys and steel in Brazil.In the state of Minas Gerais, the largest consumer of charcoal, due to steel mills, there was a 7.96% increase in charcoal consumption in 2019, totaling 11.2 million meters of charcoal (SINDIFER, 2020).

In 2019, Brazil produced approximately 30.9 million tons of pig iron, 22.5% of which using charcoal as a bio-reducer (SINDIFER, 2020). The integrated plants, producers of pig iron and steel, produced, on average, 2.33 million tons of pig iron using charcoal as a bio-reducer of iron ore, however, the independent plants are the largest consumers, producing 4.62 million tons of charcoal-fired pig iron.

The Brazilian government has signed the Paris Agreement and in the nationally determined contribution (NDC) there are incentives to increase the use of charcoal in the steel industry, as it is one of the solutions for mitigating GHG emissions in the industry. To reduce atmospheric emissions in the charcoal production process, the United Nations Development Program (UNDP) implemented the "Programa Siderurgia Sustentável", which encourages innovative technologies and more efficient production arrangements for the production of charcoal from eucalyptus (UN, 2018).

Improving the production conditions, in most cases, implies in increasing production costs, which can often make the use of new technologies unfeasible for rural producers. In addition, the sector already faces difficulties such as market price fluctuation, low productivity, and lack of qualified labor (Simioni et al., 2017; Silva et al., 2020). However, the problems related to charcoal production are mainly linked to the technology used thatdirectly and/or indirectly affects the environment (Squalli, 2017), as most of the charcoal produced in Brazil comes from rudimentary kilns, which are used by small and medium producers. These kilns are characterized by the absence of process control and low technological degree used in their construction, which results in low performance and large atmospheric emissions, causing serious economic, social, and environmental impacts (Pinto et al., 2018).

To address the aforementioned issues, the government of State of Minas Gerais, through the Normative Deliberation COPAM nº227 (COPAM, 2018) established procedures for reducing GHG emissions over charcoal production from eucalpytus and for assessing the quality of the air in its surroundings. The normative decision applies to all producers with a capacity greater than 50 thousand mdc charcoal year^{-1}.

These regulations encourage the adoption of good practices in the charcoal production, such as process control and reduction of the wood moisture to be carbonized. In addition, if these are not sufficient to comply with the maximum emission factor established, the adoption of technologies, such as GHG burners, must be installed in order to reduce emissions. In this context, the furnace-kiln system, developed by Universidade Federal de Viçosa, stands out. This system allows the burning of particulate material and methane (CH_4), higher Gravimetric Yield (GY) than the traditional kilns, and process control by pyrometry. Thus this is an outsdaing carbonization alternative, as they are carbonization system is technically, economically, and environmentally viable (Oliveira et al., 2017c; Ribeiro, et al., 2020).

The use of the GHG burner system is a relevant tool for producing charcoal, due to the burning of gases, which allow reducing GHC emissions. Also, the system leads to an increase in GY and reduced carbonization timesthat are beneficial for the commercialization of a carbon neutral product. (Birkenberg et al., 2020).

A positive carbon balance in a charcoal farm indicates sustainability in the production chain and can be used as marketing tool in the sale of a carbon neutral product. Thus, the goal of the present study was to evaluate the carbon balance in a charcoalfarm, with and without the use of the furnace-kiln system for burning methane. Also, this investigation aimed at determining the environmental impacts of adopting this new technology.

MATERIAL AND METHODS

Site characterization

The study was conducted on a charcoal farm in Lamim, State of Minas Gerais, Brazil (20°47’08.56” S and 43°26’37.78” O), in the Zona da Mata Area (Figure 1). The property was selected after registration to participate in the sustainable steelmaking project, due to the region's history in the charcoal production. The charcoal is produced from a hybrid of *Eucalyptus grandis* x *Eucalyptus urophylla*, planted at a spacing of 3.0 m x 2.0 m, in 20.05 ha, in mountainous region, and low use of technology in wood production. According to the Köppen, the climate of the region is Cwa, *i.e.*subtropical with dry winter and hot and rainy summer (Rolim et al., 2007). Precipitation occurs mainly between October and March, with averages of 1,435 mm per year. June and July present the lowest temperatures (12ºC), and January the highest temperatures (25 ºC) (Sá Junior et al., 2012).

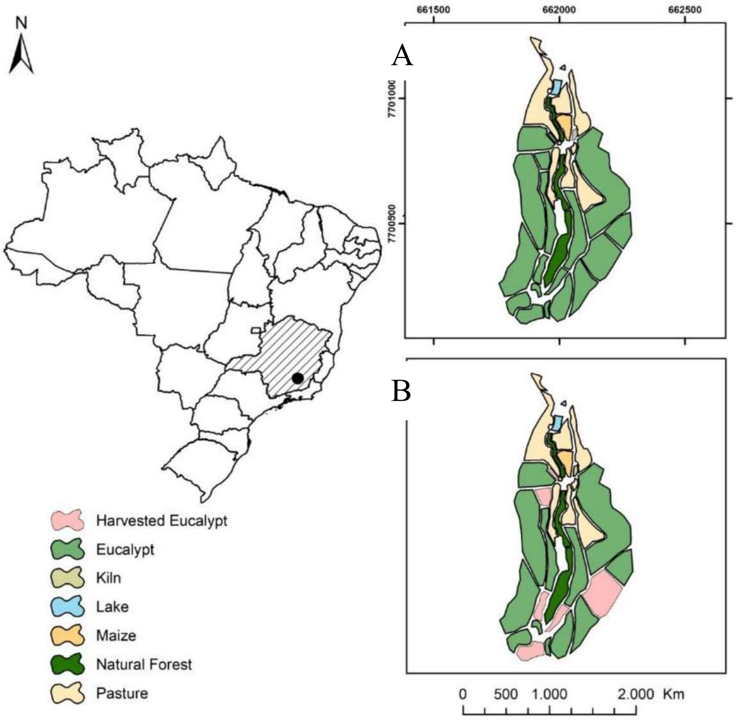

Figure 1: Farm in Lamim-MG, in the first (a) and second (b) inventory, after the removal of part of the eucalyptus plantation for charcoal production.

The dystrophic red-yellow Oxisol predominates in the city of Lamim-MG, as well as in most of the region Zona da Mata (Portugal et al., 2010). The soil chemical analysis was carried out for 5 samples collected in the layers of 0-20 and 20-40 cm in total area, using a manual auger. The soil samples were evaluated at Departamento de Solos at Universidade Federal de Viçosa – UFV (Table 1).

Table 1: Soil chemical analysis in the 0-20 cm, 20-40 cm and medium layers, in which pH was evaluated in H_2O, P (mg dm$^{3-1}$), K (mg dm$^{3-1}$), Ca^{+2}(Cmol dm$^{3-1}$), Mg^{+2}(Cmol dm$^{3-1}$), V (%), m (%), MO (Dag kg^{-1}), P-rem (Mg L^{-1})

Layers	pH	P	K	Ca^{+2}	Mg^{+2}	V	m	MO	P-rem
0-20	4.05	1.54	15.20	0.15	0.07	4.26	78.62	2.92	15.98
20-40	4.37	1.10	11.60	0.14	0.05	4.74	78.80	2.00	14.60
Mean	4.21	1.32	13.40	0.15	0.06	4.50	78.71	2.46	15.29

V= Base Saturation Index; m= Aluminum Saturation Index; MO= Organic matter; P-rem= Remaining Phosphorus.

Volumetric estimation

Simple casual sampling was carried out in the forest inventory, with 27 sample units of 300 m² (20 x 15 m), which were georeferenced. The first forest inventory was performed in January 2018 (5.5 years after planting), and the second in January 2019 (6.5 years after planting), in the same sample units. The circunference at breast height (cbh) of all trees was measured, converted to diameter at breast height (dbh) and separated into diametric classes with an amplitude of 2.5 cm. The total height of all trees present in the sample units was measured using the equipment Vertex IV®.

Three sample trees (chosen outside the sample units) were selected, by diametric class, to perform the rigorous scaling, by the destructive method. The bark diameters at heights of 0 m, 0.30 m, 0.70 m, 1.00 m, 1.30 m, and every 1 meter up to the minimum diameter of 3 cm (limit for production of charcoal), were measured. The commercial wood volume with bark, in each of the sections, was calculated based on the Smalian equation.

$$Vcc = (AS_1 + AS_2)/2 * L \qquad \text{(Equation 1)}$$

Where: Vcc – Volume with bark, in m^3; AS_1 – Sectional area of the trunk lower part, in m^2; AS_2 – Sectional area of the upper trunk, in m^2; L – Trunk length, in m; * – multiplication..

From diameter, height, and volume of the sample trees an equation based on the Schumacher and Hall model was adjusted (1933).

$$Vcc = \beta_0 * dap^{\beta 1} * Ht^{\beta 2} \qquad \text{(Equation 2)}$$

Where: Vcc – Volume with bark, in m^3; β0, β0, β0 – model parameters; dbh – diameter at breast height, in cm; Ht – total height of the sample trees, in m.

The adequacy verification of the model was carried out based on the analysis of the adjusted determination coefficient ($R_{2\ adj}$) and bias. After the model evaluation, the volume of the sample units was extrapolated to the total area.

Wood density determination and biomass and carbon estimation

The wood basic density was determined from the analysis of opposite wedges of wood discs without bark, taken from the sample trees at heights of 0, 25, 50, 75 and 100% of the total height. The method used to determine the wood basic, shelled, density was immersion in water, according to the methodology ABNT NBR 11941 (ABNT, 2003). The weighted average value of the wood basic density of the opposite wedges was considered for biomass estimation. The steam biomass was obtained by multiplying the volume with bark by the wood basic density. The tree carbon stock was obtained by multiplying the biomass values by the factor 0.47 (IPCC, 2006).

Calculation of Greenhouse gas emissions on the farm

The assessed organizational limit considered the emissions resulting from eucalyptus plantation and charcoal production on the property, which are under the responsibility of the farmer. GHG emissions related to the consumption of electricity, diesel, gasoline, and limestone were calculated based on the methodologies developed by the IPCC *Guidelines for National Greenhouse Gas Inventories* (2006). Emissions resulting from the application of nitrogen and lime fertilizers that occurred when the plantation was established were divided by the 13.5 years (7 years in first rotation and 6.5 years in second rotation).

GHG emissions related to the consumption of nitrogen fertilizers were calculated according to the following equation:

$$QN_i = QF_i \text{ x } QNF_i \qquad \text{(Equation 3)}$$

Where: QN_i – total amount of N applied to the soil by the fertilizer i, in kg $year^{-1}$; QFi – amount of type i fertilizer applied to the soil, in kg $year^{-1}$; QNFi – amount of N present in fertilizer i, in kg N kg^{-1} fertilizer.

N_2O emissions from the use of nitrogen fertilizers were calculated according to the following equation:

$$\text{Emission} = \sum([QN_i \text{ x } EF \text{ x } 44^*/28 \text{ x } 298]\div1000) \qquad \text{(Equation 4)}$$

Where: Emission – emission of synthetic and organic nitrogen fertilizers, in $MgCO_{2e}$; QNi – total amount of N applied to the soil by fertilizer i, in kg $year^{-1}$; EF – emission factor by nitrogen fertiliziers, in kg N_2O-N kg N^{-1}; (*) 44/28 is the conversion factor by N_2O-N to N_2O. Source: IPCC (2006).

The GHG emissions referring to the consumption of diesel and gasoline, in the evaluated period, were calculated according to the following equations:

$$EC = C \text{ x } (1-QB) \qquad \text{(Equation 5)}$$

Where: EC – effective fuel consumption, in liters $year^{-1}$; C – total fuel consumption, in liters $year^{-1}$; QB – amount of biofuel present in the fuel. For diesel QB – 0.11 and for gasoline is 0.275.

$$\text{EC emission} = \sum ((CEi * EFi * PAGj) \div 1000) \qquad \text{(Equation 6)}$$

Where: EC emission – emission related to fuel consumption, in $MgCO_{2eq}$; CEi – effective fuel consumption type i, in L or m^3 (1040 L for diesel and 1110 L for gasoline); EFi – emission factor for type i fuel, in $kgGEE_i$ L^{-1} or m^3 (EF for diesel – 2.603 for CO_2, 0.00014 and CH_4, 0.00014 for N_2O; EF for gasoline – 2.212 for CO_2, 0.00080 for CH_4, 0.00026); PAGj – global warming potential of the GEE_j ($PAGCH_4$ = 25; $PAGN_2O$ = 298).

GHG emissions related to limestone consumption in the evaluated period were calculated according to the following equation:

$$\text{Emission C} = (Q * EF * 44/12) \div 1000 \qquad \text{(Equation 7)}$$

Where: Emission C – emission related to the use of limestone, in $MgCO_{2eq}$; Q – amount of lime added to the soil, in kg $year^{-1}$ (334 kg); EF – emission factor for limestone, in kg C kg $lime^{-1}$; (*) 44/12 is the conversion factor of CO_2-C of CO_2.

Description of the charcoal furnace-kiln system

The furnace-kiln system is composed of 4 circular surface kilns and a furnace connected to them by ducts, which has a combustion chamber, where the burning of carbonization gases is carried out (Figure 2). Each kiln has a volumetric capacity of approximately 9.0 m^3 of wood. The temperature control is done by opening and closing the air controllers (6 per kiln)that are arranged on the bottom of the walls of the kilns. Each kiln has 4 metal wells distributed between the top and the walls, which allow the measurement of temperature. These temperature measurements were determined by an infrared sensor, pyrometer, model MT-350®, with measurement capability between 30 - 550ºC.

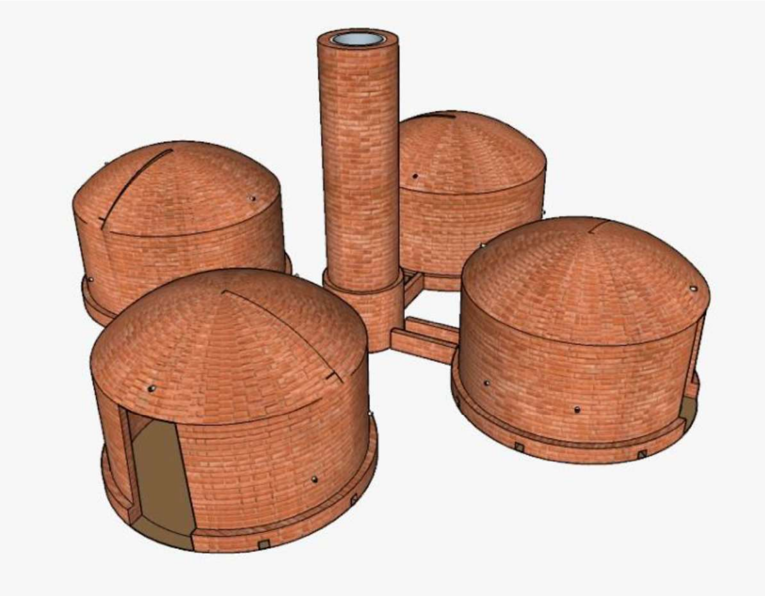

Figure 2: Furnace-kiln system used in rural properties for charcoal production.

Two carbonizations were performed to collect the data. Eucalyptus logs with an average moisture content of 26.38% were used. Continuous temperature monitoring was carried out throughout the carbonization process, using pyrometry. The temperature of the furnace combustion chamber was obtained from thermocouple, type K, every hour, throughout the period. Carbonization was divided into stages, for better process control (Table 2).

Table 2: Carbonization periods temperature (in ºC), duration (in hours), and the occurring phenomenon. Source: Oliveira et al.,(2013)

Period	Temperature	Duration	Phenomenon
I	140-150	15-16	Water vapor release - wood drying, endothermic phase.
II	150-270	11-12	Hemicelluloses degradation, elimination of gases, endothermic phase.
III	270-350	19-20	Cellulose degradation, large gas production, exothermic phase. Charcoal formation.
IV	350-380	11-12	Gas emissions reduction, exothermic phase.

The biomass residues burning (not considered in the emissions, as it would be discarded waste) in the kiln combustion chamber was started with the ignition of the kiln, with the objective of generating a temperature and pressure gradient for the exhaust of the carbonization gases. When the carbonization gases reached ± 100 ºC, measured in the furnace-kiln system combustion chamber access duct, a second filling and burning of waste was carried out to provide temperature for ignition of the carbonization gases from the kiln.

Carbonization gases collection and quantification

The gases emitted during the carbonization were collected and quantified using a gas analyzer. The collections were carried outin the transport duct of the carbonization gases to the furnace, to avoid interference from the combustion of the kiln. Another collection was performed in the furnace, to avoid external effect on the composition of the gases, thus obtaining the concentration of the gases before and after burning them. Data collection was performed using a copper tube, which was inserted up to half the width of the duct and the diameter of the furnace. The gases collection and analysis were carried out during the entire carbonization, at regular intervals (every 2 hours). The measurement time interval at each sampling point was 30 minutes, in order to clean the pipes of the gas cleaning system and the gasboard analyzer, obtaining a stable reading of the gases, according to the methodology of Oliveira et al., (2013*)*.

The gases were sucked from the collection points, being conducted to the pre-wash system and, subsequently, to the gas conditioning system: Gasboard 9030 Wuhan CUBIC Optoeletronics Co LTDA. The prewash system has five vials of kitassato inside a styrofoam box. The flasks were partially submerged in ice, to decrease the temperature, retaining the condensable fraction of the gases. The gases entrance into each bottle was through the hose that passed through the silicone cap of the bottle, while the outlet was through the side spout, exerting the role of a dreschel flask, proceeding to the next flask and finally to the gasboard.

The first kitassato was used for gas condensation, the second for washing in 80% alcohol, the third for washing in water, and the fourth and the fifth for, once again, washing in 80% alcohol. Upon reaching the gasboard, the gases were rinsed in water, cooled to 4ºC in a dehumidifier (chiller) and a cylinder containing activated carbon and cotton. Finally, a final cleaning of the gases was carried out, using precision filters FIT1 and FIT2, which are responsible for retaining impurities less than 3 and 1 µm, respectively. After this process, the gases were admitted by the online gasboard analysis system 3100 Wuhan CUBIC Optoeletronics Co LTDA., providing the reading of percentage composition, volume basis, for CH_4, CO_2, CO, H_2, O_2, in addition to the calorific power of gases in kcal/Nm^3.

Methane emission and furnace efficiency

The emission factor for charcoal production was calculated according to the following equations:

$$PE_y = EF_{CH4,BP} * GWP_{CH4} * P_{carvão,y} \qquad \text{(Equation 8)}$$

$$EF_{CH4,BP} = (A - B * Y_{P,i}) \qquad \text{(Equation 9)}$$

Where: PE_y = Project emissions in the y year ($MgCO_2$ $year^{-1}$); $EF_{CH4,BP}$ = Methane emission fact in the project scenario ($MgCH_4$ Mg $charcoal^{-1}$); GWP_{CH4} = Methane global warming ($MgCO_{2e}$ $MgCH_4^{-1}$); $P_{charcoal,y}$ = Charcoal production in the y year (Mg charcoal $year^{-1}$); A – B = regression equation parameters that expresses the statistical relationship between methane emissions and the carbonization gravimetric yield. $Y_{P,i}$ = Gravimetric yield carbonization consider average (Mg charcoal Mg $wood^{-1}$) (PNUD, 2018).

The furnace CH_4 burning efficiency was calculated according to the following equation:

$$EF (\%) = ([Gas_x * \text{period time}_n] / \text{total time}) \qquad \text{(Equation 10)}$$

Where: EF = Furnace burning efficiency, in %; Gas_x = Gas concentration x; period time $_n$ = carbonization period n time, in hours (UNFCC, 2020).

The CH_4 burning efficiency was used to reduce gas emissions in the carbon balance with the use of the furnace-kiln system.

Carbon dioxide emission due to methane burning

The CH_4 burning causes the dissociation of its molecule, which oxidizes, releasing CO_2 and water. Thus, although the charcoal comes from a biogenic source and CO_2 emissions during carbonization are not accounted for, it is necessary to quantify the CO_2 emitted during methane burning. The emission factor was calculated according to the following equation:

$$EF_{CO2} = 114.165574 - (0.025565 * TU) + (0.027518 * TU^2) \qquad \text{(Equation 11)}$$

Where: EF = CO_2 emission factor, in $kgCO_{2eq}$ Mg $wood^{-1}$; TU = Wood moisture, in %; 114.165574, 0.025565 and 0.027518 are regression parameters (Canal et al., 2016).

CO_2 emissions were calculated according to the following equation:

$$E_{CO2} = EF_{CO2} * M / 1000 \qquad \text{(Equation 12)}$$

Where: E_{CO2} = CO_2 carbonization emissions, in Mg_{CO2e}; EF_{CO2} = CO_2 emission factor, in $kgCO_{2eq}$ Mg $wood^{-1}$; M = Total wood in the kiln, in Mg $year^{-1}$. The 0.89 factor should be used to quantify CO_2 emissions only in the process of burning methane (Coelho, 2013).

Carbon balance

The annual carbon balance was calculated based on the carbon increment of the remaining eucalyptus on the farm, annual farm emissions and emissions from charcoal production without burning methane. The carbon balance in the scenario with the use of the furnace-furnace system was based on the same data, however, with the inclusion of methane burning in the production process and the CO_2 emissions originated in this process.

RESULTS

Volumetric equation

The volumetric equation adjustment was considered adequate, based on the analysis of the adjusted coefficient of determination ($R_{2adj} = 98.56\%$), Bias (-0.12%).

$$Vcc = 0.00008778 * dbh^{1.472} * Ht^{1.262} \qquad \text{(Equation 8)}$$

Wood basic density and carbon stock in the tree

The average basic wood density used to estimate biomass and carbon in eucalyptus plantations was 0.44 $g.cm^{-3}$. The carbon stock in the remainder of the eucalyptus plantation after the charcoal production, was 124.83 $MgCO_{eq}$ ha^{-1}, which represents an average annual increase in carbon (AACI) of 19.21 $MgCO_{eq}$ ha^{-1} $year^{-1}$. The wood volume used for charcoal production in one year-period was 539.49 m^3 (237.38 Mg of wood biomass) in an area of 3.28 ha (Table 3).

Table 3: Area (ha), Age (years), Volume (m^3 ha^{-1}), Density (g cm^{3-1}), Biomass (Mg ha^{-1}), Carbon (MgC ha^{-1}), CO_{2e} ($MgCO_{2e}$ ha^{-1}), $AAICO_{2e}$ ($MgCO_{2e}$ $ha^{-1}year^{-1}$), in Eucalypt forest, in the period evaluated in the present study

Year	Area	Age	Volume	Density	Biomass	Carbon	CO_{2eq}	$AAICO_{2eq}$
2018	20.05	5.5	136.50	0.44	60.06	28.23	103.60	18.84

2019	16.77	6.5	164.45	0.44	72.37	34.01	124.83	19.21

The carbon stock in the forest area that was harvested for charcoal production, in the year of the study, was not considered in the balance sheet calculations.

GHG farm emissions

The main GHG sources of emissions, in the one year-period, were the diesel (65.11%) and gasoline (22.11%) consumptions. Limestone was the smallest GHG emissions source (1.90%). The emissions for the period evaluated were 0.2370 $MgCO_{eq}$ ha^{-1} year^{-1} (Table 4).

Table 4: GHG emission sources, consume, emissions in $MgCO_{2eq}$, emissions in ha $MgCO_{2e}$ ha^{-1} and emissions percentage

Emission source	Consume	Emissons	Emissions ha^{-1}	Percentage
Diesel (L)	1,040	2.5884	0.1543	65.11%
Gasoline (L)	525	0.8789	0.0524	22.11%
Energy (R$)	1,592	0.2229	0.0133	5.61%
Lime (kg)	167	0.0750	0.0045	1.90%
NPK[a] (kg)	28	0.1569	0.0094	3.97%
NPK[b] (kg)	28	0.0525	0.0031	1.30%
Total	**-**	**3.9746**	**0.2370**	**100%**

[a] NPK formulation 20-00-20; [b] NPK formulation 06-30-06

Carbonization GHG emissions

The kilns used for the wood carbonization had their temperature monitored throughout the period, to maximize the charcoal yield and to minimize the fines and wastes production (Figure 3). The charcoal production, under the studied conditions and evaluated period, was 61.53 Mg, in a total of 43 carbonizations carried out. The gravimetric yield (GY) obtained with the use of the furnace-kiln system was 32.76%.

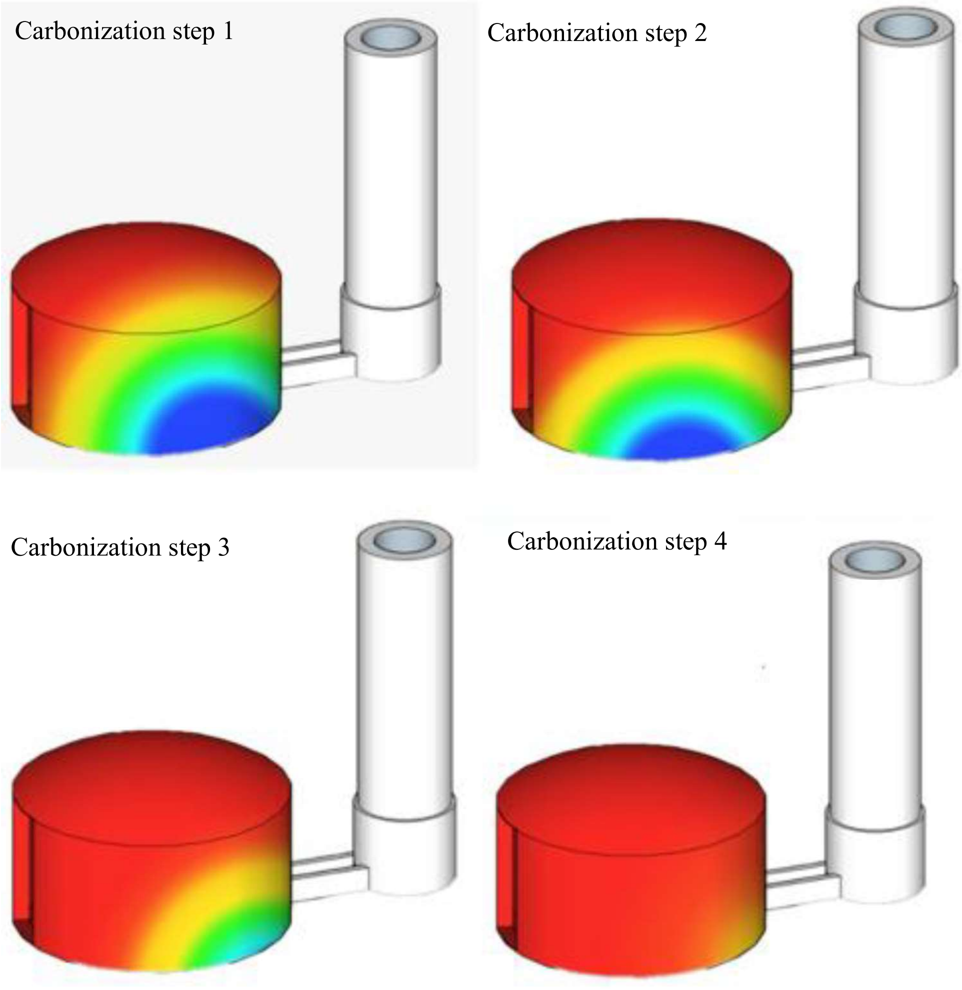

Figure 3: Carbonization thermal control, according to the carbonization phases of Table 2. The higher the kiln temperature, the redder the figure.

Total emissions without CH_4 burning were 5.0265 $MgCO_{2eq}$ ha^{-1}. GHG emissions with the use of the furnace-kiln system were 3.0030 $MgCO_{2eq}$ ha^{-1} (2.7066 $MgCO_{2eq}$ ha^{-1} from CH_4 production and 0.2964 $MgCO_{2eq}$ ha^{-1} produced due to the CH_4 thermal degradation and the H_2O and CO_2 consequent formation. The GHG emission per unit produced was 0.6105 $MgCO_{2eq}$ Mg $charcoal^{-1}$ with the CH_4 burning and 1.2433 $MgCO_{2eq}$ Mg $charcoal^{-1}$ without the GHG burning, which represents a 0.6328 $MgCO_{2eq}$ Mg $charcoal^{-1}$ reduction (Table 5).

Table 5: Two types of systems evaluated for charcoal production with the emission factor for charcoal production ($MgCO_{2eq}$ ha^{-1}), emission factor for CO_2 production due to the CH_4 burning ($MgCO_{2eq}$ ha^{-1}), total emissions ($MgCO_{2eq}$ ha^{-1}) and per unit produced emission ($MgCO_{2eq}$ Mg $charcoal^{-1}$)

System	Emission factor	MB emission factor	Emissions	UP emissions
Surface kiln	1.6380	-	5.0265	1.2433
Furnace-kiln	0.8820	0.1142	3.0030	0.6105

MB – Methane burning; UP – Unit produced.

Carbon Balance

The carbon balance without methane burning in charcoal production process was 13.9465 $MgCO_{2eq}$ ha^{-1} (Figure 4) and with the methane burning 15.9616 $MgCO_{2eq}$ ha^{-1} (Figure 5).

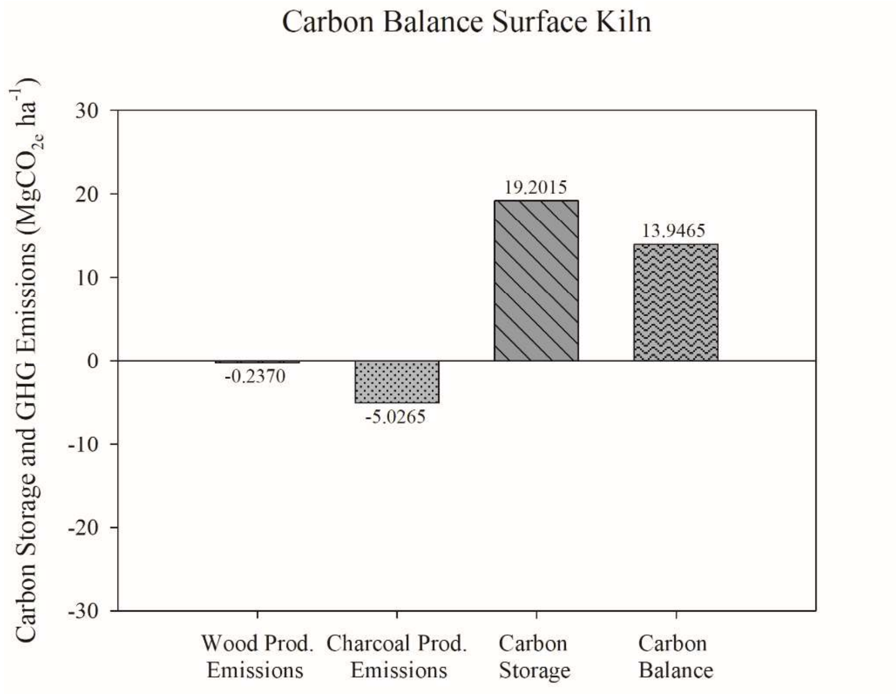

Figure 4: Carbon balance, in the baseline scenario considered, over one year-period.

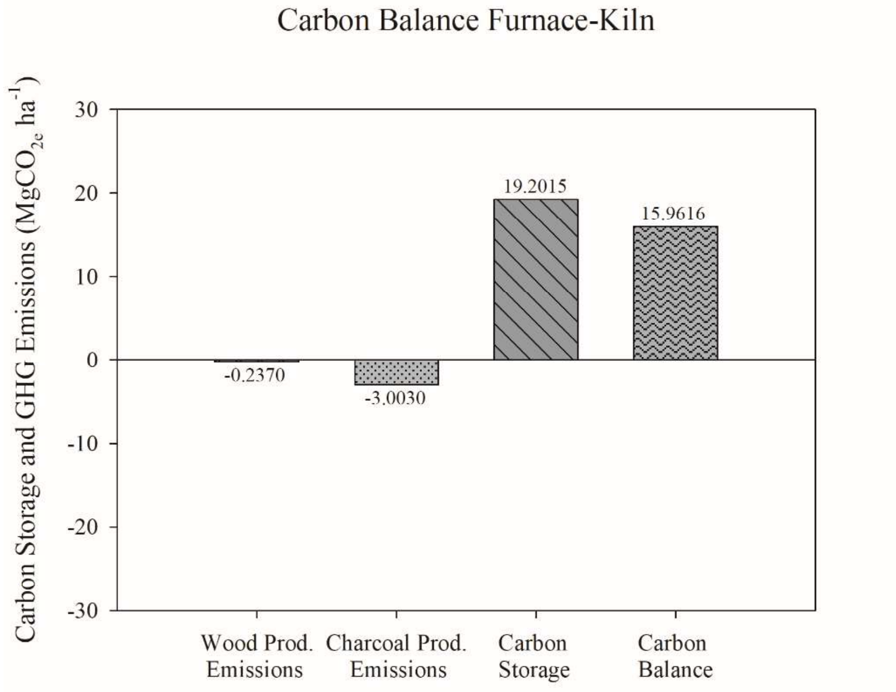

Figure 5: Carbon balance, with the methane burning from the furnace-kiln system, over a period of one year.

The methane burning in the charcoal production resulted in the emissions reduction of 2.0235 $MgCO_{2eq}$ ha^{-1} and an efficiency in GHG reducing emissions of 40.26%, over a year-period.

DISCUSSIONS

The main destinations for Brazilian charcoal are the pig iron sector (73% of production), ferroalloys industry (12%), residential sector (10%), commercial sectors, and food & chemical industries (5%) (EPE, 2018). Brazilian charcoal production, mostly uses eucalyptus as the raw material and itis concentrated in small and medium rural producers, with rudimentary, unhealthy and highly polluting production systems (Souza et al., 2020). The most used kilns in Brazil are “hot tail” type, sursuffarce, and mountain kiln, which showlower GY than the furnace-kiln system (Oliveira et al., 2017). Moreover, the mountain kiln, demands more time to reduce the kiln temperature after the carbonization, which leads to longer production times and potential economic losses.

The "hot tail" kiln releases GHG emissions directly into the atmosphere, unlike the furnace-kiln system. When comparing the GHG emissions from the “hot tail” kiln with the furnace-kiln system, through the life cycle analysis, a better environmental performance was observed by the furnace kiln, with GHG reductions between 28-119% of total CO_{2eq} $year^{-1}$ (Bailis et al., 2013). Coupling a sustainable production system with favorable economic results is crucial for the large-scale implementation of this type of charcoal production system in Brazil.

When comparing the GY, with and without CH_4 burning, the values of 33.13% with burning and 28.15% without burning were observed, which shows the better performance of the system from an economic point of view, for having a higher productivity, and from an environmental point of view, for the reduction in GHG emissions (Santos et al., 2017). The use of the furnace-kiln system in the industry resulted in a CH_4 emissions reduction by 89.65% and, due to the CO_2 production resulting from the CH_4 burning, there was an increase in CO_2 emission of 89.93% (Pereira et al., 2017). The present study showed greater efficiency in reducing methane emissions due to the use of advanced carbonization technology and greater control in the charcoal production process.

The superior gravimetric yield obtained by the furnace-kiln system is due toconstant temperature monitoring and control of the kiln by pyrometry. These lead to better control of the wood degradation bands throughout the process and wood moisture, which decrease the time of carbonization during steps I and II, where the endothermic phases of carbonization occur (Tamburini et al., 2020). The gravimetric yield obtained by furnace-kilns (32.5%) is higher than the ones obtained by “hot tail” type (26%), mountain kiln (30%) and surfarce kiln (30%), that are the kilns commonly used in Brazil, and that do not have the GHG burners (Ribeiro et al., 2020). Temperature control by pyrometry is considered a way to reduce GHG emissions, through the increase of GY, by the United Nations (ONU), by methodology ACM0041, of the Clean Development Mechanism (CDM) (ONU, 2019).

The Brazilian steel sector, in 2019, consumed 6.9 million tons of charcoal (SINDIFER, 2020), considering the use of the gas burner, in half of this production, there would be a reduction of 2.62 GgCO_{2eq}, a value that would be sufficient to reduce the Brazilian goal of GHG reduction and emissions proposed in the Paris Agreement (MMA, 2015). Burning gases technologies for charcoal production should be encouraged, as the production chain has not yet been reached comprehensively and consistently (Pereira et al., 2017). Bailis et al. (2013) carried out a life cycle analysis comparing charcoal production with traditional surface circular kiln, which releases GHG directly into the atmosphere, and rectangular kilns equipped with gas flaring systems, as an alternative scenario. The researchers found that the use of this new technology allowed the reduction of GHG emissions between 28-119% (10-43 Mg CO_{2eq} year^{-1}).

Burning carbonization gases, especially methane, generates energy in heat form that can be used to dry the wood inside of the kiln, which reduces the endothermic phase of the process and consequently promotes increase of gravimetric yield, emissions reduction, and improvement of the final product quality. Cogeneration of electricity from charcoal production is an emerging technology, with promising worldwide application. When charcoal is produced, using traditional slow pyrolysis processes, about 50% of the energy contained in the wood is lost by the pyrolysis gases (Miranda et al., 2013).

The positive carbon balance verified, from the point of view of the farmer, indicates the sustainability of his property (Accorsi et al., 2016). The result shows that the farm has forest remnants capable of neutralizing annual emissions. The largest area of forests brings environmental benefits such as improved air quality (Yuan et al., 2018), increased water recharge capacity (Mello et al., 2019), regulation of the water regime, and maintenance of local temperature (Wolff et al., 2018). The negative balance indicates that a larger area of forests is needed to neutralize the property's annual GHG emissions and that, probably, the farmer is not complying with the current environmental legislation.

The Brazilian steel industry is unable to produce all the charcoal demand, which makes it necessary to buy from rural producers. It is important to mention that the industry requires good working conditions for the employees and charcoal production from sonely commercial eucalyptus plantations. Another requirement is the carbon balance of the farm , whichis important for monitoringemissions in the production chain, for knowing if there is a need for direct mitigation actions, and the results can potentially be used for marketing a carbon neutral product. The market for carbon neutral products, after the ratification of the Paris Agreement, has become a reality (Birkenberg et al., 2020). Currently, there some marketed carbon neutral products such as coffee (Birkenberg e Birner, 2018), fruits (Kilian et al., 2012), and meat (EMBRAPA, 2016). The sustainability of charcoal production with lower GHG emissions and the ability of forest remnants to remove emissions, can leverage the commercialization of neutral charcoal, in addition to contributing to a cleaner energy matrix.

CONCLUSIONS

The carbon balance, with the methane burner in the charcoal production, is positive, when considering the forest carbon removal.

Replacing traditional kilns by the furnace-kiln system for charcoal production could help the national steel sector to achieve the goals of GHG emissions reduction.

The furnace-kiln system has the capacity to reduce GHG emissions in the charcoal production by 40.26%, whichindicates that this technology is an outsdanding tool to assist the GHG emission reduction targets of the Brazilian NDC in the Paris Agreement.

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CHAPTER 2

How the use of destructive and non-destructive methodologies impact the estimative of biomass and carbon in a eucalyptus forest?

Abstract: Predicting wood biomass and carbon stock contents in planted forests and volume of wood can vary due to limitations associated to the measurement of parameters. Therefore, reducing possible errors generated over biomass and carbon stock quantification is an important step in obtaining reliable data. The aim of the study was to compare the use of destructive and non-destructive methodologies for predicting biomass and carbon stock in a planted *Eucalyptus* forest. Scaling was performed on 21 trees and 3 methodologies were compared. For methodology 1, a control sample was harvested, sectioned, weighted in the field and the carbon stock calculated based on these data. Methodology 2 was also destructive, as the tree was harvested, scaled and the carbon stock predicted based on these data. Methodology 3 was non-destructive, as the tree was scaled upright with the aid of an equipment and the predicted carbon stock was based on these data. Biomass and carbon stock were compared by Test F and no statistical difference was observed. The data were separated according to diametric classes and compared by the Kolmogorov-Smirnov test, and again no significant difference was observed. Furthermore, three equations were generated based on the Schumacher & Hall model and compared by the identity test model and no differences between the methodologies were observed. Thus, both non-destructive and destructive methodologies herein evaluated were effective and showed equal results to the control sample. Moreover, the use of the non-destructive methodology reduces time and cost destinated to predicting biomass and carbon stock.

Keywords: Basic wood density, low carbon economy, bole volume.

INTRODUCTION

Greenhouse gas (GHG) emissions have increased over the years and have caused an imbalance on Earth and, consequently, climate changes on a global scale (Olorunfemi et al., 2019). The principal anthropogenic sources of GHG are the burning of fossil fuels and the change in land use (IPCC et al., 2014). Given this situation, the development of strategies to reduce the concentration of atmospheric CO2 is a consensus. Able to store carbon in the form of forest biomass (Zhang et al., 2019), forests are essential mitigators with a storage potential of 2-4 $PgCO_{2e}$ from the atmosphere (Qureshi et al., 2012).

Forests located in the tropics are in constant focus due to their high volumetric productivity and rapid growth (Achard et al., 2004). And accurate estimates of biomass production are needed to reduce uncertainties in the carbon storage potentials in those areas (Djomo et al., 2011). Estimates of volume, biomass, and carbon may have discrepancies associated with limitations in measuring parameters (Baccini et al., 2012). Therefore, reducing the possible errors generated in the quantification is a significant step in obtaining reliable data (Stovall et al., 2017).

Producing precise and accurate biomass forecasts is challenging for several reasons. First, an impartial forest inventory project is required, with reliable measurements of the tree's attributes, and requires that the biomass models represent the forest inventory data to which the model is applied (Dutcâ et al., 2020). The methodologies usually used are defined as destructive, where trees in a plot or diametric classes are extracted and measured (Singh et al., 2011); and non-destructive, which is not necessary to slaughter the plants (López-López et al., 2017). Non-destructive methodologies for estimating biomass are faster, cheaper, and avoid environmental problems resulting from the felling of the trees (Mòntes, 2009).

Studies on forest biomass are carried out for different purposes, including knowing its energy potential, quantifying nutrient cycling (Silveira et al., 2008), monitoring tree growth (Zhao et al., 2018), and carbon storage potential (Chieppa et al., 2020). Destructive sampling, at the highest cost, is limited by capital, labor, and logistics. Samples can be underrepresented in areas of complex topography and unfavorable climatic conditions (Picard et al., 2012).

Thus, this study aimed to compare the use of destructive and non-destructive methodologies for estimating volume, biomass, and carbon storage in a forest with a hybrid of Eucalyptus urophylla x Eucalyptus grandis. The hypothesis that motivated this study was the possibility of differences between the non-destructive methodologies concerning the destructive ones in the estimation of biomass and carbon.

MATERIAL AND METHODS

Characterization of the study site

The study was conducted on a charcoal-producing rural property in Lamim, Minas Gerais (20°47'08.56" S and 43°26'37.78" O), in the Zona da Mata (Figure 1). The tree component is a hybrid of Eucalyptus grandis x Eucalyptus urophylla, planted at a spacing of 3,0 m x 2,0 m. According to the Köppen classification, the climate of the region is Cwa, that is, subtropical with dry winter and hot and rainy summer (Rolim et al., 2007). Precipitation occurs mainly between October and March, with averages of 1,435 mm per year. June and July present the lowest temperatures (12ºC), and January the highest temperatures (25ºC) (Sá Junior et al., 2012).

Figure 3: Rural property in Lamim, MG, where the inventory was conducted to estimate volume, biomass, and carbon.

The dystrophic Oxisol predominates in Lamim, as well as in most of the Zona da Mata. Soil chemical analysis was carried out from 5 samples collected in the layers of 0-20 and 20-40 cm in the total area, with a manual auger aid. The soil samples were evaluated in the soil department of the Federal University of Viçosa (UFV). The pH average for soil is 4,21 in the 0-40 cm layer, and the organic matter content, 2,46 dag kg^{-1} (Table 1).

Table 6: Soil chemical analysis in the 0-20 cm, 20-40 cm, and average layers

Layer	pH (H_2O)	P mg dm$^{3-1}$	K mg dm$^{3-1}$	Ca^{+2} Cmol dm$^{3-1}$	Mg^{+2} Cmol dm$^{3-1}$	V (%)	m (%)	MO Dag kg^{-1}	P-rem Mg L^{-1}
0-20	4,05	1,54	15,20	0,15	0,07	4,26	78,62	2,92	15,98
20-40	4,37	1,10	11,60	0,14	0,05	4,74	78,80	2,00	14,60
Average	4,21	1,32	13,40	0,15	0,06	4,50	78,71	2,46	15,29

V = Base Saturation Index; m = Aluminum Saturation Index; MO = Organic Matter; P-rem = Remaining Phosphorus.

Forest inventory and methodologies for estimating volume, biomass and carbon

The forest inventory used simple random sampling, with 27 georeferenced sample units of 300 m² (20 x 15 m). All trees had the circumference at 1,30 m above the ground (*cap*) measured, converted to the diameter at 1,30 m above the ground (*dap*), and separated into diametric classes with an amplitude of 2,5 cm. Three sample trees (chosen outside the sample units) were selected by diametric class, to perform the rigorous scaling through the destructive and non-destructive methods. A total of 21 trees were selected for strict scaling and used for the evaluated estimative methodologies.

Methodology 1 - Destructive by Weighing - control

Methodology 1 was considered a control to compare with other methodologies, as it is the most accurate (Chavé et al., 2014). The sample trees were felled, and their trunk was cut and weighed in the field. At 0% (base), 25%, 50%, 75%, and 100% of its commercial height, wooden discs of 2,5 cm thickness were removed and weighed immediately. The same samples were placed in a forced circulation oven with controlled temperature (100ºC for branches and trunks, and 40ºC for leaves) at the Madeira Panel and Energy Laboratory (LAPEM UFV) and weighed until stabilization.

The proportionality method was used to calculate the total dry biomass in the field, by section of the tree, after harvest, according to the following equation:

$$PS(c) = PU(c)*PS(a) / PU(a) \qquad \text{(Equation 1)}$$

Where: PS(c) = Field dry weight, in g; PU (c) = Field wet weight, in g; PS (a) = Sample dry weight, in g; PU (a) = Sample wet weight, in g.

The carbon stock was calculated based on the 0,47 factor recommended for tree species (IPCC, 2006).

Methodology 2 - Destructive with scaling

The sample trees were felled, and their bark diameters collected at heights of 0 m, 0,30 m, 0,70 m, 1,00 m, and 1,30 m. From this height, every 1 meter up to the minimum diameter of 3 cm was measured. The volume in each of the sections was calculated based on Smalian's formula.

$$Vcc = (AS_1 + AS_2) /2 * L \qquad \text{(Equation 2)}$$

Where: Vcc – Volume with bark, in m^3; AS_1 – Sectional area of the trunk lower part, in m^2; AS_2 – Sectional area of the upper trunk, in m^2; L – Trunk length, in m.

At 0% (base), 25%, 50%, 75%, and 100% of its commercial height, wooden discs of 2,5 cm thickness were removed. Their opposite wedges were used to determine the basic wood density according to ABNT NBR 11941's methodology (ABNT, 2003). The average value of the basic wood density of the opposite wedges of each individual was considered to estimate the biomass. The biomass of the bole was obtained by multiplying the volume with bark by the basic wood density and the carbon stock by the 0,47 factor, recommended for tree species (IPCC, 2006).

Methodology 3 - Non-destructive with Pentaprism

The sample trees (still standing) had their diameters with bark at heights of 0 m, 0,30 m, 0,70 m, 1,00 m, and 1,30 m measured, and from this height at every 1 meter, the measurement with the Wheeler® Pentaprism was used up to a minimum diameter of 6,5 cm. The volume in each of the sections was calculated based on Smalian's formula.

$$Vcc = (AS_1 + AS_2) /2 * L \qquad \text{(Equation 3)}$$

Where: Vcc – Volume with bark, in m^3; AS_1 – Sectional area of the trunk lower part, in m^2; AS_2 – Sectional area of the upper trunk, in m^2; L – Trunk length trunk, in m.

From the diameter of 6,5 cm (Wheeler® Pentaprism measurement limit), the volume of the section was calculated based on the volume of a cone.

$$Vcc = (AS_1 * Ht) \div 3 \qquad \text{(Equation 4)}$$

The volumes obtained by Smalian's equation and the cone were added to obtain the trunk's total volume. Wood samples were taken with a manual auger at 1,30 m above the ground (*dap*) to determine the basic wood density according to the ABNT NBR 11941's methodology (ABNT, 2003). The biomass of the bole was obtained by multiplying the volume with bark by the basic wood density of each individual, and the carbon stock by the 0,47 factor, recommended for tree species (IPCC, 2006).

Data Statistical Analysis

The results were interpreted with the analysis of variance (ANOVA), applicating Test F, and if significant differences were established, the values would be compared by the Test T for paired samples, at 95% probability. The residual analysis was performed by comparing the estimated values in Methodologies 2 and 3 with the values observed in Methodology 1 (reference).

Kolmogorov-Smirnov test was used to compare the statistical significance between the reference methodology's carbon stock with the others, in the diametric classes, at 95% probability.

$$D_{cal} = \text{Max}\ (F_0\ (x) – F_e\ (x)) \qquad \text{(Equation 5)}$$

Where: F_0 (x) = cumulative frequency observed; F_e (x) = cumulative frequency observed, and n = number of observations.

D_{tab} value for 5% significance was obtained according to the following equation:

$$D_{tab} = 1{,}35 \div \sqrt{n} \qquad \text{(Equation 6)}$$

Where: D_{tab} = critical value at 5% significance and "n" is the number of observations. If $D_{cal} < D_{tab}$: H_o is accepted (observed distribution equal to projected). If $D_{cal} \geq D_{tab}$: H_o is rejected (observed distribution is not equal to the projected distribution).

Statistical analyzes were performed using the software R ®.

Model Identity

An equation based on Schumacher and Hall’s (1933) model was adjusted for each of the tested methodologies from the sample trees’ diameter, height, and carbon stock data.

$$C = \beta_0 * dap^{\beta 1} * Ht^{\beta 2} \qquad \text{(Equation 7)}$$

Where: C – carbon stock, in Mg; β0, β0, β0 – model parameters; dap – diameter with bark measured at 1,30 m from the ground, in cm; Ht – total height of the sample trees, in m.

The verification of the model adequacy was carried out based on the analysis of the adjusted determination coefficient ($R2_{adj}$), Bias (%), and RMSE (%).

The model identity test (Graybill, 1976) was used in an attempt to group the carbon storage estimation models, in relation to the reference, to a significance of 5%. The test (basically) consists of reducing the sum of squares, allowing to statistically verify, by the Test F, the significance of the difference between the total sums of squares of the regressions adjusted for each methodology alone (complete model) and the sum of the squares regression adjusted for the total data set (reduced model).

The tested hypotheses were:

H0: the reduced model adjusted for the total data set from methodologies 2 and 3 in relation to the reference does not differ from the adjusted complete models.

H1: H0 is rejected.

RESULTS

The average carbon stock obtained by methodology 1 was 0,0438 ± 0,0308 MgC, a value similar to those found in methodologies 2 (0,0470 ± 0,0343 MgC) and 3 (0,0431 ± 0,0345 MgC) (Table 2).

Table 7: Values of volume (Vol, in m³), wood density with standard deviation as a function of the samples taken along the shaft (Dens, in g cm³), and carbon stock (Carb, MgC) for the 21 sample trees evaluated in the methodologies 1 (Destructive with weighing), 2 (Destructive with scaling) and 3 (Non-destructive with Pentaprism)

Sample	**Methodology 1**	**Methodology 2**			**Methodology 3**		
	Carb	**Vol**	**Dens**	**Carb**	**Vol**	**Dens dap**	**Carb**
A1	0,0031	0,0163	0,4412 ± 0,0123	0,0034	0,0110	0,4480	0,0023
A2	0,0031	0,0166	0,4469 ± 0,0095	0,0035	0,0118	0,4418	0,0024
A3	0,0036	0,0180	0,4453 ± 0,0109	0,0038	0,0112	0,4452	0,0024
A4	0,0115	0,0492	0,4354 ± 0,0083	0,0101	0,0213	0,4314	0,0043
A5	0,0109	0,0451	0,4384 ± 0,0116	0,0093	0,0217	0,4389	0,0045
A6	0,0137	0,0671	0,4470 ± 0,0103	0,0141	0,0306	0,4347	0,0062
A7	0,0212	0,1121	0,4355 ± 0,0093	0,0229	0,0998	0,4350	0,0204
A8	0,0225	0,0898	0,4334 ± 0,0113	0,0183	0,0650	0,4265	0,0130

A9	0,0237	0,1229	0,4415 ± 0,0143	0,0255	0,1061	0,4520	0,0225
A10	0,0479	0,2480	0,4487 ± 0,0092	0,0523	0,1925	0,4564	0,0413
A11	0,0495	0,2516	0,4387 ± 0,0113	0,0519	0,2158	0,4307	0,0437
A12	0,0494	0,2552	0,4411 ± 0,0116	0,0529	0,2294	0,4327	0,0467
A13	0,0541	0,2826	0,4392 ± 0,0123	0,0583	0,2471	0,4412	0,0512
A14	0,0591	0,3058	0,4364 ± 0,0088	0,0627	0,3143	0,4384	0,0648
A15	0,0596	0,3128	0,4414 ± 0,0111	0,0649	0,3187	0,4507	0,0675
A16	0,0781	0,4126	0,4364 ± 0,0115	0,0846	0,3737	0,4325	0,0760
A17	0,0727	0,3824	0,4331 ± 0,0112	0,0779	0,3626	0,4479	0,0763
A18	0,0749	0,3975	0,4341 ± 0,0005	0,0811	0,3986	0,4376	0,0820
A19	0,1027	0,5466	0,4358 ± 0,0046	0,1119	0,5287	0,4408	0,1095
A20	0,0753	0,4091	0,4353 ± 0,0052	0,0837	0,3757	0,4354	0,0769
A21	0,0835	0,4544	0,4429 ± 0,0068	0,0946	0,4369	0,4398	0,0903
Average	0,0438	0,2284	0,4394	0,0470	0,2082	0,4399	0,0431
Stand Dev ±	0,0308	0,1671	0,0047	0,0343	0,1668	0,0078	0,0345

When comparing methodologies 2 and 3 to the control (Methodology 1), ANOVA resulted in a non-significant difference between the data (Tables 3 and 4).

Table 8: ANOVA performed to compare methodology 2 to the control (Methodology 1)

Source	**GL**	**SQ (Aj.)**	**QM (Aj.)**	**Value F**	**Value-P**
Sample	1	0,00011	0,0001088	0,102	0,751
Residue	40	0,04257	0,0010642		
Total	**41**	**0,04268**	**0,001173**		

Table 9: ANOVA performed to compare methodology 3 to the control (Methodology 1)

Source	**GL**	**SQ (Aj.)**	**QM (Aj.)**	**Value F**	**Value-P**
Sample	1	0,00001	0,000006	0,006	0,941
Residue	40	0,04282	0,001071		
Total	**41**	**0,04283**	**0,001077**		

The residual analysis showed similarity between the reference methodology data with the others for both methodologies (Figures 2 and 3), however, with an overestimation of data in the two lower-class centers (6,25 and 8,75 cm) for methodology 3.

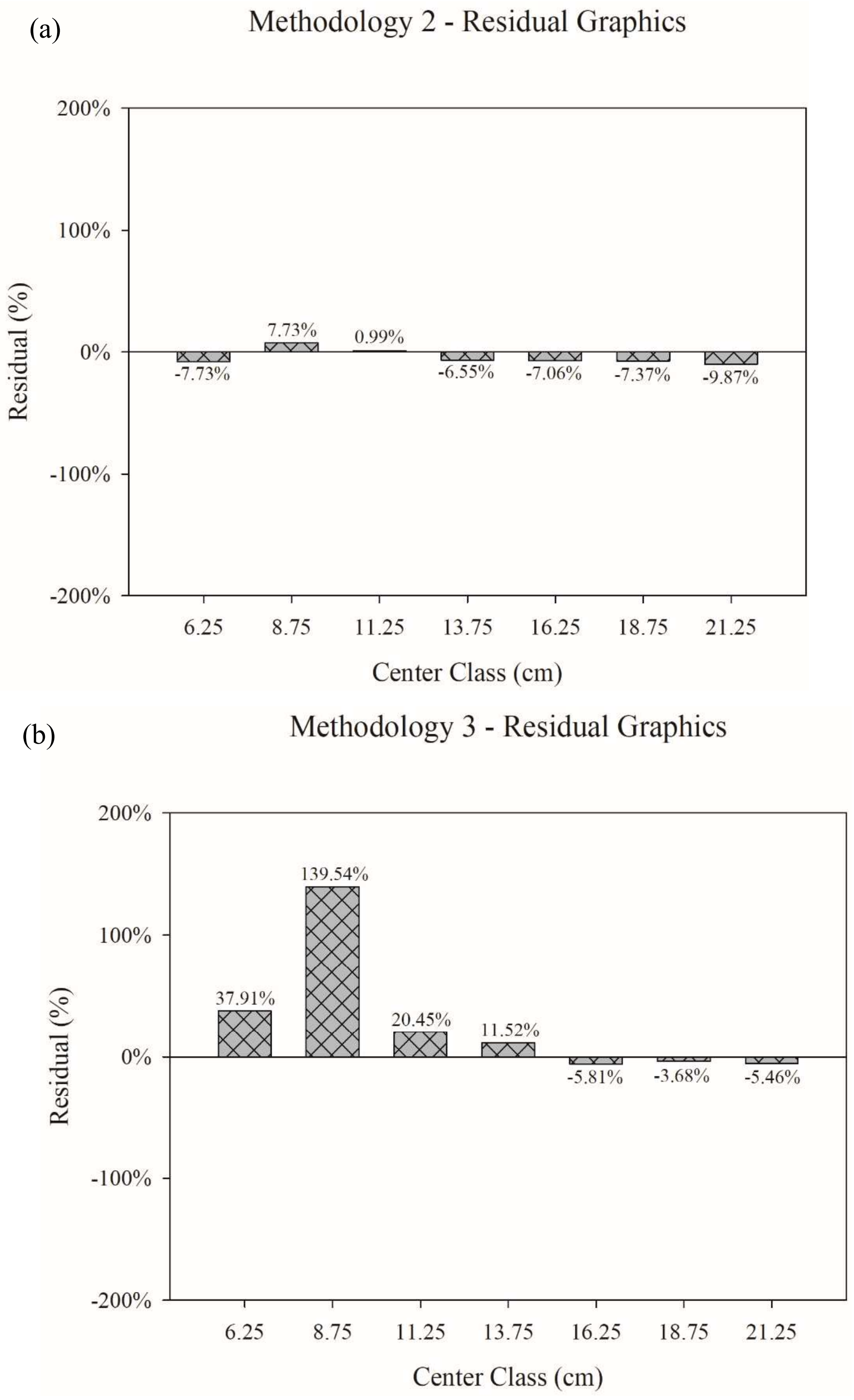

Figure 4: (a) Residual graph of methodology 2 to the control, by the class center; (b) Residual graph of methodology 3 to the control (Methodology 1), by the class center.

Kolmogorov-Smirnov test's evaluation resulted in a non-significant difference in the carbon stock by diametric class for the evaluated methodologies (Tables 5 and 6).

Table 10: Result of the Kolmogorov-Smirnov test for methodology 2 to the control. CC (class center, in cm), FO (Observed frequency), relative FO (relative observed frequency, in %), FE (estimated frequency), Relative FE (relative estimated frequency, in %)

CC	FO	Relative FO	FE	Relative FE	|FO(x) - FE(x)|
6,25	0,0098	1,07	0,0106	1,08	0,0001
8,75	0,0360	3,92	0,0335	3,39	0,0053
11,25	0,0674	7,33	0,0667	6,76	0,0057
13,75	0,1468	15,96	0,1571	15,91	0,0005
16,25	0,1728	18,78	0,1860	18,83	0,0004
18,75	0,2256	24,52	0,2436	24,66	0,0014
21,25	0,2616	28,42	0,2903	29,37	0,0096
Total	**0,9202**	**100**	**0,9878**	**100**	**-**
Dcalc	**0,010**				
Dtab	**1,407**				

Table 11: Result of the Kolmogorov-Smirnov test for methodology 3 to the control. CC (class center, in cm), FO (Observed frequency), Relative FO (Relative observed frequency, in %), FE (estimated frequency), Relative FE (Estimated frequency, in %)

CC	FO	Relative FO	FE	Relative FE	|FO(x) - FE(x)|
6,25	0,0098	1,07	0,0071	0,79	0,0028
8,75	0,0360	3,92	0,0150	1,66	0,0225
11,25	0,0674	7,33	0,0560	6,19	0,0114
13,75	0,1468	15,96	0,1316	14,56	0,0140
16,25	0,1728	18,78	0,1835	20,29	0,0151
18,75	0,2256	24,52	0,2343	25,91	0,0139
21,25	0,2616	28,42	0,2767	30,60	0,0217
Total	**0,9202**	**100**	**0,9042**	**100**	**-**
Dcalc	**0,023**				
Dtab	**1,407**				

The adjustment of the equations to estimate the carbon stock was considered adequate, with satisfactory R_{2adj}, RMSE (%), and Bias (%) values (Table 7).

Table 12: Parameters and adjustment of models to estimate carbon storage

Methodology	β_0	β_1	β_2	R_{2adj} (%)	Bias (%)	RMSE (%)
1	0,0000280	1,368	1,195	99,25	-0,084	5,932
2	0,0000187	1,458	1,264	99,60	-0,082	4,499
3	0,0000017	1,493	1,942	99,06	1,228	7,590
1x2	0,0000228	1,415	1,23	98,89	-7,790	7,379
1x3	0,0000079	1,431	1,53	98,25	-4,659	9,729

The model identity test showed the same behavior for the combination of Methodologies 2 and 3, that is, a single model (reduced model) can be adjusted to estimate the carbon stock, that is, not significant to the probability level of 95% (Table 8).

Table 13: Result of the model identity test of the equations using the Test F, for the 2 evaluated combinations

Combinations	$QM_{difference}$	$QM_{residue}$	$F_{calculated}$	$F_{fixed\ 5\%}$	P_{Value}	Test
1x2	0,0001	0,0728	0,0097	4,76	0,9987	NS
1x3	0,0085	0,0877	1,1679	4,76	0,3354	NS

DISCUSSIONS

The quantification of biomass accumulation is an essential tool to understand the carbon dynamics in forests and their ecosystem services (Houghton et al., 2009), as it is a relevant component in carbon stocks and subsequent assessment of mitigation potentials in climate changes (Huy et al., 2016). Thus, reliable biomass estimations are essential to monitor forest conditions and assist in decision-making for forest management (Ubuy et al., 2018).

The generation of reliable data on the carbon storage potential of forests is relevant in the current world scenario, in which the Paris Agreement is already in force, and some countries that have ratified it, such as Brazil, have emission reduction targets in the forestry sector (Azevedo-Ramos et al., 2020). The Brazilian government estimates that by the year 2030, the area of commercial forests will be increased by 3 million hectares, with varied storage potential, which highlights the validation of the biomass and carbon estimation methodologies (Brasil, 2015).

The equivalence between the results of the methodologies tested with the reference is explained by the low difference in absolute numbers between the results. This fact can be justified by the number of sections measured in the rigorous scaling, which contributes to a reduction in the estimation error, with the increase in the control of the taper of the shaft (Tonini et al., 2019). Wheeler's Pentaprism use in the non-destructive methodology also helped to equalize the results, as it is recommended for scaling Eucalyptus plantations up to the height of 50m, managing to maintain the precision in the results generated (Avery and Burkhart, 1997). The size of the trees can affect the results obtained with the Pentaprism due to the difficulty in collecting the diameter of the section in the correct position.

The residue found in the lowest class centers for Methodology 3 was 37,91% for 6,25 cm and 139,54% for 8,75 cm, and, despite the high percentage value, these values represent classes with less biomass accumulation. The regular distribution of eucalyptus in Brazil, with the majority of individuals concentrated in the middle-class centers, also contributes to reducing the impact of this difference on the population's carbon stock since they would affect a smaller number of trees (Nogueira et al., 2005).

The destructive method has some negative points when compared to indirect methodologies. The time required to carry out fieldwork is longer than in indirect methods (Flombaum and Sala, 2007). Destructive methodologies are also limited to smaller areas with a small number of trees to be felled (Lu et al., 2014). Sampling errors can also be a problem in direct methodologies, with trees selected wrongly (Brown et al., 1989), which would lead to tendency errors and subsequent overestimation or underestimation of biomass accumulation (Ribeiro et al., 2009).

For Eucalyptus forests, the pentaprism proved to be a reliable tool, with no difference in population or between the diameter classes. However, its use would not be possible in biomes such as the caatinga due to the limitation of measuring the diameter and the high number of trunk branches (Junior and Drumond, 2014). The device allows estimation in DAP ≥ 6,5 cm values. Due to the device limitation, the larger the tree, the larger the section considered a cone for estimating volume, and the smaller also, since the minimum diameter will not be reached.

The search for non-destructive methodologies that reliably estimate the accumulation of biomass and carbon stock is the focus of the researchers (Huff et al., 2018; Kramer et al., 2018) and, despite the possible uncertainties surrounding them, the need for data from direct methodologies demonstrates the importance of these methods in research related to the topic.

CONCLUSIONS

The Wheeler® Pentaprism is an accurate tool for estimating biomass and carbon in eucalyptus forests.

The non-destructive methodology using Wheeler® Pentaprism and the destructive one with rigorous scaling is effective, with statistically similar results to the reference methodology, which reduces time and cost in estimating biomass and carbon in eucalyptus forests without compromising the result.

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CHAPTER 3

Wood and charcoal production on a small farm: How does the costs and revenues variation affect economic viability?

Abstract: Traditional methods of wood and charcoal production projects economic analysis are based on indicators analysis, however, they are subject to market variations and uncertainties. The study was carried out in the city of Lamim -Minas Gerais State, to assess the wood and charcoal production economic viability, and how the variation in costs and revenues can impact this result, through sensitivity analysis using Monte Carlo analysis. The wood and charcoal production cash flow was prepared and the following criteria were used in the economic analysis: Net Present Value (NPV), Cost Benefit Ratio (B/C), Equivalent Periodic Value (EPV) and Internal Return Rate (IRR). The wood and charcoal production sensitivity analysis was carried out using software @RISK, according to the VPE parameter, which allows you to compare projects with different times. Wood production was economically viable, with NPV of \$40.26 ha^{-1} and EPV of \$16.80 ha^{-1} with average production cost of \$13.51 m^{3} wood^{-1}. The EPV mean value found in the sensitivity analysis was \$18.33 ha^{-1}. The charcoal production was economically viable, with NPV of \$4.43 mdc charcoal^{-1} and EPV of \$3.52 mdc charcoal^{-1}. The EPV mean value found in the sensitivity analysis was \$9.80 mdc charcoal^{-1}. It was possible to conclude that the wood and charcoal production area economically viable in the region.

Keywords: Risk analysis, Sensitivity analysis, Sustainable steelmaking.

INTRODUCTION

Brazil is the largest charcoal producer and consumer in the industry in the world, with pig iron and ferro-alloy steel industries responsible for consuming 84% of the total available. The brazilian charcoal consumption in 2018, in the steel sector, was 4.6 million tons and, Minas Gerais State was the main producer. Commercial forests, mostly eucalyptus plantations, are the main raw material used in the charcoal sector in the country, with a total of 91% (IBA, 2020).

Small rural producers are responsible for approximately 80% of the brazilian charcoal production (Oliveira et al., 2013) in a carbonization process done, mostly, in rudimentary masonry kilns, “hot-tailed” and surface type, with low gravimetric yield (GY) and no greenhouse gas (GHG) emissions control (Costa et al., 2019). The replacement of these rudimentary systems by technological systems is a challenge in the sector, for requiring greater investments, that would increase carbonization costs, and may inhibit the adoption by small and medium producers (Vilela et al., 2014; Ribeiro et al., 2020). The charcoal price variation over the years, the technologies used in production and environmental issues are considered the main problems in the sector in Brazil (Cardoso et al., 2010).

The United Nations Development Program (UNDP) implemented the Sustainable Steel Project to improve the Brazilian charcoal production process, after the commitments assumed by the government to reduce GHG emissions in the Paris Agreement. The project encourages innovative and more efficient technologies and productive arrangements for the charcoal production from planted forests in the Brazilian steel industry. The Sustainable Steel Project was designed to improve charcoal production efficiency with the least possible impact on GHG emissions (UNITED NATIONS, 2018).

Within the Sustainable Steel Project, the furnace furnace system was developed. This system allows the GHG burning, with an innovative layout that has a centralized furnace with 4 kilns, and that allows the increase of the GY when compared with the traditional kilns (Oliveira et al., 2017). Despite being a viable carbonization alternative compared to traditional models, for being technically and environmentally viable, there are still questions about the furnace-kiln system economic viability (Oliveira et al., 2014). This is because "hot-tail" kilns, which are the most used in Brazil, despite being simple and with low GY, are economically viable, which makes the business attractive to rural producers and helps supply industrial demand (Silva et al., 2014). Thus, economic viability studies of charcoal production in this new arrangement are necessary, to encourage the new technology adoption by rural producers (Oliveira et al., 2015).

Economic analysis traditional methods in charcoal production are based on indicators analysis, although, as well in forestry activities, since they are long-term, they are subject to market variations and uncertainties (Oliveira et al., 2017), due to the product price fluctuation over the years (Oliveira et al., 2013). These studies make the economic evaluation jointly, that is, the same economic indicator represents wood and charcoal production viability, not being able to assess which of the two products impact the project the most, positively and/or negatively.

Monte Carlo simulation can be used to assess risk in decision making, for allowing the performance of a variable to be observed due to the behavior of other (Zarony et al., 2019). The Monte Carlo method is used to numerically operate systems that have random components, several simulations are carried out and, in each of them, random values are generated for the variables subject to uncertainty input, with previously determined distributions. At the end of the simulation, results are generated based on random values and the probabilities of their occurrence (Yang et al., 2020).

The study was conducted on a rural property in the city of Lamim Minas Gerais State, with the goal of economic viability evaluating in the wood and charcoal production, and how the costs and revenues variation can impact this result, through risk analysis using the Monte Carlo technique.

MATERIAL AND METHODS

Site characterization

The study was conducted on a charcoal farm in Lamim, State of Minas Gerais, Brazil (20°47’08.56” S and 43°26’37.78” O), in the Zona da Mata Area (Figure 1). The charcoal is produced from a hybrid of *Eucalyptus grandis* x *Eucalyptus urophylla*, planted at a spacing of 3.0 m x 2.0 m, in 20.05 ha, in mountainous region, and low use of technology in wood production. According to the Köppen, the climate of the region is Cwa, *i.e.*subtropical with dry winter and hot and rainy summer (Rolim et al., 2007). Precipitation occurs mainly between October and March, with averages of 1,435 mm per year. June and July present the lowest temperatures (12ºC), and January the highest temperatures (25 ºC) (Sá Junior et al., 2012).

Figure 5: Farm in Lamim-MG, where the study was conducted.

The dystrophic red-yellow Oxisol predominates in the city of Lamim-MG, as well as in most of the region Zona da Mata (Portugal et al., 2010). The soil chemical analysis was carried out for 5 samples collected in the layers of 0-20 and 20-40 cm in total area, using a manual auger. The soil samples were evaluated at Departamento de Solos at Universidade Federal de Viçosa – UFV (Table 1).

Table 14: Soil chemical analysis in the 0-20 cm, 20-40 cm and medium layers, in which pH was evaluated in H_2O, P (mg dm$^{3-1}$), K (mg dm$^{3-1}$), Ca^{+2}(Cmol dm$^{3-1}$), Mg^{+2}(Cmol dm$^{3-1}$), V (%), m (%), MO (Dag kg^{-1}), P-rem (Mg L^{-1})

Layers	**pH**	**P**	**K**	**Ca^{+2}**	**Mg^{+2}**	**V**	**m**	**MO**	**P-rem**

0-20	4.05	1.54	15.20	0.15	0.07	4.26	78.62	2.92	15.98
20-40	4.37	1.10	11.60	0.14	0.05	4.74	78.80	2.00	14.60
Mean	4.21	1.32	13.40	0.15	0.06	4.50	78.71	2.46	15.29

V= Base Saturation Index; m= Aluminum Saturation Index; MO= Organic matter; P-rem= Remaining Phosphorus.

Forest Inventory

Simple casual sampling was carried out in the forest inventory, with 27 sample units of 300 m^2 (20 x 15 m). The circunference at breast height (cbh) of all trees was measured, converted to diameter at breast height (dbh) and separated into diametric classes with an amplitude of 2.5 cm. The total height of all trees present in the sample units was measured using the equipment Vertex IV®. The equation for estimating the wood volume present in the stem was based on the model by Schumacher & Hall (1933) and presented an appropriate adjustment, with the following results:

$$Vcc = 0.00008778 * dbh^{1.472} * Th^{1.262} \qquad \text{(Equation 1)}$$

$$R_{2adj} = 98.56\%; \text{Bias} = -0.12\%$$

The Average Annual Volume Increment (AAVI) used in the economic analysis was 26 m^3 ha^{-1} $year^{-1}$, at 7 years old, in the first rotation and 23,4 m^3 ha^{-1} $year^{-1}$ in the second rotation.

Wood Carbonization

The furnace-kiln system is composed of 4 circular surface kilns and a furnace connected to them by ducts, which has a combustion chamber, where the burning of carbonization gases is carried out (Figure 2). Each kiln has a volumetric capacity of approximately 9.0 m^3 of wood, value obtained by checking the weight in three kiln loads. The wood moisture entrance in the kilns was 35.00% and the GY found was 32.76%. The temperature control is done by opening and closing the air controllers (6 per kiln) that are arranged on the bottom of the walls of the kilns. Each kiln has 4 metal wells distributed between the top and the walls, which allow the measurement of temperature. These temperature measurements were determined by an infrared sensor, pyrometer, model MT-350®, with measurement capability between 30 - 550ºC.

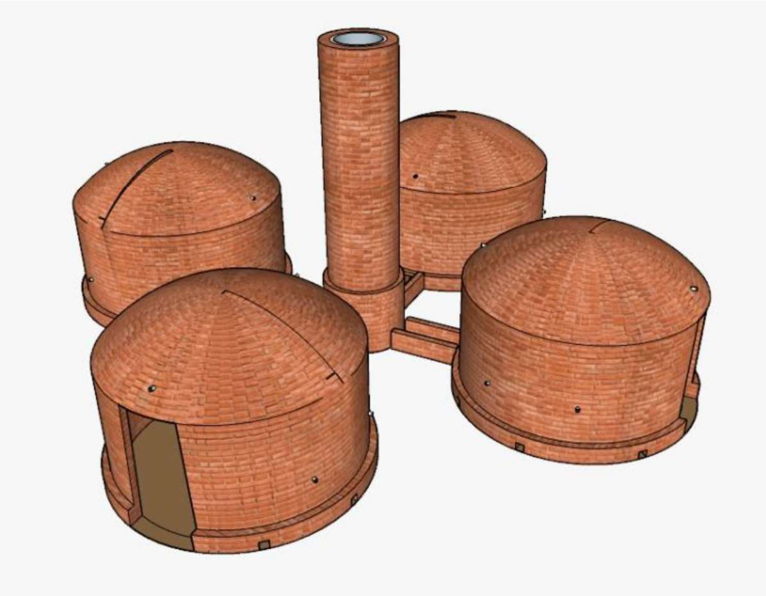

Figure 6: Furnace-kiln system used in rural properties, for the charcoal production.

Carbonization was divided into stages, for better process control (Table 2). The 4 kilns cannot operate simultaneously in phases III and IV due to the high temperature and risk of the furnace giving way, so 2 layouts are required.

Table 15: Carbonization periods temperature (in ºC), duration (in hours), and the occurring phenomenon. Source: Oliveira et al.,(2013)

Period	Temperature	Duration	Phenomenon
I	140-150	15-16	Water vapor release - wood drying, endothermic phase.
II	150-270	11-12	Hemicelluloses degradation, elimination of gases, endothermic phase.
III	270-350	19-20	Cellulose degradation, large gas production, exothermic phase. Charcoal formation.
IV	350-380	11-12	Gas emissions reduction, exothermic phase.

Costs and revenues composition

Wood production was analyzed separately from the charcoal production. The costs and revenues used were based on data collection during the monitoring period, rural producers information and municipality environmental agencies.

Wood Production

The Eucalyptus plantation area considered for the economic analysis was 20.05 ha and the costs were separated into the following groups:

- Area preparing: Area cleaning, marking planting lines, marking pits and dimpling, building and maintaining firebreaks.
- Planting: Eucalyptus seedlings, fertilizers (NPK), purified MAP, pre- and post-emergent herbicide and its application, insecticide bait and its application, termite, transport of inputs, pit fertilization, planting and replanting.
- Harvesting and transportation: Cutting, twisting, bucketing, loading and transport.
- Machines: Chainsaw, motor scooter and tractor.
- Land cost.

Eucalyptus cultivation in the region is usually commercialized in two productive cycles. The wood sale was considered in the years 7 and 14, per \$14.20 m^3, a value that is commonly used in the Lamim-MG region, according to data provided by the timber buyer. The interest rate was 6% p.a. The labor charges considered were 68% (Sebrae, 2015). The transportation radius considered for the economic analysis of the sale of wood was 50km.

Charcoal production

Charcoal production costs have been separated into the following groups:

- Labor: Carbonizer, kiln construction, land preparation.
- Kiln items construction cost.
- Furnace items construction cost.
- Wood purchase.
- Land cost.
- Charcoal transportation.

The carbonization period considered in the charcoal production assessments was 10 years, which is the furnace-kiln service life. The carbonization duration, from the kiln loading to the unloading, was 7.5 days. The charcoal selling price was \$47.32 mdc $charcoal^{-1}$, value that is marketed in the region. The charcoal and wood costs of fees and taxes related were not considered in the assessment. The wood consumption by the furnace considered during carbonization, was approximately 100 kg per carbonization cycle (Oliveira et al., 2014).

Economic analysis

The wood and charcoal production cash flow was prepared and the following criteria were used in the economic analysis:

Net Present Value (NPV)

NPV is defined as the sum of revenues less costs associated with it. A project is considered economically viable if its NPV is bigger than zero, at a certain interest rate (Rezende e Oliveira, 2013), according to the following equation:

$$NPV = \sum R_j \div (1+i)^j - \sum C_j \div (1+i)^j \qquad \text{(Equation 2)}$$

Where: NPV - net present value; Rj - revenue at the end of year j; Cj - cost at the end of year j; i - interest rate and j - cost or revenue period of occurrence.

Cost Benefit Ratio (B/C)

The Cost Benefit ratio consists of the revenues and costs relationship given project, for a certain interest rate (Rezende e Oliveira, 2013), according to the following equation:

$$B/C = (\sum R_j \div (1+i)^j) \div (\sum C_j \div (1+i)^j) \qquad \text{(Equation 3)}$$

Where: B / C - cost benefit; Rj - revenue at the end of year j; Cj - cost at the end of year j; i - interest rate and j - period of occurrence of the cost or revenue.

Equivalent Periodic Value (EPV)

It is defined as the periodic installment that equals the NPV of an investment option to be valued, over the project duration (Rezende e Oliveira, 2013). Calculated according to the following equation:

$$EPV = NPV *[(1+i)^t-1] \div 1-(1+i)^{-nt} \qquad \text{(Equation 4)}$$

Where: NPV - Net Present Value; n - duration of the project, in years; t - number of capitalization periods, in years; i - interest rate. The project is considered economically viable if the EPV is positive.

Internal Return Rate (IRR)

It is the discount rate that equals NPV to zero, that is, present value of revenue equal to present value of costs (Rezende e Oliveira, 2013). Calculated according to the following equation:

$$\sum R_j(1+IRR)^{-j} = \sum C_j(1+IRR)^{-j} \qquad \text{(Equation 5)}$$

Where: R - Revenues at the end of year j; C - Costs at the end of year j; IRR - Internal return rate; j - duration of the project, in years. The project will be economically viable when the IRR is higher than the Minimum Attractiveness Rate.

Risk analysis

The risk analysis of the wood and charcoal production economic viability was carried out with the aid of the @RISK software (Palisade, 2019). The program makes use of the Monte Carlo method for random variables. The input variables considered were costs and revenues, for the wood and charcoal production. Ten thousand interactions were performed on the input data, with normal distribution of data with variations between -10 and + 10% in costs and revenues, a percentage considered sufficient for project evaluation (Palisade, 2019), according to the VPE parameter, which allows projects comparing with different durations.

RESULTS

Eucalyptus Forest

Wood harvesting and transporting were the main costs of wood production, representing 52% of the total. Land cost represented 22% of the total and those related to planting activities 20% (Table 3).

Table 16: Costs preparing the area, planting, harvesting and transport, machinery and land cost composition

Year	Area Preparing ($ ha^{-1})	Planting ($ ha^{-1})	Harvest and Transport ($ ha^{-1})	Machine ($ ha^{-1})	Land Cost ($ ha^{-1})	Total Cost ($ ha^{-1})
0	119.82	590.59	0.00	105.62	68.15	884.18
1	0.00	35.11	0.00	0.00	68.15	103.26
2	0.00	9.75	0.00	0.00	68.15	77.90
3	0.00	9.75	0.00	0.00	68.15	77.90
4	0.00	9.75	0.00	0.00	68.15	77.90
5	0.00	9.75	0.00	0.00	68.15	77.90
6	0.00	9.75	0.00	0.00	68.15	77.90
7	0.00	9.75	1,240.62	4.45	68.15	1,322.97
8	14.98	192.37	0.00	0.00	68.15	275.50
9	0.00	9.75	0.00	0.00	68.15	77.90
10	0.00	9.75	0.00	0.00	68.15	77.90
11	0.00	9.75	0.00	0.00	68.15	77.90
12	0.00	9.75	0.00	0.00	68.15	77.90
13	0.00	9.75	0.00	0.00	68.15	77.90
14	0.00	9.75	1,160.37	3.67	68.15	1,241,94
Total	134.80	935.07	2,400.99	113.74	1,022.25	4,606.85

Cash flow was positive only in the years 7 and 14, due to the wood sale, which minimized costs over the years and allowed the project to be economically viable, with NPV of \$40.26 ha^{-1} and EPV of \$16.80 ha^{-1}. The wood production average cost found was \$13.51 m^{3} wood^{-1} (Table 4).

Table 4: Eucalyptus production costs, revenues, cash flow and economic analysis, after two rotations

Year	Costs ($ ha^{-1})	Revenues ($ ha^{-1})	Cash Flow ($ ha^{-1})
0	884.18	0.00	-884.18
1	103.25	0.00	-103.25
2	77.90	0.00	-77.90
3	77.90	0.00	-77.90
4	77.90	0.00	-77.90
5	77.90	0.00	-77.90
6	77.90	0.00	-77.90
7	1,322,97	2,952.87	1,629,90

8	275.49	0.00	-275.49
9	77.90	0.00	-77.90
10	77.90	0.00	-77.90
11	77.90	0.00	-77.90
12	77.90	0.00	-77.90
13	77.90	0.00	-77.90
14	1,241.94	2,657.58	1,415.64
Total	4,606.83	5,610.45	1,003.62
NPV	\$40.26 ha^{-1}	**NPV**	\$0.19 m^{3}
B/C	1,01	**EPV**	\$0.08 m^{3}
TIR	6,38%	**Production Cost**	\$13.51 m^{3}
EPV	\$16.80 ha^{-1}		

Risk analysis, with a input data (costs and revenues) variation of -10 to 10%, presented minimum and maximum EPV values of \$-585.74 ha^{-1} and \$598.84 ha^{-1} for wood production, that is, due to the cost and revenue variations, the project may remain economically viable or be unfeasible. The VPE mean value found in the risk analysis was \$18.33 ha^{-1}. From 67 km of freight, the wood production becomes economically unfeasible.

Charcoal Production

Charcoal production was analyzed separately from the wood production. The period considered in the charcoal production was 10 years, which is the kiln useful life. The charcoal annual production was 1,086.50 mdc. The costs related to the wood purchase, land cost and charcoal transportation accounted for 81.98% and the labor costs and area preparation were 15.52% of the total (Table 5).

Table 5: Labor costs, kiln and furnace construction, wood purchase, land cost, transportation and total cost, in \$

Year	**Labor**	**Kiln Construction**	**Furnace Construction**	**Wood Purchase**	**Land Cost**	**Transport**	**Total Cost**
0	7,771.77	1,134.39	661.82	12,436.12	306.64	3,520.80	25,831.54
1	5,946.00	113.44	53.20	24,872.23	306.64	7,040.61	38,332.12
2	5,946.00	113.44	53.20	24,872.23	306.64	7,040.61	38,332.12
3	5,946.00	113.44	53.20	24,872.23	306.64	7,040.61	38,332.12
4	5,946.00	113.44	53.20	24,872.23	306.64	7,040.61	38,332.12
5	5,946.00	113.44	53.20	24,872.23	306.64	7,040.61	38,332.12
6	5,946.00	113.44	53.20	24,872.23	306.64	7,040.61	38,332.12
7	5,946.00	113.44	53.20	24,872.23	306.64	7,040.61	38,332.12
8	5,946.00	113.44	53.20	24,872.23	306.64	7,040.61	38,332.12
9	5,946.00	113.44	53.20	24,872.23	306.64	7,040.61	38,332.12
Total	61,285.77	2,155.35	1,140.62	236,286.19	3,066.40	66,886.29	370,820.62

Cash flow was positive from the second year onwards, due to the charcoal sale. The lower cash flow in the first year compared to the others, is justified by the lower charcoal production, due to the kiln time construction. The charcoal production was economically viable, with NPV of \$5.93 mdc charcoal^{-1} and EPV OF \$4.71 mdc charcoal^{-1} (Table 6).

Table 6: Costs, revenues, cash flow and economic analysis of charcoal production over a ten-year period, which is the useful life for the furnace-kiln system

Year	**Costs**	**Revenues**	**Cash Flow**
0	25,831.54	23,941.45	-1,890.09
1	38,332.12	47,882.92	9,550.80
2	38,332.12	47,882.92	9,550.80
3	38,332.12	47,882.92	9,550.80
4	38,332.12	47,882.92	9,550.80
5	38,332.12	47,882.92	9,550.80
6	38,332.12	47,882.92	9,550.80
7	38,332.12	47,882.92	9,550.80
8	38,332.12	47,882.92	9,550.80
9	38,332.12	47,882.92	9,550.80
Total	370,820.62	454,887.73	84,067.11
B/C	1,59	**NPV**	\$5.93 mdc CV^{-1}
TIR	52%	**EPV**	\$50,022.00
NPV	\$63,064.71	**EPV**	\$4.71 mdc CV^{-1}

CV = charcoal.

Risk analysis, with a input data (costs and revenues) variation of -10 to 10%, presented minimum and maximum EPV values of -\$7.60 mdc CV^{-1} and \$233.90 mdc CV^{-1} for charcoal production. Due to costs and revenues variations the charcoal production may become economically unfeasible. The EPV average value found in the risk analysis was \$9.80 mdc CV^{-1}. The charcoal production is economically viable, under the conditions evaluated, from the price of \$39,18 mdc CV^{-1}.

DISCUSSIONS

The Brazilian total area of commercial forests is 7.83 million hectares and eucalyptus plantations represent 72.80% of the total, mainly for the cellulose industry and charcoal production. Minas Gerais State is the main eucalyptus producer in the country, with 21.77% of the entire area (IBÁ, 2020) and, assessing how costs and revenues affect your economic viability is important, since in this project type the revenue comes, usually, from the wood sale in the last year.

Eucalyptus forest implementing costs vary from region to region, depending on input and labor costs, which are those that can compromise the eucalyptus planting economic viability (Rezende et al., 2006). The implantation cost found in the present study was \$884.18 ha^{-1} and the wood sale by \$13.51 m³ made the project viable, with NPV of \$40.26 ha^{-1} and EPV of \$16.80 ha^{-1}. Eucalyptus production was economically unfeasible, with and without land cost consideration, with NPV of –\$865.92 ha^{-1} and -\$1,182.92 ha^{-1}, respectively, at an interest rate of 6% year (Queiroz et al., 2016). The authors found that the implantation cost (\$1,077.13 ha^{-1}) and wood standing sale revenue (\$808.92 ha^{-1}), marketed to \$2.84 m³ , were not sufficient to offset the negative cash flow.

The sensitivity analysis, in the wood production, allowed to evaluate that, due to the implementation costs in the early years, variations in revenue from the wood sale made it economically unfeasible. The negative cash flow in the first years was not always offset by the wood sale revenue in the last year.

The furnace-kiln system, in addition to being environmentally better than traditional charcoal production systems, due to the methane burning, has technical advantages (Ribeiro et al., 2020). In addition to being economically viable, the furnace kiln system has other advantages, when compared to traditional kiln, such as greater gravimetric yield (Ribeiro et al., 2020). Wood consumption, when comparing the furnace-kiln system with the "hot tail" type was 20% lower, for the same amount of charcoal production, which resulted in better cash flow and better economically results, with profitability 16.4% higher (Oliveira et al., 2014[a]). The carbonizations number using the furnace kiln system, according to the same authors, it is also smaller to traditional kilns which, in addition to the lower wood consumption, it reduces the carbonizers labor costs. The carbonizations, when comparing the furnace kiln system with the "hot tail" kiln type, was 20% lower, for the same amount of charcoal production, which resulted in a 17.88% lower expense with the wood purchase (Oliveira et al., 2014[b]).

Charcoal production in innovative systems is dependent on a higher GY when compared to conventional methodologies, to be more attractive to rural producers, since it has implantation costs higher than traditional kilns (Protásio et al., 2021). When comparing the charcoal production in "hot-tail" kilns with metallic cylinder kilns, the most innovative layout showed better economic viability, with higher NPV, despite the higher implantation cost, due to the better GY. The metallic cylinder kiln *Pay Back* was 3.09 years, higher than the 2.93 years observed for the "hot tail" (Silva et al., 2014).

The charcoal production sensitivity analysis, for all the interactions carried out, it remained economically viable, because the charcoal sale revenues were higher than the costs, in all scenarios. Sensitivity analysis is an important tool to show how changes in costs and revenues impact the project economic analysis, however, project economic viability in the forestry is subject to unforeseen risks such as adverse weather, pests, diseases and other natural hazards that can reduce productivity and substantially affect results (Martinelli et al., 2019).

Economic analysis per wood unit produced (NPV of \$0.19 m^3 ha^{-1} and EPV of \$0,08 m^3 ha^{-1}), with production cost of \$13.51 m^{-3} and sold to \$14.20 m^{-3}, shows that changes in production costs can make the business economically unfeasible. Charcoal, due to the price increase in recent years, has become more attractive to the producer, with favorable indicators in relation to the wood production (NPV of \$5.93 mdc CV^{-1} and EPV of \$4.71 mdc CV^{-1}).

Wood and charcoal price, interest rate, planning horizon and production costs, must be taken into account in the economic analysis of forestry projects, which, if not properly planned and executed, may be economically unfeasible.

CONCLUSIONS

Eucalyptus wood and charcoal production is economically viable in the region of Lamim, in Minais Gerais State.

The wood production economic viability is more impacted by the costs and revenues variation, due to the fact that the production cost is only 4.84% lower than the wood sale value. In the case of charcoal production, economic viability is less impacted by changes in values, since revenues are much higher than costs.

Wood purchase costs are the main costs in the wood and charcoal production.

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FINAL CONSIDERATIONS

The furnace kiln system superior carbon balance when compared to the kiln usually used, shows the new system environmental benefits. Minas Gerais State has a Normative Resolution that establishes procedures to reduce atmospheric emissions in the charcoal production from planted forests, evidencing furnace-kiln system positive results is extremely important.

The furnace-kiln system use, in addition to the environmental benefits resulting from the reduction in emissions, brings benefits to carbonizers. The inclusion of pyrometry for temperature control replaces control by smoke coloring, which reduces the inhalation of toxic particles by the oven operator, which reduces respiratory problems caused by the production of charcoal in ovens without burning gases. This fact is an important advance for the charcoal sector, in which informal work without the use of safety equipment still occurs.

In order to successfully implement the furnace-kiln system on a large scale for small rural producers, it is necessary to increase the availability of technical assistance, as it is a new technology, which requires training and courses for its use and, consequently, obtaining better results.

In addition to greenhouse gas emissions reducing, the economic analysis positive result encourages the new kiln layout adoption, due to favorable economic indicators, in addition to the higher gravimetric efficiency and shorter kiln cooling time. The wood and charcoal price fluctuation over the years, makes the constant economic analysis of these activities important and values the positive result found.

Accurate biomass and carbon stock producing forecasts is a challenge. An impartial forest inventory design with accurate tree attributes measurements is required and requires that the biomass models be representative for the forest inventory data to which the model is applied. To show that there were no statistical differences between the results of biomass and carbon estimation, for destructive and non-destructive methodologies, in relation to the witness is important, as they are faster, cheaper and avoid environmental problems resulting from the felling of trees.

ANNEXES

Tabela 17: Custos e receitas da produção de madeira em Lamim-MG

Preparo da área	**Unidade**	**Quantidade**	**Custo (R$)**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Limpeza de área	d/H	40	79,33	3173	0	0	0	0	0	0	0	1586,5	0	0	0	0	0	0
Marcação de linhas de plantio	d/H	20	79,33	1586,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Marcação de covas	d/H	20	79,33	1586,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coveamento	d/H	40	79,33	3173	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Contrução e manutenção de aceiros	d/H	40	79,33	3173	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**R$**			**12692**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1586,5**	**0**	**0**	**0**	**0**	**0**	**0**
Plantio	**Unidade**	**Quantidade**	**Custo (R$)**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Mudas de Eucalipto	Milheiro	33	450	15003	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NPK (6-30-6)	Saca 50kg	133	123	16359	0	0	0	0	0	0	0	16359	0	0	0	0	0	0
NPK (20-00-20)	Saca 50kg	133	113	15029	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MAP purificado	Kg	4	7,2	26,42	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Herbicida pré emergente	Kg	4	745,5	2989,46	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Herbicida pós emergente	Kg	40	27,4	1098,74	1098,74	0	0	0	0	0	0	0	0	0	0	0	0	0

Isca Formicida	Kg	100	12	1200	0	0	0	0	0	0	0	1200	0	0	0	0	0	0
Repasse Formiga	Kg	20	12	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240
Cupinicida	Kg	1,24	560	696,14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Transporte de insumos	d/H	5	79,33	396,63	0	0	0	0	0	0	0	198,31	0	0	0	0	0	0
Adubação de cova	d/H	20	79,33	1586,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plantio e replantio	d/H	40	79,33	3173	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aplicação de formicida	d/H	20	79,33	1586,5	793,25	793,25	793,25	793,25	793,25	793,25	793,25	793,25	793,25	793,25	793,25	793,25	793,25	793,25
Aplicação herbicida pré-plantio	d/H	20	79,33	1586,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aplicação de herbicida pós plantio	d/H	20	79,33	1586,5	1586,5	0	0	0	0	0	0	0	0	0	0	0	0	0
Desbrota	d/H	20	79,33	0	0	0	0	0	0	0	0	1586,5	0	0	0	0	0	0
Total	**R$**			**62557,4**	**3718,49**	**1033,25**	**1033,25**	**1033,25**	**1033,25**	**1033,25**	**1033,25**	**20377,1**	**1033,25**	**1033,25**	**1033,25**	**1033,25**	**1033,25**	**1033,25**
Colheita	**Unidade**	**Quantidade**	**Custo (R$)**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Corte e Toragem	d/H	200	118,99	0	0	0	0	0	0	0	23797,5	0	0	0	0	0	0	27843,1
Baldeio	d/H	100	79,33	0	0	0	0	0	0	0	7932,5	0	0	0	0	0	0	6246,84
Carregamento	d/H	100	79,33	0	0	0	0	0	0	0	7932,5	0	0	0	0	0	0	6246,84
Transporte da Madeira	R$ m³	50	31,8	0	0	0	0	0	0	0	132577	0	0	0	0	0	0	119319
Total	**R$**			**0**	**0**	**0**	**0**	**0**	**0**	**0**	**172240**	**0**	**0**	**0**	**0**	**0**	**0**	**159656**

Máquinas	**Unidade**	**Quantidade**	**Custo (R$)**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Motoserra	Ud	1	2594	0	0	0	0	0	0	0	389,1	0	0	0	0	0	0	389,1
Motocoveadora	Ud	1	1238	185,7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trator	Ud	1	120000	10800	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pulverizador	Ud	1	228,71	82	0	0	0	0	0	0	82	0	0	0	0	0	0	0
Ferramentas	Ud	1	500	120	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**R$**			**11188**	**0**	**0**	**0**	**0**	**0**	**0**	**471**	**0**	**0**	**0**	**0**	**0**	**0**	**389**
Outros	**Unidade**	**Quantidade**	**Custo (R$)**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**12**	**13**
Custo da Terra	R$	20,05	6000	7218	7218	7218	7218	7218	7218	7218	7218	7218	7218	7218	7218	7218	7218	7218
Total	**R$**			**7218**	**7218**	**7218**	**7218**	**7218**	**7218**	**7218**	**7218**	**7218**	**7218**	**7218**	**7218**	**7218**	**7218**	**7218**
Total geral	**R$**			**93655,4**	**10936,5**	**8251,25**	**8251,25**	**8251,25**	**8251,25**	**8251,25**	**180962**	**29181,6**	**8251,25**	**8251,25**	**8251,25**	**8251,25**	**8251,25**	**168296**
Total geral	**R$/há**			**4671,09**	**545,46**	**411,53**	**411,53**	**411,53**	**411,53**	**411,53**	**9025,55**	**1455,44**	**411,53**	**411,53**	**411,53**	**411,53**	**411,53**	**8393,84**
Receitas	**Unidade**	**Quantidade**	**Preço(R$)**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Venda da Madeira	R$/m³	4170,4	75	0	0	0	0	0	0	0	312780	0	0	0	0	0	0	281502
Total geral				**0**	**0**	**0**	**0**	**0**	**0**	**0**	**312780**	**0**	**0**	**0**	**0**	**0**	**0**	**281502**
Total geral	**R$/há**			**0**	**0**	**0**	**0**	**0**	**0**	**0**	**15600**	**0**	**0**	**0**	**0**	**0**	**0**	**14040**

Tabela 18: Custos e Receitas da Produção de Carvão Vegetal em Lamim-MG

Mão de Obra	**Unidade**	**Quantidade**	**Custo (R$)**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Carbonização	Salário Mensal	12	2617,73	31412,7	31412,7	31412,7	31412,7	31412,7	31412,7	31412,7	31412,7	31412,7	31412,7
Mão de Obra Construção do Forno	d/H	21	79,33	1665,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Preparo do Terreno	d/H	30	79,33	2379,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Preparo do Terreno	máquina/hora	40	140,00	5600,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Total				**41058,3**	**31412,7**	**31412,7**	**31412,7**	**31412,7**	**31412,7**	**31412,7**	**31412,7**	**31412,7**	**31412,7**
Construção do Forno	**Unidade**	**Quantidade**	**Custo (R$)**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Tijolo	Ud	12400	0,37	4588	0	0	0	0	0	0	0	0	0
Gabarito para Forno	Ud	4	16,25	65	0	0	0	0	0	0	0	0	0
Cinta Metálica	Ud	4	8,75	35	0	0	0	0	0	0	0	0	0
Barra de Ferro Rosqueada	Ud	4	2,30	9,2	0	0	0	0	0	0	0	0	0
Suporte para Porta	Ud	4	22,75	91	0	0	0	0	0	0	0	0	0
Chapa Metálica	Ud	4	8,00	32	0	0	0	0	0	0	0	0	0
Chapa Metálica	Ud	8	25,13	201	0	0	0	0	0	0	0	0	0
Válvula Borboleta	Ud	4	20,25	81	0	0	0	0	0	0	0	0	0
Chapa de Fechamento de Duto	Ud	4	22,75	91	0	0	0	0	0	0	0	0	0
Tupo Metálico	Ud	4	3,75	15	0	0	0	0	0	0	0	0	0
Cantoneira	Ud	8	14,50	116	0	0	0	0	0	0	0	0	0
Chapa Metálica	Ud	48	0,60	28,8	0	0	0	0	0	0	0	0	0
Cilindros Metálicos	Ud	8	30,00	240	0	0	0	0	0	0	0	0	0

Cilindros Metálicos	Ud	16	20,00	320	0	0	0	0	0	0	0	0	0
Cilindros Metálicos	Ud	4	20,00	80	0	0	0	0	0	0	0	0	0
Manutenção	%	10	-	0	599,3	599,3	599,3	599,3	599,3	599,3	599,3	599,3	599,3
Total				**5993**	**599,3**	**599,3**	**599,3**	**599,3**	**599,3**	**599,3**	**599,3**	**599,3**	**599,3**
Construção da Fornalha	**Unidade**	**Quantidade**	**Custo (R$)**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Tijolo	Ud	1350	0,37	499,5	0	0	0	0	0	0	0	0	0
Cinta Metálica	Ud	5	16,80	84	0	0	0	0	0	0	0	0	0
Barra de Ferro Rosqueada	Ud	5	2,40	12	0	0	0	0	0	0	0	0	0
Porta Metálica	Ud	1	90,00	90	0	0	0	0	0	0	0	0	0
Manta de Fita Cerâmica	Ud	1	2100,00	2100	0	0	0	0	0	0	0	0	0
Pinos para Assentar massa	Ud	70	1,17	81,9	0	0	0	0	0	0	0	0	0
Chapéu Chinês Metálico	Ud	1	500,00	500	0	0	0	0	0	0	0	0	0
Grelha	Ud	1	50,00	50	0	0	0	0	0	0	0	0	0
Chapa Metálica	Ud	4	9,75	39	0	0	0	0	0	0	0	0	0
Chapa Metálica	Ud	1	15,00	15	0	0	0	0	0	0	0	0	0
Chapa Metálica	Ud	1	25,00	25	0	0	0	0	0	0	0	0	0
Manutenção	%	10	-	0	281,0	281,0	281,0	281,0	281,0	281,0	281,0	281,0	281,0
Total				**3496,4**	**281,049**	**281,049**	**281,049**	**281,049**	**281,049**	**281,049**	**281,049**	**281,049**	**281,049**
Outros	**Unidade**	**Quantidade**	**Custo (R$)**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Custo da Madeira	m³	1752	75	131400	131400	131400	131400	131400	131400	131400	131400	131400	131400
Custo de Terra	R$/há	2	9000	1080	1080	1080	1080	1080	1080	1080	1080	1080	1080

Transporte Carvão	RS/mdc carvão	1062,88	35	37200,80	37200,80	37200,80	37200,80	37200,80	37200,80	37200,80	37200,80	37200,80	37200,80
Total				**169680,80**	**169680,80**	**169680,80**	**169680,80**	**169680,80**	**169680,80**	**169680,80**	**169680,80**	**169680,80**	**169680,80**
Total Geral				**220228,48**	**201973,85**	**201973,85**	**201973,85**	**201973,85**	**201973,85**	**201973,85**	**201973,85**	**201973,85**	**201973,85**
Receitas	**Unidade**	**Quantidade**	**Custo (R$)**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Venda de Carvão	mdc carvão	1062,88	238	126482,72	252965,44	252965,44	252965,44	252965,44	252965,44	252965,44	252965,44	252965,44	252965,44